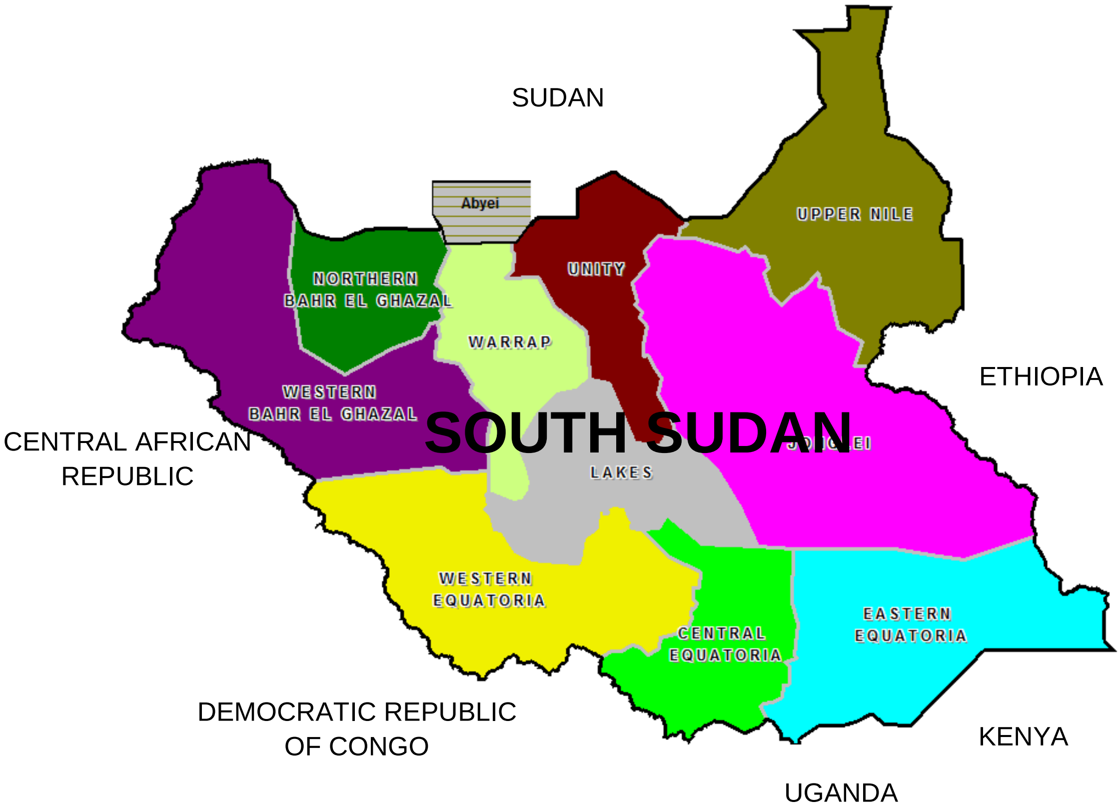
SOUTH SUDAN
LOW VOLUME ROADS
DESIGN MANUAL



Volume 1
ROAD DESIGN

June 2013

Ministry of Roads and Bridges
Government of South Sudan

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FOREWORD

Low Volume Roads (LVR) typically carry less than 300 vehicles per day and less than 1 million esa loading during their design life. They provide important links from homes, villages and farms to markets and offer the public access to health, education and other essential services. These roads also provide important links between village community centres and the State and National road network.

Many aspects of the design and construction of roads in South Sudan have stemmed from technologies and practices emanating from research and experience in Europe and the USA some 40 years ago. These practices have to some extent been modified in the intervening years, but the basic philosophy of road provision has remained the same. While these "standard" approaches might still be appropriate for much of the main trunk and strategic road network, they remain overly conservative, inappropriate and far too costly for application on much of the country's rural road network. In facing the major challenges of improving and expanding South Sudan's low volume rural road network, application of the previously accepted "traditional" planning, design, construction and maintenance approaches cannot provide the solution.

Many innovative practices and unconventional techniques, often developed and proved through years of research, have not found the degree of application and implementation that they should. Opportunities are missed that would provide better and lower cost engineering solutions and more sustainable low volume roads.

There is a wealth of local and international information, experience and research that when utilised, can change past practices and thinking and provide South Sudan with an appropriate and affordable low volume road network. To benefit fully from these advances and to see necessary improvements implemented on the ground, the Ministry of Roads and Bridges (MRB) has developed its first comprehensive national road design manual specifically for low volume roads. The task was completed with the assistance of a team of international experts managed by UNPOS and commissioned through DFID's Africa Community Access Programme (AFCAP).

Compilation of the documents was undertaken in close consultation with a Technical Working Group (TWG) comprising representatives of the local industry, national and state authorities. The National and State Roads Authorities, the contracting and consulting industry, the University, development agencies and other industry stakeholders all participated in the formulation of the documentation. Local issues and experience on the geometric, earthwork, drainage, pavement and surfacing design for low volume roads were discussed and debated in detail. Of particular interest were aspects of the condition and under-development of the existing road network; better use of local materials and scarce operational resources; Environmentally Optimised Design (EOD); dealing with problem soils and the scarcity of construction materials; traffic loading; works durability; testing and improvement of materials; construction methods and the beneficial utilisation of labour based, intermediate and heavy equipment technology options; route selection; and the essential role of maintenance.

Mainstreaming of social, cross-cutting and environmental aspects received special attention to develop additional complementary components to the design process.

On behalf of the Ministry of Roads and Bridges and the South Sudanese sector stakeholder I would like to take this opportunity to thank DFID, Crown Agents and the AFCAP team for their cooperation, contribution and support in the development of the South Sudan Low Volume Roads manual and supporting documents. I would also like to extend my gratitude and appreciation to all of the industry stakeholders and participants who contributed their time, knowledge and effort during the development of the documents.

I trust that the Low Volume Roads manual will provide the essential information needed to guide our road asset managers and design engineers in the provision of appropriate and sustainable low volume roads.

H.E. General Gier Chuang Aluong

Minister of Roads & Bridges, RSS

PREFACE

The South Sudan Ministry of Roads and Bridges is the custodian of the series of technical manuals and other reference documents that are written for the practicing engineer in South Sudan. The documents describe current and recommended good practice and set out the national standards for roads and bridges. They are based on national experience and international practice and are approved by the Ministry of Roads and Bridges (MRB).

This Design Manual for Low Volume Roads (2013) forms part of the MRB series of Road and Bridge Planning, Design and Maintenance documents.

It is intended that companion documents and manuals will be developed to include the Standard Technical Specifications, Standard Detailed Drawings and Standard Bidding Documents etc.

Manual Updates

Significant changes to criteria, procedures or any other relevant issues related to new policies or revised laws of the land or that are mandated by the relevant national or state Ministry or Agency should be incorporated into the manual from their date of effectiveness.

Other minor changes that will not significantly affect the whole nature of the manual may be accumulated and made periodically. When changes are made and approved, new page(s) incorporating the revision, together with the revision date, will be issued and inserted into the relevant chapter.

The road sector is encouraged to not only to put into practice this initial version of the South Sudan Low Volume Roads Manual but to feed back to the MRB Director any suggestions for future updates.

MINISTRY OF ROADS & BRIDGES LVR MANUAL

CHANGE CONTROL

MANUAL UPDATE	This area to be completed by the MRB Director of Quality Assurance
Manual Title	CHAPTER NO. CHANGE NO.

Section Table Figure Page	Explanation	Suggested Modification

Submitted by: ____________________ Name/Designation: ____________________

Company/Organisation Address ____________________

____________________email: ____________________Date: ____________________

Manual Change Action

Authority	Date	Signature	Recommended Action	Approval
Registration				
Chairman TWG				
Director General MRB				
Issued				

Approval / Provisional Approval / Rejection of Change:

Director General MRB ____________________ Date: ____________________

ACKNOWLEDGEMENTS

The South Sudan MRB wishes to thank the UK Government's Department for International Development (DFID) through their Africa Community Access Programme (AFCAP) for their support in developing this Low Volume Roads Design Manual. The manual will be used by all authorities and organisations responsible for the provision of low volume roads in South Sudan.

From the outset, the approach to the development of the manual was to include all sectors stakeholders in South Sudan. The input from the international team of experts was supplemented by our own local experience and expertise. Local knowledge and experience was shared through a series of Technical Working Group (TWG) meetings and workshops. MRB wishes to thank all the individuals who gave their time to attend the TWG meetings and workshops and provide valuable inputs to the compilation of the manual.

Finally, MRB would like to thank UNOPS and Crown Agents for their overall management of the project

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ABBREVIATIONS & ACRONYMS

> : Greater than
< : Less than
% : Percentage

A

AADT: Annual Average Daily Traffic
AASHTO: American Association of State Highway and Transportation Officials
AFCAP: Africa Community Access Programme
AIDS: Acquired Immune Deficiency Syndrome,
ALD Average Least Dimension
ARRB: ARRB Group, formerly the Australian Road Research Board
ARVs: Anti retrovirals
ASTM: American Standard Test Methods

B

BDS: Bid Data Sheet

C

CB : Clay Brick (fired)
CBO: Community Based Organisation
CBR: California Bearing Ratio
CI: Complementary Interventions
CMG : Crown Agents Core Management Group
COLTO: Commission of Land Transport Officials (South Africa)
CPT: Cone Penetrometer Test
CS : Cobblestone
CS13: Cape Seal with 13mm aggregate in first seal
CS19: Cape Seal with 19mm aggregate in first seal
CSIR: Council for Scientific and Industrial Research (South Africa)

D

DBM:: Drybound macadam
DC : Design Class
DCP: Dynamic Cone Penetrometer
DCS: Double Chip Seal
DF: Drainage Factor
DFID: UK Government's Department of International Development
DMT: Dilatometer Test
DOS: Double Otta Seal
DS : Dressed Stone
DSS: Double Sand Seal
DV : Design Vehicles

E

EDCs: Economically emerging and Developing Countries

EF : Equivalency Factor
e.g. : For example (abbreviation for the Latin phrase exempli gratia)
EIA : Environmental Impact Assessment
EMP: Environmental Management Plan
ENS: Engineered Natural Surfaces
EOD: Environmentally Optimised Design
ERA: Ethiopian Roads Authority
esa : Equivalent standard axles
EVT : Equiviscous Temperature

F
FACT: Fine Aggregate Crushing Test
FED: Final Engineering Design

G
g/m²: Grams per square metre
GDP: Gross Domestic Product
GM : Grading Modulus
GoSS: Government of South Sudan
gTKP: Global Transport Knowledge Partnership
GVW: Gross Vehicle Weight

H
ha : Hectare
HDM 4: Highway Development and Management model
HIV : Human immunodeficiency virus
HPS: Hand Packed Stone
HQ : Headquarters
HVR: High Volume Road

I
ICB : International Competitive Bidding
ICT : Information Communication Technology
IDA : International Development Agency
i.e. : That is (abbreviation for the Latin phrase id est)
ILO : International Labour Organisation
IMT : Intermediate Means of Transport
IRR : Internal Rate of Return
ITB : Instructions to Bidders

K
km : Kilometre
km² : Square kilometre
km/h: Kilometres per hour

L
LB : Labour Based
LIC : Labour Intensive Construction
LVR : Low Volume Road

M

m : Metre
m² : Square metre
m³ : Cubic metre
MAF: Ministry of Agriculture and Forestry
MCB: Mortared Clay Brick (fired)
MCS: Mortared Cobblestones
MDS: Mortared Dress Stone
Mesa: Million equivalent standard axles
mg/m³: Milligram per metre cubed
mm : Millimetre
mm²: Square millimetre
mm³: Cubic millimetre
m/s : Metres per second
MC : Medium Curing
MPa: megapascal (a unit of pressure equal to 1000 kilopascals (kPa), commonly used in the building industry to measure crushing pressure of brick
MS: Mortared Stone
MPI: Ministry of Physical Infrastructure
MRB: Ministry of Roads and Bridges
MSSP: Mortared Stone Setts or Pavé

N

NBP: Non-Bituminous Pavement
NCB: National Competitive Bidding
NCT: National Competitive Tendering
NGO: Non-Government Organisation
nm : Nanometre
NMT: Non-Motorised Transport
NRC: Non-reinforced concrete
NRCP: Non-reinforced concrete pavement

O

OGL: Original Ground Level
OMC : Optimal Moisture Content
ORN: Overseas Road Note

P

PCU: Passenger Car Unit
PDM: Pavement Design Manual
Pen.: Penetration
PI : Plasticity Index
PIARC: World Road Association
PM : Plasticity Modulus
PM : Pressure Meter
PPA: Public Procurement Agency
PPP: Public Private Partnership
PSD: Particle Size Distribution

Q

QA : Quality Assurance

R

R : Radius
RC : Reinforced concrete
Ref : Reference
RFP: Request for Proposals
RS : Road Safety
RTS : Road Transport Services

S

SADC: Southern Africa Development Community
SBL : Sand Bedding Layer
SCS: Single Chip Seal
SDMS: Surfacing Decision Management System
SE : Super Elevation
SlS: Slurry Seal
SMEs: Small and Medium Enterprises
SOS: Single Otta Seal
SOS+SS: Single Otta Seal plus Sand Seal
SS : South Sudan
SSP: Stone Setts or Pavé
SSS: Single Sand Seal

T

TBA: To Be Advised
Tc : Time of Concentration
ToR: Terms of Reference
TRL: Transport Research Laboratory

U

UK : United Kingdom
UKAID: Development assistance provided by the UK Department for International Development
UNOPS: United Nations Office for Project Services
USA: United States of America
USAID: United States Agency for International Development
USCS: Unified Soil Classification System
USD: United States Dollar
UTRCP: Ultra Thin Reinforced Concrete Pavement

V

VI: Impinging Velocity
VAVE: Average Velocity

VP: Parallel Velocity
vpd: vehicles per day
VOCs: Vehicle Operating Costs
VST: Vane Shear Test

W

WBM: Waterbound Macadam
WC : Wearing Course
WLC: Whole Life cycle Costs

GLOSSARY OF TECHNICAL TERMS

Aggregate (for construction)
A broad category of particulate material including sand, gravel, crushed stone, slag and recycled material that forms a component of composite materials such as concrete and pre-mix asphalt.

Apron
The flat invert of the culvert inlet or outlet.

Asphalt
A mixture of inert mineral matter, such as aggregate, mineral filler (if required) and bituminous binder in predetermined proportions (Sometimes referred to as Asphaltic Concrete or Asphalt Concrete). Usually pre-mixed in a plant before transport to site to be laid and compacted. Expensive and usually only used on main roads. Also used as an alternative term for Bitumen in some regions, and may be a petroleum processing product or naturally occurring in deposits.

Atterberg Limits
Basic measures of the nature of fine-grained soils which identify the boundaries between the solid, semi- solid, plastic and liquid states.

Basin
A structure at a culvert inlet or outlet to contain turbulence and prevent erosion.

Berm
A low ridge or bund of soil to collect or redirect surface water.

Binder, Bituminous
Any bitumen based material used in road construction to bind together or to seal aggregate or soil particles.

Binder, Modified
Bitumen based material modified by the addition of compounds to enhance performance. Examples of modifiers are polymers, such as PVC, and natural or synthetic rubbers.

Bitumen
A non-crystalline solid or viscous mixture of complex hydrocarbons that possesses characteristic agglomerating properties, softens gradually when heated, is substantially soluble in trichlorethylene and is usually obtained from crude petroleum by refining processes. Referred to as Asphalt in some regions.

Bitumen, Cutback
A liquid bitumen product obtained by blending penetration grade bitumen with a volatile solvent to produce rapid curing (RC) or medium curing (MC) cutbacks, depending on the volatility of the solvent used. After evaporation of the solvent, the properties of the original penetration grade bitumen become operative.

Bitumen, Penetration Grade
That fraction of the crude petroleum remaining after the refining processes which is solid or near solid at normal air temperature and which has been blended or further processed to products of varying hardness or viscosity.

Bitumen emulsion
A mixture of bitumen and water with the addition of an emulsifier or emulsifying agent to ensure stability. Conventional bitumen emulsion most commonly used in road works has the bitumen dispersed in the water. An invert bitumen emulsion has the water dispersed in the bitumen. In the former, the bitumen is the dispersed phase and the water is the continuous phase. In the latter, the water is the dispersed phase and the bitumen is the continuous phase. The bitumen is sometimes fluxed to lower its viscosity by the addition of a suitable solvent.

Bitumen Emulsion, Anionic
An emulsion where the emulsifier is an alkaline organic salt. The bitumen globules carry a negative electrostatic charge.

Bitumen Emulsion, Cationic
An emulsion where the emulsifier is an acidic organic salt. The bitumen globules carry a positive electrostatic charge.

Bitumen Emulsion Grades
Premix grade: An emulsion formulated to be more stable than spray grade emulsion and suitable for mixing with medium or coarse graded aggregate with the amount smaller than 0.075mm not exceeding 2%.
Quick setting grade: An emulsion specially formulated for use with fine slurry seal type aggregates, where quick setting of the mixture is desired.
Spray grade: An emulsion formulated for application by mechanical spray equipment in chip seal construction where no mixing with aggregate is required.
Stable mix grade: An emulsion formulated for mixing with very fine aggregates, sand and crusher dust. Mainly used for slow-setting slurry seals and tack coats.

Black Cotton Soil
An expansive clay found widely in the North East of the country that expands and loses most of its strength when wetted.

Blinding
a) A layer of lean concrete, usually 5 to 10 cm thick, placed on soil to seal it and provide a clean and level working surface to build the foundations of a wall, or any other structure.
b) An application of fine material e.g. sand, to fill voids in the surface of a pavement or earthworks layer.

Brick (fired clay)
A hard durable block of material formed from burning (firing) clay at high temperature.

Bridge
A structure usually with a span of 5 metres or more, providing a means of crossing above water, a railway or another obstruction, whether natural or artificial. A bridge consists of abutments, deck and sometimes wingwalls and piers, or maybe an arch.

Camber
The road surface is normally shaped to fall away from the centre line to either side. The camber is necessary to shed rain water and reduce the risk of passing vehicles colliding. The slope of the camber is called the Crossfall. On sharp bends the road surface should fall directly from the outside of the bend to the inside (superelevation).

Cape Seal
A multiple bituminous surface treatment that consists of a single application of binder and stone followed by one or two applications of slurry.

Carriageway
The road pavement or bridge deck surface on which vehicles travel.

Cascade
A drainage channel with a series of steps, sometimes with intermediate silt traps or ponds, to take water down a steep slope.

Catchpit
A manhole or open structure with a sump to collect silt.

Catchwater Drain
See **Cutoff**.

Causeway or Vented Drift
Low level structure constructed across streams or rivers with openings to permit water to pass below road level. The causeway may become submerged in flood conditions.

Cement (for construction)
A dry powder which on the addition of water (and sometimes other additives), hardens and sets independently to bind aggregates together to produce concrete. Cement can also be used to stabilise certain types of soil. Cement is also sometimes used as a fine filler in bituminous mixes.

Chippings
Clean, strong, durable pieces of stone made by crushing or napping rock. The chippings are usually screened to obtain material in a small sise range.

Chip Seal, Single
An application of bituminous binder followed by a layer of stone or clean sand. The stone is sometimes covered with a fog spray.

Chip Seal, Double
An application of bituminous binder and stone followed by a second application of binder and stone or sand. The second seal usually uses a smaller aggregate size to help key the layers together. A fog spray is sometimes applied on the second layer of aggregate.

Chute
An inclined pipe, drain or channel constructed in or on a slope.

Cobble Stone (Dressed stone)
Cubic pieces of stone larger than setts, usually shaped by hand and built into a road surface layer or surface protection.

Coffer Dam
A temporary dam built above the ground to give access to an area which is normally, or has a risk of being, submerged or waterlogged. Cofferdams may be constructed of soil, sandbags or sheet-piles.

Collapsible soil
Soil that undergoes a significant, sudden and irreversible decrease in volume upon wetting.

Compaction
Reduction in bulk of fill or other material by rolling or tamping.

Complimentary Interventions
Actions or initiatives that are implemented through a roads project which are targeted toward the communities that lie within the influence corridor of the road and are intended to optimise the benefits brought by the road and to extend the positive and mitigate the negative impacts of the project.

Concrete
A construction material composed of cement (most commonly Portland cement, but occasionally using other available cementitious materials such as fly ash and slag cement), aggregate (generally a coarse aggregate such as gravel or crushed stone plus a fine aggregate such as sand), water, (and sometimes chemical admixtures to improve performance or for special applications).

Concrete Block Paving
A course of interlocking or rectangular concrete blocks placed on a suitable base course and bedded and normally jointed with sand.

Counterfort Drain
A drain running down a slope and excavated into it. The excavation is partly or completely filled with free draining material to allow ground water to escape.

Cribwork
Timber or reinforced concrete beams laid in an interlocking grid, and filled with soil to form a retaining wall.

Crossfall
See **Camber**

Crushed Stone
A form of construction aggregate, typically produced by mining a suitable rock deposit and breaking the removed rock down to the desired size using mechanical crushers, or manually using hammers.

Curing
The process of keeping freshly laid/placed concrete moist to prevent excessive evaporation with attendant risk of loss of strength or cracking. Similarly with cement or lime stabilised layers, the measures to minimise moisture loss during the initial period of strength development.

Cut-off/Catchwater Drain
A ditch constructed uphill from a cutting face to intercept surface water flowing towards the road.

Debris Rack or Grill
Grill, grid or post structure located near a culvert entrance to hold back floating debris too large to pass through the culvert.

Deck
The part of a bridge that spans between abutments or pier supports, and carries the road traffic.

Design speed
The assessed maximum safe speed that can be maintained over a specified section of road when conditions are so favourable that the design features of the road govern the speed.

Dispersive soil
Soil in which the clay particles detach from each other and from the soil structure in the presence of water and go into suspension.

Distributor
A vehicle or towed apparatus comprising an insulated tank, usually with heating and circulating facilities, and a spray bar capable of applying a thin, uniform and predetermined layer of binder. The equipment may also be fitted with a hand lance for manual spraying.

Ditch (Drain)
A long narrow excavation designed or intended to collect and drain off surface water.

Drainage
Interception and removal of ground water and surface water by artificial or natural means.

Drainage Pipe
An underground pipe to carry water.

Dressed Stone
See **Cobble Stone**

Drift or Ford
A stream or river crossing at bed level over which the stream or river water can flow.

Dry-bound Macadam
A pavement layer constructed where the voids in a large single-sized stone skeleton are filled with a fine sand, vibrated in with suitable compaction equipment.

Earth Road
See **ENS.**

Embankment
Constructed earthworks below the pavement raising the road above the surrounding natural ground level.

ENS (Engineered Natural Surface)
An earth road built from the soil in place at the road location, and provided with a camber and drainage system

Expansive soil
Typically clayey soil that undergoes large volume changes in direct response to moisture changes.

Filler
Mineral matter composed of particles smaller than 0.075mm.

Flow Spreader
A structure designed to disperse the flow at the outfall of a ditch or drain to minimise the risk of erosion downstream.

Fog Spray/Seal
A light application of diluted bitumen emulsion to the final layer of stone of a reseal or chip seal, or to an existing bituminous surfacing as a rejuvenating maintenance treatment.

Ford
See **Drift**

Formation
The shaped surface of the earthworks, or subgrade, before constructing the pavement layers.

Gabion
Stone-filled wire or steel mesh cage. Gabions are often used as retaining walls or river bank/bed scour protection structures.

Geocells
Typical cellular confinement systems are made with ultrasonically-welded high-density polyethylene (HDPE) or Novel Polymeric Alloy strips that are expanded on-site to form a honeycomb-like structure which may be filled with sand, soil, rock or concrete. Used in construction for erosion control, soil stabilisation on flat ground and steep slopes, channel protection, and structural reinforcement for load support and earth retention.

Gravel (Construction Material)
A naturally-occurring, weathered or naturally transported rock within a specific coarse particle size range. Gravel is typically used as a pavement layer in its natural or modified condition, or as a road surface wearing course. Suitable gravel may also be used in a graded gravel seal in appropriate circumstances.

Hand Packed Stone
A layer of large, angular broken stones laid by hand with smaller stones or gravel rammed into the spaces between stones to form a road surface layer.

Heavy Equipment
Sophisticated civil engineering equipment typically designed for, and manufactured in, high-wage, low-investment-charge economies. It is expected to operate with close support and high annual utilisation; usually designed for a single function with high efficiency operation. Currently imported 'Heavy Equipment' dominates the South Sudan road sector. It is expensive to own and operate in the local environment.

Incremental paving
Road surface comprising small blocks such as shaped stone (setts) or bricks, jointed with sand or mortar.

Intermediate Equipment
Simple or intermediate equipment, designed for low initial and operating costs, durability and ease of maintenance and repair in the conditions typical of a limited-resource environment, rather than for high theoretical efficiency. It is preferable if the equipment can also be manufactured or fabricated locally/regionally..

Invert
The lowest point of the internal cross-section of a ditch, pipe or culvert.

Labour Based Construction
Economically efficient employment of as great a proportion of labour as is technically feasible throughout the construction process to produce the standard of construction as demanded by the specification and allowed by the available funding. Substitution of equipment with labour as the principal means of production..

Labour Intensive Construction
Works using large numbers of labourers with the prime objective of creating temporary or permanent employment, often with achieving sustainable and durable infrastructure as a secondary concern.

Layby
An area adjacent to the road for the temporary parking of vehicles.

Lime
Lime in a material derived from the burning of limestone or chalk. It is normally obtainable in its 'hydrated' form (slaked) as Calcium Hydroxide. It can be used for the drying, improvement and stabilisation of suitable soils, as an anti-stripping agent in the production of bituminous mixes and as a binder in masonry or brick work mortars.

Local Resources
These can be human resources, local government, private, NGO, and community institutions, local entrepreneurs such as contractors, consultants, industrialists and artisans, local skills, locally made or fabricated intermediate equipment, local materials such as local produced aggregates, bricks, timber and marginal materials, locally raised finance or provision of materials or services in kind.

Local Resource Based Road Works aim to deliver the maximum benefits to local communities and development.

Low Volume Road
Roads carrying up to about 300 motor vehicles per day and intended to carry less than about 1 million equivalent standard axles over their design life.

Macadam
A mixture of broken or crushed stone of various sizes (usually less than 3cm) laid to form a road surface layer. Bitumen macadam uses a bituminous binder to hold the material together. Tarmacadam uses tar for the same purposes. Bound macadams are usually expensive for use on LVR.

Manhole
Accessible pit with a cover forming part of the drainage system and permitting inspection and maintenance of underground drainage pipes.

Margins
The right of way or land area maintained or owned by the road authority or owner.

Mitre Drain (Turn Out Drain)
A drain that leads water away from the Side Drains to the adjoining land.

Otta Seal
A carpet of graded (natural gravel or crushed rock) aggregate spread over a freshly sprayed hot bituminous ‘soft’ (low viscosity) binder and rolled in with heavy roller.

Outfall
Discharge end of a ditch or culvert.

Parapet
The protective edge, barrier, wall or railing at the edge of a bridge deck.

Pavé
See **Sett**

Paved Road
A paved road is a road with a Stone, Bituminous, Brick or Concrete surfacing.

Pavement
The constructed layers of the road on which the vehicles travel.

Penetration Macadam
A pavement layer made from one or more applications of coarse, open-graded aggregate (crushed stone, slag, or gravel) followed by the spray application of bituminous binder. Usually comprising two or three applications of stone each of decreasing particle size, each grouted into the previous application before compaction of the completed layer.

Permeable Soils
Soils through which water will drain easily e.g. sandy soils. Clays are generally impermeable except when cracked or fissured (e.g. ‘Black Cotton’ soil in dry weather).

Prime Coat
A coat of suitable bituminous binder applied to a non-bituminous granular pavement layer as a preliminary treatment before the application of a bituminous base or surfacing. While adhesion between this layer and the bituminous base or surfacing may be promoted, the primary function of the prime coat is to assist in sealing the surface voids and bind the aggregate near the surface of the layer. Not to be confused with **Tack Coat**

Reinforced Concrete
A mixture of coarse and fine stone aggregate bound with cement and water and reinforced with steel rods or mesh for added strength.

Reseal
A surface treatment applied to an existing bituminous surface.

Rejuvenator
A material which may range from a soft bitumen to petroleum which, when applied to reclaimed asphalt or to existing bituminous surfacing, has the ability to soften aged, hard, brittle binders.

Riprap
Stones, usually between 5 to 50 kg, used to protect the banks or bed of a river or watercourse from scour.

Roadbase and Sub-base
Pavement courses between surfacing and subgrade.

Road Maintenance
Suitable regular and occasional activities to keep pavement, shoulders, slopes, drainage facilities and all other structures and property within the road margins as near as possible to their as constructed or renewed condition. Maintenance includes minor repairs and improvements to eliminate the cause of defects and avoid excessive repetition of maintenance efforts.

Roadway
The portion within the road margins, including shoulders, for vehicular use.

Scarifying
The systematic disruption and loosening of the top of a road or layer surface by mechanical or other means.

Scour - Defect:
Erosion of a channel bed area by water in motion, producing a deepening or widening of the channel.

Scour Checks
Small checks in a ditch or drain to reduce water velocity and reduce the possibility of erosion.

Scuppers
Drainage pipes or outlets in a bridge deck.

Seal
A term frequently used instead of “reseal” or “surface treatment”. Also used in the context of “double seal”, and “sand seal” where sand is used instead of stone.

Selected layers
Pavement layers of imported selected gravel or soil materials used to bring the subgrade support properties up to the required structural standard for placing the sub-base or road base layer.

Sett (Pavé)
A small piece of hard stone trimmed by hand to a size of about 10cm cube used as a paving unit.

Shoulder
Paved or unpaved part of the roadway next to the outer edge of the pavement. The shoulder provides side support for the pavement and allows vehicles to stop or pass in an emergency.

Site Investigation
Collection of essential information on the soil and rock characteristics, topography, land use, natural environment, and socio-political environment necessary for the location, design and construction of a road.

Slope
A natural or artificially constructed soil surface at an angle to the horizontal.

Slurry
A mix of suitably graded fine aggregate, cement or hydrated lime, bitumen emulsion and water, used for filling the voids in the final layer of stone of a new surface treatment or as a maintenance treatment (also referred to as a slurry seal).

Slurrybound Macadam
A surfacing or pavement layer constructed where the voids in single-sized stone skeleton are filled using bituminous slurry.

Sods
Turf but with more soil attached (usually more than 10 cms soil thickness).

Soffit
The highest point in the internal cross-section of a culvert, or the underside of a bridge deck.

Spray Lance
Apparatus permitting hand-application of bituminous binder at a desired rate of spread through a nozzle.

Squeegee
A small wooden or metal board with a handle for spreading bituminous mixtures by hand.

Stringer
Longitudinal beam in a bridge deck or structure.

Sub-base
See **Roadbase.**

Subgrade
The native material or earthworks formation underneath a constructed road pavement.

Sub-Soil Drainage
See **Underdrainage.**

Surface Dressing
A sprayed or hand applied film of bitumen followed by the application of a layer of stone chippings, which is then lightly rolled.

Surface Treatment
A general term incorporating chip seals, slurry seals, micro surfacing, or fog sprays.

Surfacing
The road layer with which traffic tyres make direct contact. Consists of wearing course, and sometimes a base course or binder course.

Tack Coat
A coat of bituminous binder applied to a primed layer or to an existing bituminous surface as a preliminary treatment to promote adhesion between the existing surface and a subsequently applied bituminous layer.

Tar Binder
A binder made from processing coal.

Template
A thin board or timber pattern used to check the shape of an excavation.

Traffic Lane
The portion of the carriageway usually defined by road markings for the movement of a single line of vehicles.

Transverse Joint
Joint normal to, or at an angle to, the road centre line.

Turf
A grass turf is formed by excavating an area of live grass and lifting the grass complete with about 5 cms of topsoil and roots still attached.

Turn Out Drain
See **Mitre Drain.**

Underdrainage (Sub-Soil Drainage)
System of pervious pipes or free draining material, designed to collect and carry water in the ground.

Unpaved Road
A road with a soil or gravel surface.

Vented Drift
See **Causeway.**

Waterbound Macadam
A pavement layer constructed where the voids in a large single-sized stone skeleton are filled with a fine sand, washed in by the application of water.

Wearing Course
The upper layer of a road pavement on which the traffic runs and is expected to wear under the action of traffic. This applies to gravel and bituminous surfaces.

Weephole
Opening provided in retaining walls or bridge abutments to permit drainage of water in the filter layer or soil layer behind the structure. Weepholes prevent water pressure building up behind the structure.

Windrow
A ridge of material formed by the spillage from the end of the machine blade or continuous heap of material formed by labour.

Wingwall
Retaining wall at a bridge abutment to retain and protect the embankment fill behind the abutment.

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Appendices:

1 INTRODUCTION: CONTEXT AND SCOPE OF THE MANUAL

This Low Volume Roads Manual promotes rational, appropriate and affordable designs for low volume roads in South Sudan. In doing so it aims at making cost effective and sustainable use of Local Resources. These can be human resources, local government, private, NGO, and community institutions, local entrepreneurs such as contractors, consultants, industrialists and artisans, local skills, locally made or fabricated intermediate equipment, local materials such as local produced aggregates, bricks, timber and marginal materials, locally raised finance or provision of materials or services in kind.

The Manual reflects local experience and advances in low volume road technology gained in the region and elsewhere.

Application of appropriate design standards for low volume roads in South Sudan aims to optimise whole service life construction and maintenance costs and meet requirements to:

- Improve the economic and social well-being of rural communities and access to social and other services;
- Facilitate inclusion of different ethnic and other groups in society;
- Develop the road network in a cost-effective and sustainable way;
- Lower road user costs and promote socio-economic development, poverty reduction, trade growth and wealth creation in rural areas;
- Protect and manage non-renewable natural resources and reduce import dependency.

This manual is intended for use by roads practitioners responsible for the design of low traffic earth, gravel or paved roads throughout South Sudan. It is appropriate for roads which, over their design life, are required to carry an average of up to about 300 motor vehicles per day, and less than about 1.0 million equivalent standard axles (Mesa) in one direction. The Manual complements and links to the latest versions of other existing South Sudan Government reference documents focusing on High Volume Roads:

- Drainage Design Manual;
- Bridge Design Manual;
- Geometric Design Manual;
- Pavement Design Manual;
- Site Investigation Manual.

It is intended to be complemented by separate volumes focusing on LVR, dealing specifically with Technical Specifications, Drawings and appropriate level Bidding Documents and other related issues for these secondary and minor routes.

The client for the low volume road works could be the MRB, a State or other Road Authority. The client could also be a local level administration, private enterprise, NGO, development agency, community organisation or cooperative. Road works, whether undertaken by a contractor, through an in-house capability or by community will require a design. This design will work towards satisfying a national standard set for a particular type of road. The degree of sophistication of the design will in general increase as the standard of the road increases. However, this does not mean that unpaved earth or gravel roads are any easier to design than a first generation low volume sealed/paved road. Often it is quite the contrary.

The road design engineer is normally supported by a team of individuals, with varying specialities, and equipped to deal with all aspects of the road design. The job of the design team is to provide a robust technical design (geometric, drainage, structures, pavement and ancillary works) and to reflect this in the instructions to bidders, conditions of particular application, the specifications, the bills of quantities and the detailed drawings. The design team should also include (or consult) environmentalists and sociologists for additional specialist inputs, as well as ensure that the designs are robust in initial cost, maintenance and Whole Life Cycle Cost (WLC) terms.

The general approach to the design will be guided by the client and will build on information and data collected during the project pre-feasibility and feasibility stages. The client will have a budget in mind for the works, the location and route will be known in outline, and the preferred approach to the works will also be known, for example labour, intermediate or heavy equipment- based. The client may also have views and guidance on apportioning works and contract size, technical issues, social, environmental and time constraints. The job of the road design engineer will then be to develop the project within and around these boundaries and limitations, whilst at the same time alerting the client to issues, constraints or challenges that may limit or require adjustment of expectations.

The approach to the design of low volume roads follows the general principles of any good road design practice. There are, however, subtle differences from the traditional road design practice. This manual sets out to provide the design engineer with the requisite tools that will provide the client with an optimised design based on the financial, technical and other constraints that define the project.

Optimising a design requires a multi-dimensional understanding of all of the project elements and in this respect all design elements become context specific. The design team therefore needs to be able to work with consideration and understanding of issues outside their normal areas of expertise and to understand implications of their recommendations or decisions on all other elements of the design.

The successful design of low volume roads relies on:

- A full understanding by the design engineer of the local environment (natural, operational and social);
- An ability to work within the demands of the local environment and to turn these to a design advantage;
- Recognition and management of risk;
- Innovative and flexible thinking through the application of appropriate engineering solutions rather than following traditional High Volume, high cost thinking related to road design;
- A client who is open and responsive to innovation;
- Realistic assessment and arrangements for maintenance needs and capacity.

There is an onus on the design engineer to provide a road that meets the expected level of service. Design engineers are traditionally conservative and build in factors of safety that cater for their perceptions of risk and extremes of caution. This approach prevents the application of innovation, uses scarce or inappropriate resources and results in high financial costs for the client and the country. There is also often a temptation to provide or upgrade roads to a future level of service not justified by the economic or other project projections or road user requirements. This type of approach absorbs the available resources and prevents extension of access to many other worthy recipients. It is the role of the design engineer to properly represent the client’s and country’s interests.

The level of attention and engineering judgment required for optimal provision of low volume roads is no different from, and in most cases is higher than, that required for the provision of other roads. The design engineer needs to draw on all of his engineering skills, judgment and local experience if appropriate designs are to be developed without incurring unacceptable levels of cost and risk. This manual will assist the engineer in that task.

The Manual is fully compatible with the South Sudan series of 2006 design manuals for higher volume roads.

The Manual contains technical explanations of all the steps in deriving the standards for low volume roads related to specific environmental conditions.

1.1 Structure and Layout of Manual

The low volume road manual has been drafted to be fully adaptable for different clients. The Manual has application for roads at national, state and local level for roads administered by authorities, enterprises or communities.

The Low Volume Road manual caters for a range of road type, from basic earth tracks to bituminous sealed roads. It is unlikely that one institution will cater for all standards of road and more likely that the document will have application across a number of different authorities, agencies and ministries. Bituminised and major gravel roads in South Sudan are usually constructed and maintained by the National and State Roads Authorities.

All authorities are expected to have networks of unpaved gravel and earth roads. Substantial kilometres of unpaved road are also provided through community programmes, NGOs, private enterprises, cooperative ventures and by programmes operating through other sector ministries, such as the Ministry of Agriculture and Forestry.

The document can cater for interventions that deal with individual critical areas on a road link (spot improvements) through to providing total rural road link designs. In this latter case, this could comprise different design options along the total length.

This Volume 1 of the Manual is presented in the following format:

> Chapter 1 provides an overview of the Manual, its application, context, and use, and discusses issues of road classification and categorisation.
>
> Chapter 2 describes the legal framework and ownership of the document.
>
> Chapter 3 introduces the Philosophy of low volume road design and presents the typical design controls that should be considered during the design process and the national Design Standards for low volume roads in South Sudan. These are mandatory standards that must be adhered to by the engineer. Departures from these standards are only permitted in exceptional circumstances and with the prior approval of the relevant authorities.
>
> Chapter 4 describes the particular challenges of the South Sudan Road Environments and provides advice on addressing the various issues of climate, hydrology, materials, traffic, terrain, construction & maintenance regimes, road safety and the green environment.
>
> Chapter 5 provides guidance on Route Selection and Investigation, including desk studies, site investigation and testing.
>
> Chapter 6 provides guidance on Geometric Design, including influential factors, and aspects of traffic characteristics, cross section, alignment, and safety.
>
> Chapter 7 provides guidance on Surfacing and Pavement Design and the range of design options using the materials available from Engineered Natural Surfaces (ENS), through gravel to various paving techniques, and issues of internal pavement drainage.

Chapter 8 addresses Construction Materials issues for each component of the road works and the desirability to optimise the use of locally available resources.

Chapter 9 provides guidance on Road Drainage and structures, including hydrology, components of road works drainage, erosion control and challenging terrain.

Chapter 10 addresses Road-side Slope Stability and protection issues and bio-engineering solutions.

Chapter 11 addresses the vital issue of Maintenance. The chapter is an introduction to the subject which is tackled more comprehensively in Volume 3.

Appendices are provided on the topics of Traffic Analysis; Materials Testing; Marginal Materials; Expansive Soils; Ground Investigations; Design Compliance; Complementary Interventions; Environmentally Optimised Design and Spot Improvement.

In companion documents there are separate volumes that cover:

- Cross Drainage and Structures (Volume 2);
- LVR Maintenance Booklet (Volume 3) providing practical guidance on the maintenance of LVR and structures).

The structure of the Manual is such that it allows client authorities, engineers and other practitioners to extract and use those parts (Chapters or Appendices) of the Manual most appropriate to their individual set of circumstances. The complete document can be downsized to capture specific and appropriate aspects.

1.2 Road Network Classification

At the time of the preparation of this Manual, the road classification system and network inventory for South Sudan are under development. The following proposals are derived from the September Coffey 2011 report: Sudan Infrastructure Services Project TO8: Capacity Building Program.

1.2.1 Importance of road classification

Classification of roads entails their orderly grouping into a set of sub-systems according to the type of service they are intended to provide to the public. Such a system is not only necessary for effective delegation of administration and political responsibilities for different parts of the road network but also provides a number of important outcomes that depend on the class assigned to each road, including:

- Road numbering;
- Guidance to the general public;
- Establishment of road design criteria;
- Development of road management systems;
- Planning of road construction and maintenance.

1.2.2 Road classification system

A classification system based on road function has been adopted for classifying the South Sudan road network in line with international good practice. This Functional Classification System draws a clear distinction between *mobility* roads, whose function is to move traffic over relatively long distances quickly, effectively and efficiently and *access* roads whose function is to provide access to various land uses and activities. Based on internationally accepted classification criteria and the territorial structure of South Sudan, a six-class, route numbered classification system has been developed as follows:

Table 1.1: Functional classification of roads

Basic Function	Class Number	Class Name	Route Number Prefix
Mobility	1	International	N
	2	Interstate	A
	3	State	B
Access	4	County	C
	5	Local	D
	6	Walkway	-

It is anticipated that the majority of routes categorised under Classes 3 – 6 will be appropriate for LVR design considerations using this Manual.

For design purposes, it is necessary to augment the above functional classification with a further categorisation based on the design traffic loading of the route. The geometric design is provisionally based on the following traffic related geometric standards (Table 1.2). Of interest to designers of Low Volume Roads are the Geometric Design categories DC1 to DC4.

Table 1.2: Categorisation for geometric design of roads

Traffic Grouping	Geometric Standards	Intended Level of Service	AADT
High Volume (HVR)	DC8	A	>10,000
	DC7		3,000 – 10,000
	DC6	B	1,000 – 3,000
	DC5		300 – 1,000
Low Volume (LVR)	DC4	C	150 - 300
	DC3 DC2		75 – 150
	DC2		25 – 75
	DC1	D	<25
	Track		-

It is economically justified to provide a higher level of service for roads carrying higher volumes of traffic, thus:

High Volume Roads

Level A: This is highest level of service. Traffic is free flowing, with the volumes and types of traffic easily accommodated. Safety is a high priority. Design speed is very important and takes precedence over topographic constraints.

Level B: Traffic may not flow smoothly in all situations. Safety is a high priority, but some safety controls may need to be enforced. Design speed is important, but topography may dictate some design changes and controls.

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Level C: The efficiency of traffic movement and flow is not a limiting factor. Traffic will be accommodated, but some design controls may need to be applied. Safety provisions are adapted to lower and variable speed scenarios. The topography will dictate alignment and the design speed.

Level D: Service level is geared to provision of access rather than efficiency. Design standards for water crossings may allow service interruption and some roads may even be temporarily closed in adverse weather or flood situations to protect these assets. Other design standards for geometrics, surfacing and safety will reflect lower speed environments and access requirement.

The density of roads in most areas of South Sudan is relatively low and many existing low volume roads are relatively long (>25km). Alternative routes are often long or non-existent and the consequences of disruption are high. It is prudent therefore to adopt design standards that provide an appropriate level of reliability and service commensurate with the functional characteristics of the road.

While there are exceptions to every rule, **low volume roads** in South Sudan can be considered as roads carrying less than 300vpd and generally of DC4 standard or below and meeting C or D service level criteria (the majority of roads in South Sudan carry relatively low levels of traffic by international standards, and most carry less than 300 vehicles per day). However they are all an essential component of the road system; their importance and reach extends to all aspects of the economic and social development of rural communities and the country at large.

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References

Coffey 2011 Report: *Sudan Infrastructure Capacity Building programme* US Aid TO8

2 LEGAL FRAMEWORK AND OWNERSHIP

During the period of the implementation of the Comprehensive Peace Agreement (CPA), the current Ministry of Roads and Bridges (MRB) and the current Ministry of Transport were one Ministry whose core functions were roads, railways, airports, and river transport. After the independence of the Republic of South Sudan from the Republic of Sudan, the Ministry of Road and Bridges (MRB) became a separate Ministry with the core functions of roads and bridges. The rest of the core functions of the original Ministry of Transport and Roads are retained by the current Ministry of Transport.

At Central Government Level the MRB is the key ministry with respect to overall policy and strategy for the road sector. It is therefore appropriate for the Ownership and custody of the LVR Manual to be vested with the MRB. However, other national bodies also have an interest and involvement with road development. Furthermore, at State Level the individual Ministries of Physical Infrastructures (MPIs) have specific responsibilities with respect to the development and maintenance of infrastructure and they should play a key role in the application and mainstreaming of the Manual at State level. In recognition of this the Technical Working Group (TWG) was closely involved with the development of this Manual and representatives of key road sector organisations were involved in its detailed preparation.

It is anticipated that development of the Manual and associated reference document will be a continuing process. It is appropriate that MRB will be responsible for coordinating the generation and incorporation of future amendments and improvements to them.

3 THE APPROACH TO LVR DESIGN

The design of LVR needs to make careful consideration of the following important aspects:

- Design Principles and the road environment;
- Use of local resources;
- Road Maintenance capacity and development;
- Feasibility and characteristics of Earth and Gravel Roads;
- Surfacing and Paving Options;
- Operational Environment;
- Technology Rationale, Options and Choice;
- Viability and Sustainability;
- Physical Environment protection and sustainability.

These issues are addressed in the sections of this Chapter.

South Sudan is in a unique situation in terms of recent history of conflict, past neglect and severe underdevelopment of transport infrastructure, limited institutional capacity and skill base, immature and fragile revenue raising and planning, budgeting and control arrangements, lack of public understanding and appreciation of road infrastructure, and extreme accessibility challenges and engineering materials availability issues in vast tracks of the country (the north east). There is, understandably, enormous demand for new and improved roads to support economic and social development and, indeed, nation building. However, capacities for transport infrastructure asset management, and funded and effective maintenance regimes are currently severely constrained.

3.1 Design Principles, the Road Environment, Use of Local Resources

The circumstances of South Sudan are unique and make it necessary to develop and adopt a very South Sudan-specific approach to the design of the Low Volume Roads network that allows:-

- Best use to be made of existing limited sector funds and resources;
- Rapid provision of strategic routes with year round (full) access;
- Rapid provision of basic access to the majority of the population for most of the year;
- Roads that are suitable for the types of traffic that will use them;
- Roads that are serviceable and safe for the users and general public;
- Roads that are cost-effective in consideration of their life cycle investments in initial construction and maintenance costs and road user costs;
- Minimisation of the impact on the natural environment;
- The best use of available local resources, allowing a range of technology options;
- Encouragement of the development of local capacity.

Environmentally Optimises Design (EOD) allows all of these objectives to be met in the circumstances of South Sudan. Environmentally Optimised Design is the over-arching framework for the application of appropriate LVR designs. It covers a spectrum of solutions for improving or creating low volume rural access, from Basic Access through to complete route rehabilitation/improvement (Full Access).

Under an EOD approach, the road is designed to suit a variety of task and environmental factors such as rainfall, available materials, construction capacity, gradient, flood risk, maintenance regime and so on. Some of these factors vary from road to road and even from location to location along a road. Therefore a road design may vary along the length of a road with, for example, a sealed surface up a hill or gravel along a level section. The following concepts form components of the EOD approach.

3.1.1 Basic Access

Reliable all-season access for the prevailing means of transport with limited periods of inaccessibility (typically for a period of up to about 24 hours during/after rain when the road can be impassable to motorised traffic). In practical terms; the provision of Basic Access consists of taking or bringing back the route to a minimum motorable and maintainable standard by:

- Clearing of vegetation;
- Reforming or providing the running surface camber;
- Opening of drains and any existing culverts/drifts.

These are the basic requirements for a serviceable low volume traffic access road. In most cases the in situ soil will form the running surface for the road (Engineered Natural Surface – ENS). However, to ensure all-season access, it may be necessary to provide Spot Improvements (Appendix H) at critical locations along the route. Although low cost to provide, Basic Access roads will require essential maintenance (Chapter 11) every year for continued for traffic.

3.1.2 Full Access

Uninterrupted all-year, high quality, high speed, low surface roughness access. No closures in the rainy season. In practical terms this may involve the provision of a gravel or sealed surface throughout the length of the route link. This level of access will also require appropriate levels of maintenance.

3.1.3 Meeting the challenges

Soils are highly variable and often problematic in South Sudan and therefore available materials for construction can be very variable or scarce and involve long haulage, particularly in large tracts of the north east of the country.

Seasonal rain and flooding, and likelihood of increasingly extreme weather events with global warming are also significant challenges to the construction of LVRs with limited resources.

Heavy vehicle loading and poor vehicle driver/owner discipline can lead to risk of abuse and damage of LVR infrastructure.

Hence, traditional engineering, and traditional road engineering in particular, is challenging in the face of such diversity. For low volume road provision the challenges can be even greater. . Given the vital importance of LVRs, design engineers need to work with and around such challenges. Clients also need to be flexible and adaptable, if low volume roads are to be provided at reasonable cost.

Typically in South Sudan, low volume roads are unpaved; with earth or gravel running surface. Very few routes are in good condition and can provide the level of all-weather access that is required. In facing the challenge of improving the low volume road network with severely constrained budgets, the application of the conventional planning, design, construction and maintenance philosophies used for higher traffic roads is unlikely to provide an optimal solution.

In determining cost-effective solutions for the provision of low volume roads it is important to understand the mechanics of how the road deteriorates in the first place. Deterioration of the existing unpaved low volume roads in South Sudan is governed by the type of material used on the surface (gravel to soil); the strength of the underlying soil (soft, erodible and/or expansive), the type and action of traffic (heavy vehicle to pedestrian) and probably most importantly, the influence of the "road environment". The term "road environment" includes both the natural or bio-physical environment and the human environment. It includes the interaction between the different environmental factors and the road structure. Some of these factors are uncontrollable, such as those attributable to the natural environment, including the interacting influence of climate (e.g. wind, rainfall and its intensity), local hydrology and drainage, terrain and gradient. Collectively, these will influence the performance of the road and the design approach needs to recognise such influence by providing options that minimise the negative effects. Others factors, such as the construction and maintenance regime; safety and environmental demands; and the extent and type of traffic are largely controllable and can be more readily built into the design approach.

Typical road environment factors are presented and covered in more detail in Chapter 4 of the Manual.

3.2 Maintenance Capacity and Development

Maintenance is the range of on-going activities to keep the roads within an acceptable band of serviceable conditions so that these infrastructure assets perform the function they were designed for in a cost effective way. There are serious maintenance deficiencies in many developing and emerging economies. The need, practical arrangements, and good practice for maintenance are well documented (TRL 1985, TRL 2003, PIARC 2006). However, the 'enabling environment' for arranging and delivering cost-effective maintenance is lacking in many countries (O'Neil et al 2010). The World Bank's World Development Report 1994 advised that 'in Africa and elsewhere, costly investments in road construction have been wasted for lack of maintenance'. The report cites that "Inadequate maintenance has been an almost universal (and costly) failure of infrastructure providers in developing countries." Unfortunately insufficient improvements have been achieved in many countries in the years since. The current circumstances of very little road maintenance achievement in South Sudan make this a particularly important issue to address.

It is therefore proposed that assessment of the existing maintenance regime and development of maintenance capacity should be an integral part of the design process. It may be appropriate to incorporate assessment of maintenance capacity and the development of capacity enhancement initiatives in the design and implementation phases of a project. The maintenance capacity for the constructed road will certainly have an impact on the Whole Life cycle Cost considerations of any investment.

3.3 Low volume earth and gravel roads

Surface materials, where these are present, need to resist wear and abrasion in dry weather and promote surface drainage and run-off in wet weather. Under traffic they need to resist whip off, dust generation and be stable enough when compacted to resist deformation. The compacted material needs to resist erosion and scour.

The nature and strength of the underlying soil is critical in determining the performance of low volume roads, particularly in periods of wet weather. Many rural roads are characterised by deep rutting, where the road formation is not strong enough to support the traffic loads. Some roads have loose and/or stony materials on the surface, leading to dusty, rough and/or slippery conditions. Potholes create difficult and unsafe surfaces. Severe erosion and scouring may prevent access by any form of motorised, and many types of intermediate, transport. Transverse scouring can start at the edge or on the side slope of the road and work its way to the centre of the carriageway. Longitudinal scour occurs where water flows against the direction of road crossfall. Inadequate scour protection in drainage ditches may lead to serious erosion, dangerous conditions for road users, local access restrictions, and loss of valuable agricultural land along the road.

Rural access may be prevented for long periods during the rains when streams and rivers start to flow. In some situations wash-aways may occur. When the rains have eased or stopped the same points may be subject to saturation and ponding. This weakens the underlying soils and any movement on the surface can churn up the surface causing deep rutting and the bogging down of vehicles.

This problem is worsened in areas where there is a prevalence of expansive, black cotton soils. These soils have high agricultural potential, but become weak and slippery when wet. They often cannot support even the lightest vehicles in the wet condition. Where gravel is placed directly over this material it may rut under the influence of traffic and mix into the weak soil below.

Vehicle operating costs (VOCs) are high on roads with high roughness and restricted access. VOCs include spares, repairs, maintenance, fuel and tyre replacement, finance/opportunity costs and depreciation/amortisation. The consequence is that transport operators tend to avoid roads with high roughness and other defects forcing people to walk long distances to reach the nearest point where transport services are prepared to operate.

Dust is often overlooked as a problem on unpaved roads. It is caused by the action of traffic and wind. Unpaved roads lose fine material which can travel over 100 metres from the road. The dust affects other road users, pedestrians and school children, houses, shops and crops near the road. Roads in dry areas can lose up to 33 tonnes of surface fines per kilometre per year. Dust has significant and costly adverse consequences including eye and respiratory problems, vehicle and equipment damage, damage to crops and the natural habitat, and increased risks to pedestrian and vehicle safety and social aspects such as cleanliness. Approaches to alleviate dust problems, particularly in populated areas are offered in the Manual.

Gravel for road works is a non-renewable natural resource. On unpaved roads it is used as a sacrificial layer and must be periodically replaced. Good materials for gravel surfaced roads are not commonly found in South Sudan, and are almost totally absent in the north east regions of the country. It is possible to lose up to 150mm thickness of gravel surface layer per year depending on conditions. Gravel roads require a continuous cycle of reshaping and regravelling to maintain the required running surface and the desired level of service. The type of materials prevalent in South Sudan, the nature of the climate and the terrain presents significant challenges to achieving this type of maintenance. Screening and blending techniques are available to improve the properties and such techniques are described in the Manual.

The major technical challenges for unpaved roads are to provide durable and functional water crossings, surfacing with materials that provide the desired and necessary level of service and to provide effective maintenance management. These challenges are recognised in the Manual and, in many cases, options and solutions are offered to mitigate and manage problems.

The key issue with regards to earth and gravel surfaced roads is to construct ***and maintain*** an adequate camber and drainage system.

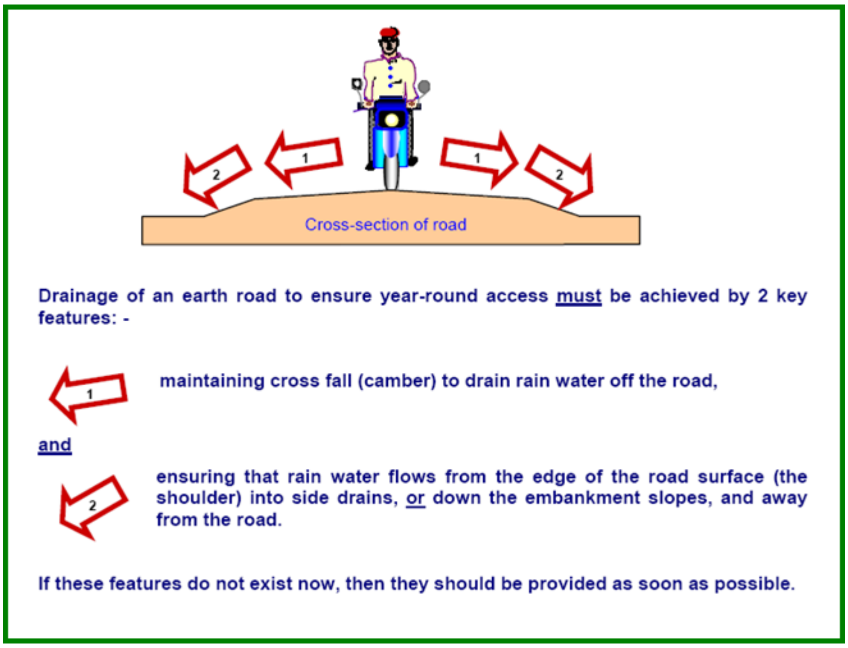

Figure 3.1: The importance of water management for unpaved roads

Earth roads require regular (routine) maintenance, which can be carried out at relatively low cost with local labour and simple inexpensive equipment. Gravel roads require similar levels of regular maintenance. However, there are substantial additional resource and cost implications in maintaining the gravel running surface through provision of occasional (periodic) maintenance. These liabilities must be understood and allowed for in any project life cycle assessment. Failure to provide the arrangements, resources and funds for these maintenance liabilities *on a timely basis* will inevitably lead to a gravel road quickly reverting to a rough and possibly impassable condition in the rains, and a waste of the initial investment.

Failure to provide regular maintenance of unpaved roads will also incur excessively high VOCs for the road users.

3.4 Low volume paved roads

The design manual draws on international research carried out over several decades. This research was carried out by a number of research organisations in collaboration with national road authorities in the region. The research questioned existing paradigms associated with the design of low volume roads with a paved surfacing and, combined with local experience, derived local specifications, designs and techniques for improving the cost-effective provision of such roads paved with either a bituminous or non-bituminous surfacing. This included more appropriate geometric, drainage and pavement design standards and innovative construction techniques and methods that optimised the use of local labour, introduced intermediate equipment techniques and improved opportunities for the local private sector to participate in road construction and maintenance. Guidance on a number of proven non-bituminous paving techniques has also been incorporated in the Manual.

The approaches adopted for the design of low volume paved roads differs in a number of fundamental respects from roads carrying higher traffic volumes. In particular, the relative influences of road deterioration factors are significantly different for low volume roads compared with higher volume roads. A critical observation is that for sealed roads, carrying below a total of about 1.0 Mesa throughout the design life, pavement deterioration was controlled mainly by how the road responded to environmental factors, such as moisture changes in the pavement layers, fill and subgrade and to the effects of age hardening of bituminous surfacings. The appropriate design options for low volume roads therefore need to be responsive to a wider range of factors captured in the road environment, the most critical being the internal and external drainage.

The role of the design engineer is to recognise and design to these parameters and optimise the design to the expected performance within the limited resource constraints prevailing. This is known as an environmentally optimised design (EOD) approach. EOD takes account of road environment changes along the alignment and the design responds to these changes.

3.5 Surface Improvement Technology

Gravel and earth roads are particularly vulnerable to the effects of the road environment. A range of more durable surfacing options other than gravel or earth are available for low volume roads. These include thin bituminous surfacings, and non-bituminous surfacings such as cobbles, hand packed stone, brick/block paving and even unreinforced concrete. Options also include full paving and wheel-track-only paving. The selection, design and use of the various surfacing options are described in detail in Chapter 7 along with design standards presented later in this Chapter.

Improved surfacings may be provided for the entire length of a road, or only on the most vulnerable sections. The approach may include dealing only with individual critical sections (weak or vulnerable sections; roads through villages or settlements) on a road link (spot improvements), or providing a total whole rural link design, which could comprise different surface design options along its length.

The choice of surfacing type, and when to use it, involves a trade-off between initial cost, level of service and maintenance requirements. Cobblestone may use locally available resources and require very little maintenance, but it gives a relatively rough riding surface. Surface dressings provide smoother riding surfaces but may require more expensive earthworks and pavement layers, as well as imported bitumen, specialised equipment and skilled operators. Appropriate selection will be driven to some extent by the service level required, as well as locally available materials, skills and costs.

Surface dressings should not be constructed where there is no capacity for routine maintenance, including pothole repairs and crack sealing, as well as periodic re-sealing. Edge break is a common problem on sealed roads due to vehicles and pedestrians moving on and off the road, and needs to be controlled through appropriate road width, provision of stopping places, and possibly kerbing.

The challenge for the design engineer for a low volume road is to achieve the required level of service, using appropriate engineering approaches and to minimise costs over the whole life of the road. This should be done in a context sensitive way that recognises the needs of the client, the road environment and the prevailing maintenance management regime.

3.6 Operational Environment

In addition to ensuring that the design developed is technically appropriate and is within the financial envelope, the design engineer needs to bear in mind other factors that could influence the success of the low volume road design approach, its implementation and its long term sustainability.

This requires a broadly focused, multi-dimensional and context sensitive approach in which a number of other influential factors of the Operational Environment are considered, illustrated in Figure 3.2.

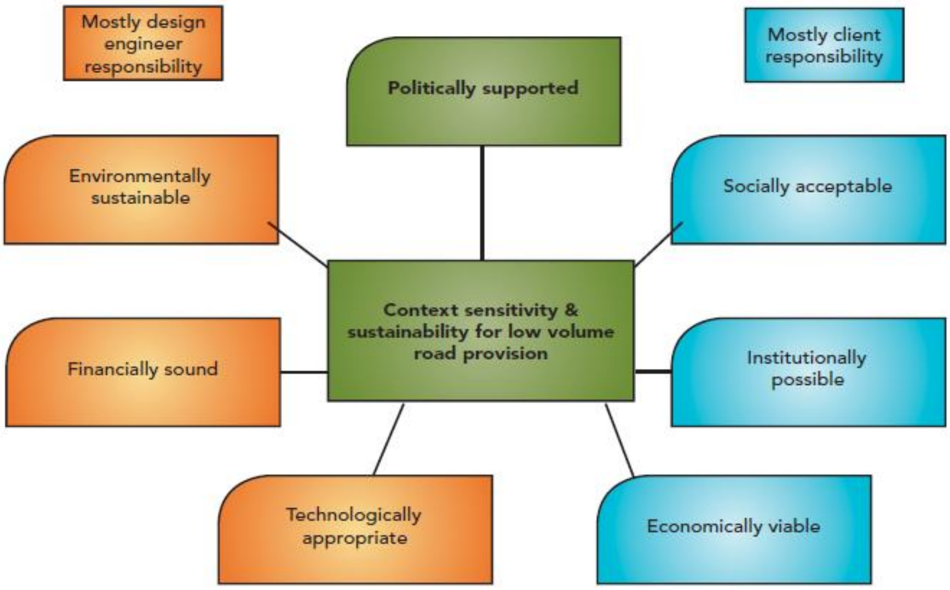

Figure 3.2: Framework for sustainable provision of low volume roads

3.6.1 Political support

Demand for appropriate low volume roads needs to be framed under a national policy driven by government and should be supported at the highest level. The cross-sectoral influence of low volume road provision and its role in under-pinning other sectoral development strategies and poverty alleviation programmes should be highlighted, quantified and understood by policy makers, clients and other sector stakeholders.

The approach adopted for low volume road provision should complement national plans, policies and strategies and should be responsive to wider needs and demands, including:

- The social and economic goals of poverty alleviation and development;
- Increasing rural accessibility;
- The use of appropriate technology, promotion of the domestic construction industry and employment creation;
- Protection of the environment;
- Cost minimisation and improved efficiency.

There is a need to maintain dialogue with political and public stakeholders in order to highlight the advantages of design approaches and alternative, often unfamiliar, solutions selected for low volume road provision. The language used for advocacy should be carefully chosen and should avoid negative connotations such as “low standard”; “low cost” and “marginal”, which may be understood in professional circles, but which can be misinterpreted in political and public terms.

3.6.2 Social acceptance

Provision of low volume rural road networks should be managed in a way that:

- Ensures community participation in planning and decision making;
- Eliminates gender bias and promotes participation by women in the road sector;

- Promotes activities and investment for sustainable livelihoods (including Complementary Interventions as discussed in Appendix G);
- Promotes road safety and community awareness in all aspects of low volume road provision;
- Supports cost-effective labour-based and intermediate equipment methods of construction and maintenance where appropriate;
- Minimises resettlement and mitigates unavoidable resettlement through appropriate compensation.

3.6.3 Institutional capacity

Road authorities and clients should:

- Promote institutional, economic and technical understanding in the provision and management of low volume roads;
- Promote commercial management practices;
- Develop a conducive environment for the development of national contractors;
- Develop the necessary asset management and maintenance capacity and culture to safeguard the considerable national road investments and ensure their intended benefits;
- Ensure that design, construction and maintenance approaches and good practice for low volume roads are represented on all tertiary civil engineering training curricula.

3.7 Technology Choice

For most road construction and maintenance operations there is a choice of technology between labour, intermediate and heavy equipment, and often possible combinations of these. Each option will have cost, operational, development and social implications that should be considered at policy planning and design levels.

Technologies for designing, constructing and maintaining low volume roads should:

- Employ appropriate design standards and specifications;
- Utilise intermediate equipment technology options and reduce reliance on heavy equipment imports where feasible and cost-effective;
- Promote road construction and maintenance technologies that create local employment opportunities;
- Use types of contract that support the development of domestic contractors and consultants;
- Be robust to the vagaries of climate and recognise potential impacts of a changing climate.

When cost comparisons between technology options are made, all cost components should be considered, including finance/opportunity costs and depreciation/amortisation of capital items such as equipment. Overheads, logistics, contingencies/risks and profit components are also significant considerations. In a relatively small road construction market such as South Sudan, the market may not operate efficiently. It is advisable to prepare Engineer’s Estimates of costs from first principles to allow understanding of the true costs and as a basis for any cost negotiations.

3.8 Viability and Sustainability

3.8.1 Economic viability

Economic appraisal for low volume roads should:

- Employ assessment tools for low volume roads that are capable of quantifying social, economic and environmental costs and benefits;
- Ensure investment decisions for low volume roads are based on an assessment of whole life cycle costs.

3.8.2 Financially sound

Sustainable provision of low volume roads depends on the sustainable provision of funding to the sector in that:

- Roads should not be upgraded to engineered standards if funding is not in place for regular (routine) and occasional (periodic) maintenance requirements;
- Designs should not be developed that require excessive allocation of maintenance resources.

3.8.3 Protection of the environment

The design and management of low volume roads should:

- Minimise the physical impacts of construction and maintenance activities on the natural environment;
- Ensure that any temporary works or quarrying sites are reinstated or left in a safe and environmentally stable condition;
- Take account of socio-cultural impacts (community cohesion);
- Minimise the carbon footprint;
- Optimise resource management and allow for possible recycling of non-renewable materials; and
- Minimise impacts and emissions that might contribute to climate change.

3.9 Road Project Implementation

3.9.1 Contract of works

The key to successful execution of a low volume roads project will be to ensure clearly defined requirements and adequate provisions are included in all bidding and contract documents. A clear understanding of the requirements from both the works contractor and the supervising engineer is needed.

Bidding documents need to contain all of the information and provisions for the interested companies or organisations on all that is relevant to obtain the contract. The bidding document informs interested bidders on all of the procedures to be followed, documents to be submitted, the bid evaluation procedure and the award of contract.

The approach used for execution of low volume roads can differ in many respects from the traditional road provision approaches. For example, the client may favour labour-based approaches; the use of intermediate equipment; sub-contracting to empower small enterprises; and/or additional enhancements through complementary interventions (Appendix G). It is therefore important that the provisions within the bidding documents clearly reflect these preferences and adjust the provisions of the contract accordingly.

Failure to properly differentiate low volume road approaches can lead to complications during the bidding procedure or execution of the contract. Moreover, clear and well prepared bidding documents are essential to ensure that sufficient companies or organisations are confident to bid for works in a fair and transparent way.

It is anticipated that in order to facilitate preparation of documents a series of model bidding documents will be developed for use with works of differing complexity.

The main issues for a bidder/contractor are to fully understand the scope of all the works, including any complementary interventions, and the fundamental issues of measurement and payment. For the preparation of Works Bidding Documents the key documents requiring attention are:

Instructions to Bidders (ITB) and the Bid Data Sheet (BDS): The ITB is generally a standard document, slightly varying for the different clients. For a LVR project the client should include an additional item that will draw the attention of the bidder to the low volume road approach and any requirements for complementary interventions. The BDS is linked to the ITB and provides specific project information.

Standard Technical Specifications: These will define the scope of the technical requirements of the contract, including the type and quality of materials and equipment, the standards of workmanship. Standard Technical Specifications should include information on the format of Bill Items for the Bill of Quantities, on item coverage and the method of payment.

Particular Specifications: This is where any detailed technical requirements and specifications, and implementation mechanisms specific for the project should be clearly defined. The particular technical specification should also include any specifications and limitations on the freedom of choice for the contracting company related to the execution of works. Particular technical specifications add further detail to complement or replace those stated in the Standard Technical Specifications.

Bills of Quantities or Schedules of Rates: This should be linked by item number to the Standard Technical Specifications and to the Particular Specifications; and is where the schedule of activities and estimated quantities are set out for the bidder to price.

Drawings: Some standard detailed drawings may be applied directly for low volume roads works (e.g. cross-sections, standard culvert design and signage). Supplementary drawings, linked with the Particular Specifications, may also be required where new, innovative or special approaches are included.

Conditions of Contract: This includes standard provisions for execution of the contract and unless amended in the Conditions of Particular Application, these will apply. For major and intermediate works projects it is anticipated that amendments may be required to reflect the desired approach for low volume road works.

Conditions of Particular Application: This is where any Provisions in the General Conditions of Contract may be amended, as required, to make them more appropriate to the requirements of the low volume road approach, including complementary interventions.

In promoting small and medium scale enterprises; emergent contractors; employment intensive or labour-based works; and utilisation of intermediate equipment options, consideration should be given to the clauses referring to Performance Security, Performance Program, Insurances, Cash Flow, Plant, Equipment & Workmanship, Payments, Retention and Advances, Price Adjustment and currency restrictions. There will be cases where the general conditions of contract may prevent, or work against, the small scale industry and these should be adjusted accordingly to promote competition and fairness to the emergent industry.

Due consideration should also be given to strengthening clauses aimed at promoting sub-contracting/ assignment; local employment and conditions (particularly for women); rights and insurances; and for strengthening complementary interventions.

Works Contract Evaluation: Recognition that the context of the works is using low volume road approaches must be included within the evaluation of bid process. The aim should be to ensure that the bidder confirms an understanding of the Client's perception for implementation. If complementary intervention requirements are built into the prospective works, the evaluation should also ensure that the complementary interventions are fully understood.

3.9.2 Supervision services

In addition to adequately defining the scope and understanding of the project and its approach for the works bid, it is essential that the same level of understanding is reflected in the Request for Proposals (RFP) for the supervising consultant. The RFP should specifically include appropriate inputs of key personnel with the requisite skills to meet the requirements of the low volume roads project approach. The supervising consultant should be fully familiar with the techniques and approaches to be employed on the works, including any complementary interventions.

The RFP should include:

- Clear definition of the role of the supervisor in the context of the project: if small scale or emergent contractors are employed, the client may require the consultant to act both as supervisor and mentor or to provide training, for example to client or authority staff;
- Clearly defined and appropriate inputs for key personnel with requisite experience on low volume road implementation;
- Requisite skills to cater for socio-environmental safeguard supervision and oversight of any complementary interventions;
- Reference to this Manual and supporting documents.

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4 South Sudan Road Environments

4.1 Introduction

It is now recognised that the life-time performance of LVRs is influenced to a greater extent than higher volume roads by the impacts of what is termed the Road Environment. Figure 4.1 illustrates this schematically by indicating the relative impacts of traffic to other Road Environment factors on pavement performance over a range traffic volumes. The impact on other road alignment elements such as earthworks, drainage and structures is equally or even more evident.

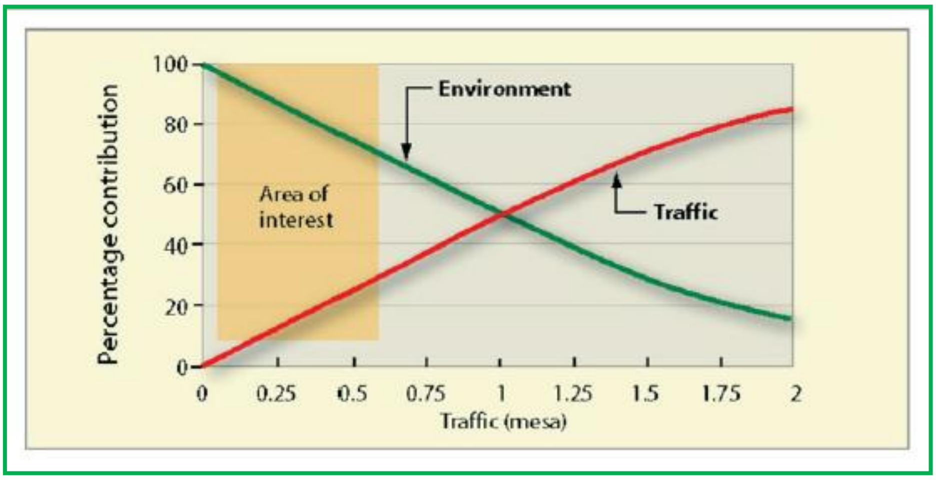

Figure 4.1 The relative impacts of traffic and other Road Environment factors on pavement performance

The various factors making up this Road Environment are categorised in Figure 4.2 into those factors over which the road designer or owner may have least some control and those over which there is no control. Table 4.1 defines these environment factors and their importance in the context of road whole-life performance.

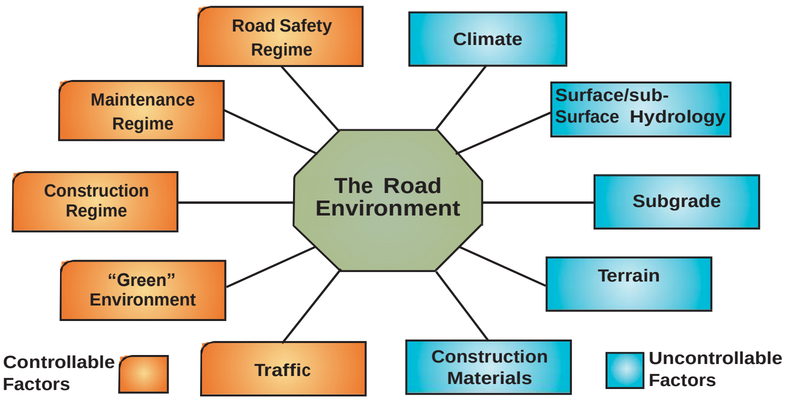

Figure 4.2 Road Environment factors

Table 4.1 Road Environment impact factors

Impact Factor	Description
Climate/rainfall.	The prevailing climate will influence the supply and movement of water and impacts upon the road in terms of direct erosion through run-off and influences on the groundwater regime. Climate, particularly rainfall, can have significant impact on the performance of earthwork slopes, the design options for side drainage and cross-drainage structures. Thus climatic indices can have a significant influence on the selection of pavement options and their design using “wet” or “dry” design parameters.
Surface and sub-surface hydrology**.**	The interaction of water, and its movement, within and adjacent to the road corridor has an over-arching impact on the pavements performance, earthworks and drainage structures. Changes in near surface moisture condition trigger significant subgrade and earthwork volume changes in the large areas of South Sudan underlain by “expansive” clay.
Subgrade and foundation conditions	The subgrade is essentially the foundation layer for the pavement and the assessment of its condition is critical to the pavement or surfacing design. Weak, soft or compressible foundations have a significant impact on the design and performance of embankments or culverts placed on them. In situ foundation strength is a key issue in the design of bridges.
Construction Materials	The nature, engineering character and location of construction materials are key aspects of the road environment assessment. For LVRs, where the use of local materials is a priority, the key issue should be what design options are compatible with the available materials rather than seeking to find material to meet standard specifications as is the case with higher level roads.
Terrain	The terrain, whether flat, rolling or mountainous reflects the geological and geomorphological history. Apart from its obvious influence on the long section geometry (grade) of the road and earthwork requirements, the characteristics of the terrain will also reflect and influence the availability of materials and other resources.
Traffic	Although the relative influence of traffic on LVRs is less than that from other road environment parameters, consideration still needs to be given to the influence of traffic and, in particular, the risk of axle overloading on light road pavements.
Construction Regime	The construction regime governs whether or not the road design is applied in an appropriate manner. Key elements include: Experience of contractors or construction groups • Appropriate plant use; • Selection and placement of materials; • Quality assurance; • Compliance with specification; • Technical supervision.
Maintenance Regime	All roads will require regular maintenance to ensure that their basic task is delivered throughout their design life. Achieving this will depend on the maintenance strategies adopted, the timeliness of the interventions, the local capacity, and available funding to carry out the necessary works. When selecting a road option it is recommend assessing the actual maintenance regime that will be in place during its design life so that designs may be appropriately adjusted where possible.
The “Green” Environment	Road construction and on-going road use and maintenance have an impact on the natural environment, including flora, fauna, hydrology, slope stability, health and safety. These impacts have to be assessed and mitigated as much as possible by appropriate design and construction procedures.
Road Safety Regime	LVRs are likely to be required to accommodate a wide range of users from pedestrians through to trucks. The traffic mix should be assessed and taken into account in the basic geometry of the road; including, for example, the use of wide shoulders for pedestrian or bicycle use. Adequate signage and protective barriers, particularly in hilly or mountainous terrain, are key safety requirement.

4.2 Climate

The main features of climate that are of importance in the design of LVRs are:

- Rainfall;
- Rainfall intensity;
- Temperature;
- Evaporation.

The overall rainfall pattern for South Sudan is presented in Figure 4.3 and the general climatic zones are summarised in Figure 4.4 and the associated Table 4.2.

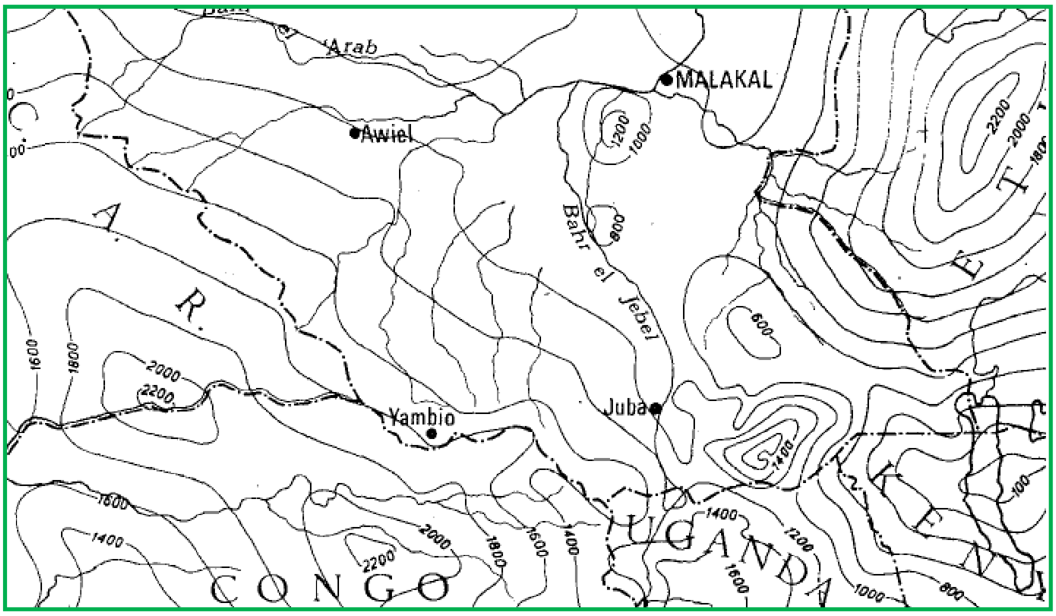

Figure 4.3 Rainfall pattern for South Sudan in mm/year

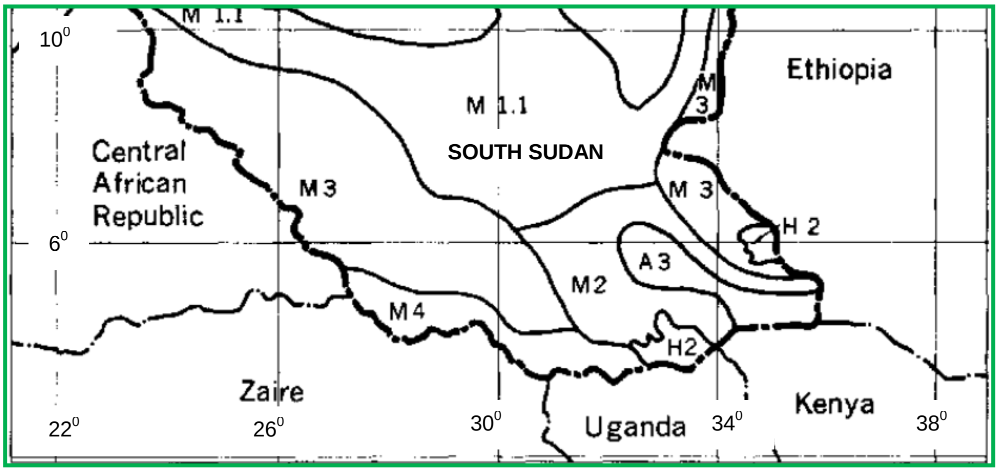

Figure 4.4. Climatic zones in South Sudan (after Van der Kevie, 1976)

Table 4.2. Detail of climatic zones in South Sudan (after Van der Kevie, 1976)

Zone	Description	Humid Months	Dry Months	Annual Rainfall (mm)	Mean Max (T 0^c)	Meant Coldest (T 0^c)	Approx. "N" Value
A3	Arid; no marked seasons	0	8-9	550-750	37-38	18-20	N>4
M1.1	Dry Monsoon; Long dry season, warm winter	3-5	5-7	750-1000	36-41	17-20	N<4
M2	Dry Monsoon; medium dry season	2-3	4-6	850-1000	36-38	18-21	N<4
M3	Wet Monsoon; medium wet season	5-7	3-5	950-1400	34-39	12-10	N<4
M4	Wet Monsoon; long wet season	7-8	1-2	1200-1600	34-35	14-19	N<4
H2	Highlands; medium wet season, cool winter	5-6	3-4	1000-1600	22-33	10-17	N<4

Rainfall, temperature and evaporation may also be combined into a Climatic Index (Weinert, 1974). The Weinert "N" Value has been adopted as part of the pavement design process. This index is calculated as follows:

$$N = 12Ej/Pa$$

where:

Ej = evaporation for the warmest month

Pa=total annual precipitation

N-values less than 4 apply to a climate that is seasonally tropical and wet, whereas N-values greater than 4 apply to a climate that is arid, semi- arid or dry. The implication for pavement design is that drier climates (N>4) can allow a reduction in pavement materials' strength specifications. This is discussed further in Chapter 7.

4.3 Surface/Sub-surface Hydrology

The Nile river and tributaries in association with the contrasting terrain patterns of the central level plain and the southern and western hills dominate the drainage pattern and hydrology of South Sudan. A general map of South Sudan's hydrological provinces is available and this has a close relationship both with the terrain and geological maps, Figure 4.5.

Heavy rainfall, clay soils (black cotton) and proximity to the Nile drainage system combine to create poor drain-off and high levels of standing water over most of the low lying plain, particularly in Jonglei, Upper Nile and Unity state which can be flooded for nine out of twelve months of the year.

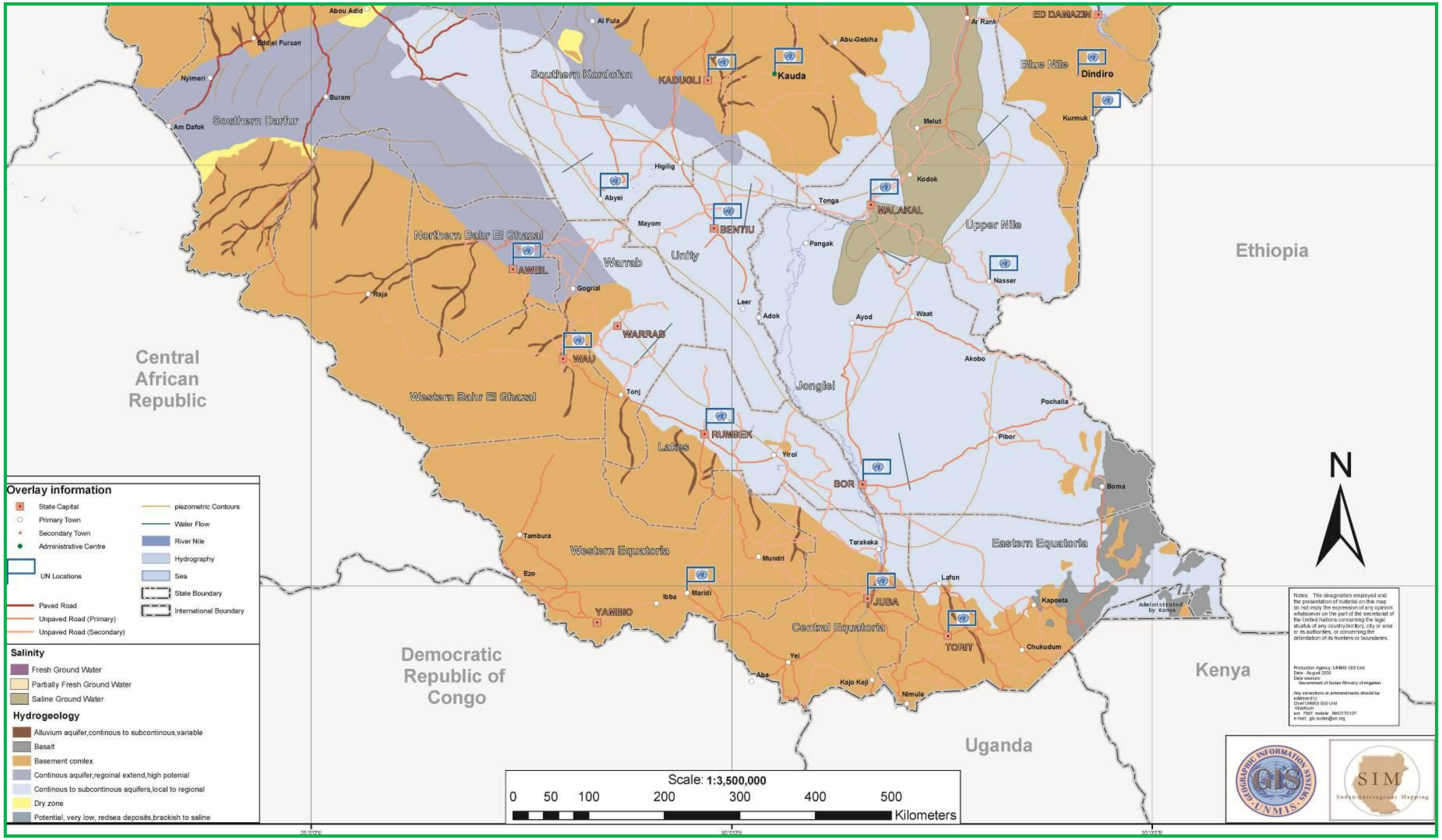

Figure 4.5 General hydrological map of South Sudan

4.4 Subgrade and Foundations

Subgrades and foundations in South Sudan are inherently variable and reflect the country's diverse geology, topography, soil type, climate and drainage conditions. Subgrades in the extensive flat, floodable, areas in the centre and east of South Sudan are likely to be low strength and comprise potentially problematic moisture sensitive expansive clays. In contrast subgrades on the higher ground to the South and West that are composed of either weathered bedrock or pedogenic (lateritic) materials are likely to be significantly stronger.

4.5 Traffic

The types of traffic using LVRs in South Sudan vary significantly and include both motorised and non-motorised traffic involving a wide spectrum of road users from pedestrians and animal-drawn vehicles to large commercial vehicles. The traffic environment in South Sudan is rapidly evolving and little detailed information is available as to its current make-up or the likely development over the next 10-15 years.

The deterioration of paved and unpaved roads caused by traffic results from both the magnitude of the individual wheel loads and the number of times these loads are applied. It is necessary to consider not only the total number of vehicles that will use the road but also the axle loads of these vehicles. There are currently no official axle load limits in South Sudan and no way of checking and therefore enforcing axle load limits. Anecdotal evidence does, however, indicate that axle overloading is a potentially serious problem, particularly for light LVRs

The current Main Roads Design Manual defines the present vehicle fleet in South Sudan as comprising 'a high number of four-wheel drive utility vehicles and overloaded trucks.

4.6 Construction Materials

The availability of suitable construction materials in South Sudan is largely a function of the geological environment. As indicated in Figure 4.7 the surface geological environment may be broadly summarised as comprising strong fresh to weathered igneous, sedimentary and metamorphic basement rocks in the higher lands of south and west of the country with an extensive central flat low lying plain underlain by Quaternary and Recent clays and sands (including expansive materials). The basement areas are potential sources not only of rock aggregate but also of derived lateritic gravels. In contrast, there are significant areas of central and eastern South Sudan that are largely deficient in conventional road building materials, Figure 4.8. The process of identification and selection of appropriate materials for incorporation in a road is discussed in detail in Chapter 7.

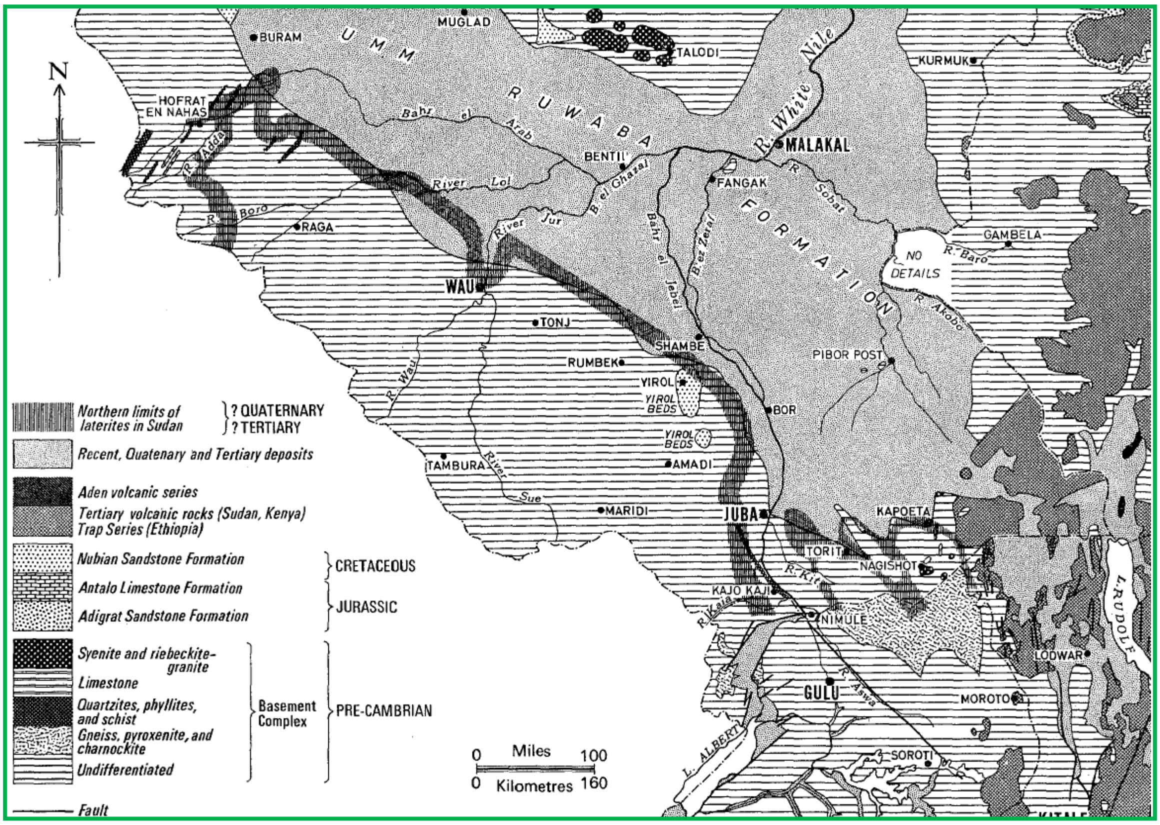

Figure 4.7 General geology of Southern Sudan and adjacent areas (Based on Sudan Geological Survey Map and ASGA-UNESCO Geological Map of Africa)

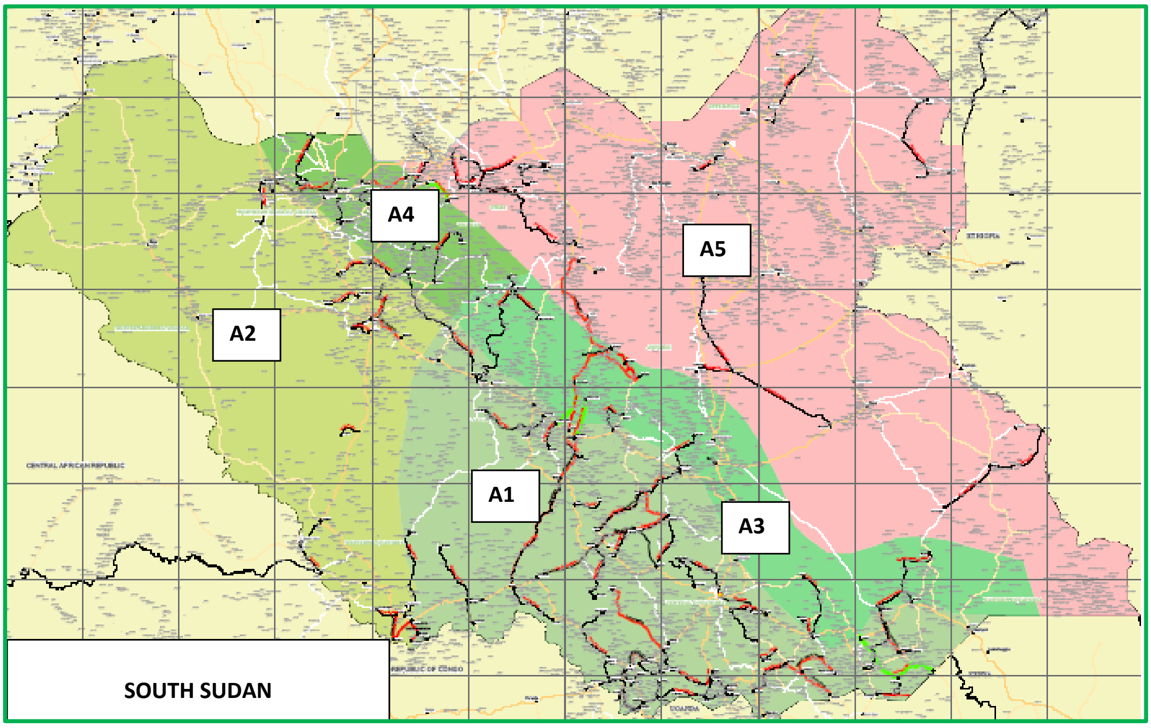

Figure 4.8 Broad divisions of the availability of road construction material

Table 4.5 Materials resource areas in South Sudan

Area	Materials Resources
A1	Area has good materials, lateritic gravels and rock. Assume haul at an average of 10km
A2	As above, but long logistics lines increase costs. Assume average haul 10km.
A3	Area has NO gravel or rock materials, characterised by expansive soils, and sandy /silty areas. Average haul 30km
A4	Area has NO gravel or rock materials. It is characterised by expansive soils, and sandy /silty areas. Average haul is 30km. Costs are 10-20% higher than area 3 due to longer logistics lines.
A5	Area has no known gravel sources. It is characterised by expansive soils, gravel beyond 60km overhaul, currently dry season roads only.

4.7 Terrain

The South Sudan terrain model may be characterised as being dominated by an extensive low-lying plain with higher ground above 500m above sea level (asl) to the west and higher hills and mountains to the south rising to 2500m asl, Figure 4.9.

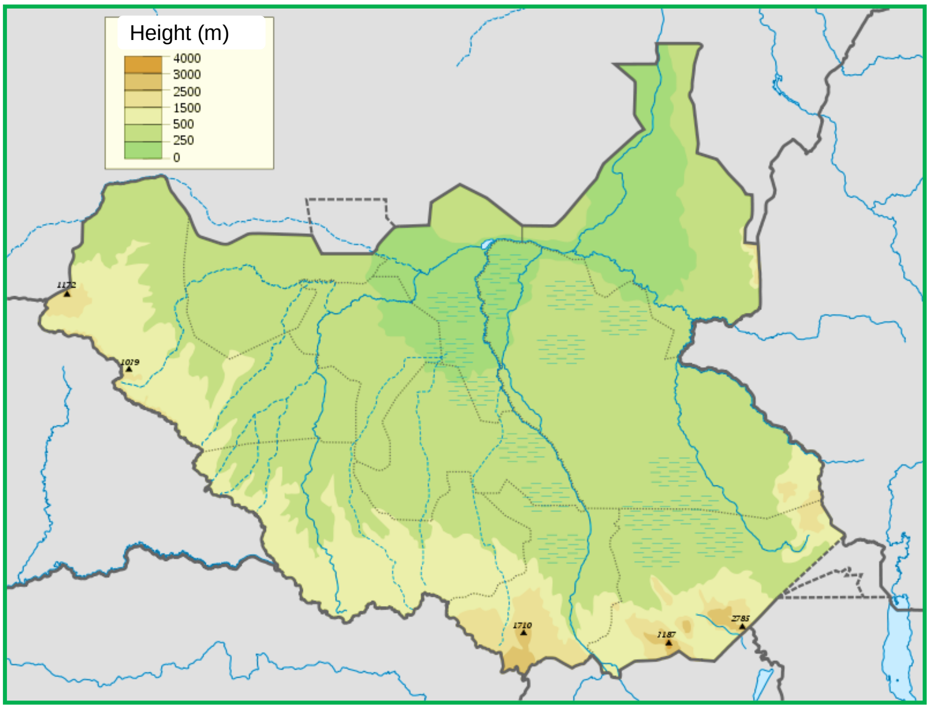

Figure 4.9 General terrain model for South Sudan

4.8 South Sudan Construction Regime

The existing road construction regime in South Sudan is currently evolving under a general intention by the MRB that a construction strategy should be developed that is appropriate to the prevailing social, economic, cultural and other needs of South Sudan.

Such a strategy could be aimed at making maximum use of the relatively abundant resource of labour through the use of labour-based technology, where appropriate. This approach would involve using a combination of labour and light equipment rather than heavy plant, without compromising the quality of the end product. It is reported, however, that in most rural areas of South Sudan a predominantly labour-based approach to rural road may not be appropriate due to a combination of low population density and social structure.

Any large scale involvement of locally-based small contractors on LVR development programmes is likely to require a significant training and demonstration component.

4.9 Maintenance Regime

Currently there are serious deficiencies in relation to the maintenance of road infrastructure in South Sudan. The need to develop adequate road maintenance funding and capacity are vital to achieving the intended benefits of road infrastructure investments. The guidance provided in Section 3.2 in assessing existing and necessary maintenance regime should be an integral part of the road design process.

Assessment of the existing maintenance regime should include investigation of funding scope disbursement arrangements and continuity, institutional responsibilities, arrangements for implementation, performance and cost-effectiveness in whole life terms. It is likely that these investigations will influence the balance of investment into construction activities and maintenance capacity development initiatives, and the design of certain road works components such as surfacing and drainage provision.

4.10 The Road Safety Regime

Some aspects of pavement structural design are affected by the road environment and can have an impact on the safety aspects of the roads. For example, the generation of dust from some wearing course gravels, the slipperiness of some earth surfaces and the skid resistance of bituminous surfacing. These factors can be addressed through a surface selection procedure as discussed in Chapter 7.

Many other aspects of road safety are concerned with geometric alignment and vehicle speeds and are addressed in Chapter 6 Geometric Design.

4.11 The Green Environment

Any road construction and on-going road use and maintenance will have an impact on South Sudan's natural or bio-physical environment including flora, fauna, hydrology, slope stability, health and safety. These impacts have to be assessed through Environmental Impact Assessment procedures and mitigated as much as possible by appropriate design and construction procedures.

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5 ROUTE SELECTION AND GEOTECHNICAL INVESTIGATION

5.1 Introduction

Site investigation is an integral part of the location, design and construction of a road and provides essential information on the alignment soil characteristics, construction materials availability, topography, land use, environmental issues (including climate) and socio-political considerations for the client related to the following:

- Selection of the route/alignment of the road;
- Location of water crossings and drainage structures;
- Design information for the road pavements, bridges and other structures;
- Areas for specialist geotechnical investigation;
- Areas of potentially problematic soils requiring additional investigation and treatment;
- Location and assessment of suitable, locally available borrow and construction material.

This list indicates that the main component of site investigations is focussed on what is generally described as 'engineering' or, more precisely, 'geotechnical engineering'. However, various other types of survey are required. Hydrological surveys are required to determine the water flows that determine the drainage design of the road; traffic surveys are required to estimate the numbers of vehicles, both motorised and non-motorised, that will use the road; surveys are required to evaluate environmental impacts and how to control them; surveys are required in which the local communities are consulted about the road project; and so on. This chapter deals primarily with the geotechnical-related surveys. Surveys required primarily for non-geotechnical or specialist purposes are described in the Chapters and related Appendices dealing with those topics.

The focus of this chapter is to provide guidance on the appropriate type and level of site investigation that is required for route selection and subsequent design of low volume roads. The chapter also provides practitioners with the necessary tools to develop suitable site investigation programmes and in-situ testing schedules and with assistance in interpreting the data obtained.

Site investigation techniques encompass a large range of methods and the amount and type of exploration that is needed for a specific road project will depend on the nature of the proposed project and the environment in which it is to be built. It is not the purpose of this chapter to explain individual site investigation techniques. More detailed information on the type, use and interpretation of site investigation techniques is included in Appendix D. The reader is also referred to appropriate sections of the MRB Site Investigation Manual for main roads (USAID, 2006).

This Chapter only deals with the investigation of the site in terms of gathering relevant and appropriate engineering information for the selection of the most suitable route and the subsequent design of the road along that route. Where complimentary interventions are required to increase the positive impact of the road project under consideration, the design consultant should be familiar with the requirements in Appendix G of this manual.

5.2 Site Investigation Components

In addition to the characteristics of projects and their physical environment site investigations for LVRs must be designed to suit the particular stage of the Project Cycle that is under consideration, Figure 5.1. Each of the stages within this project cycle will demand a different level of detail.

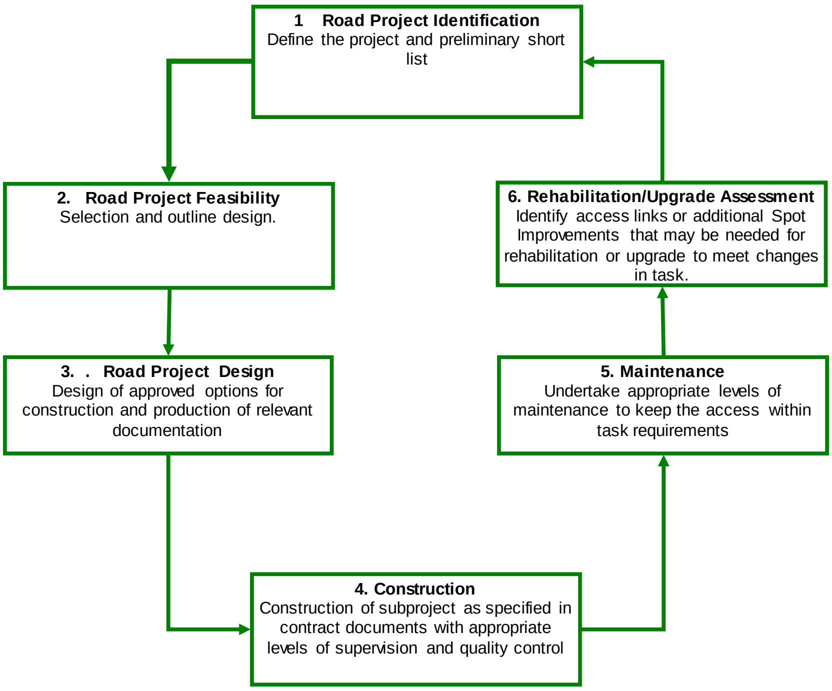


Figure 5.1 The project cycle related to LVRs

In some larger projects, for example, involving a number of LVRs within a single programme, there may be a requirement for an additional Prefeasibility Stage. In contrast, in the case of single small basic access alignments there may be a combination of the general planning and feasibility stages. In the majority of cases, however, the overall site investigation can be considered as a phased programme linked to the following project stages:

- Identification and general planning;
- Feasibility Study or Preliminary Engineering Design;
- Final Engineering Design.

Additional special investigations may be required for specific purposes during the Project Cycle; for example for additional construction materials or to investigate slope issues during the construction phase or a subgrade condition assessment during an upgrade assessment. These may involve a simpler preliminary and main stage programme.

5.3 Principal Considerations for Route Selection

This section highlights most of the issues that require consideration when establishing and finalising the route alignment. For upgrading an existing road many of the points raised will not be relevant. For entirely new roads most of the issues should at least be considered and can act as an investigation and design check list.

5.3.1 General considerations and good practice

Socio-Economic:

1. The road should be as direct as possible (within the bounds of the geometric standards for the particular class of road) between the cities, towns or villages to be linked, thereby minimising road user transport costs and probably minimising construction and maintenance costs as well.

2. The road should not be so close to public facilities that it causes unnecessary disturbance. Cultural sites such as cemeteries, places of worship, archaeological and historical monuments should be specifically protected. Although a road is designed to facilitate access to hospitals, schools and so on, it should be located at a reasonable distance away for safety and to reduce noise.
3. Where the proposed location interferes with utility lines (eg over-head transmission cables and water supply lines), the decision between changing the road alignment and shifting the utility line should be based on a study of the feasibility and the relative economics.
4. The road should, as far as possible, be located along edges of properties rather than through them to minimise interference to agriculture and other activities and to avoid the need for frequent crossing of the road by the local people.
5. The location should be such as to avoid unnecessary and expensive destruction of trees and forests. Where intrusion into such areas is unavoidable, the road should be aligned on a curve so as to preserve an unbroken background.
6. The road should be ‘integrated’ with the surrounding landscape as far as possible. Normally, it is necessary to study the environmental impact of the road and ensure that its adverse effects are kept to the minimum.

Engineering:

1. Where possible marshy and low-lying areas and places having poor drainage and weak materials should be avoided.
2. When feasible the preferred alignment should be one that permits a balancing of cut and fill to minimise borrow, spoil and haul.
3. The road should if possible be close to sources of borrow materials and should minimise haulage of materials over long distances.
4. When the road follows a railway line or river, frequent crossings of the railway or river should be avoided.
5. Problematic and erosion susceptible soils should also be avoided as much as possible.
6. An important control point in route selection is the location of river crossings. The direction of the crossings of major rivers should be normal to the river flow.
7. Areas liable to flooding and areas likely to be unstable due to toe-erosion by rivers should be avoided.

Other:

1. Where possible, the road should be located such that the road reserve can be wide enough to allow future upgrading to a wider carriageway.
2. Areas of valuable natural resources and wildlife sanctuaries should remain protected.

5.3.2 Special considerations in hilly and mountainous areas

General principles:

1. The location should, as far as possible, facilitate easy grades and curvatures.
2. High fills should be avoided and special attention should be paid to the compaction of all fills.
3. The alignment should minimise the number of hairpin bends. Where unavoidable, the bends and switchbacks should be located on stable ground. A series of hairpin bends on the same face of the hill should be avoided.

4. On stable slopes, half cut and half fill cross-sections should be considered as a means to minimise the disturbance to the natural ground.
5. Natural terrain features such as stable benches, ridge-tops, and low gradient slopes should be utilised. If a ridge top is considered, roads should be located far enough above convergent gully headwalls or confluences to provide a buffer; otherwise a structure is needed to intercept moving sediment below the road.
6. In crossing mountain ridges, the location should be such that the road preferably crosses the ridge at the lowest elevation.
7. Needless rise and fall should be avoided, especially where the general purpose of the route is to gain elevation from a lower to a higher point.
8. Locations along river valleys have the inherent advantage of comparatively gentle gradients, proximity to inhabited villages, and easy supply of water for construction purposes. However, there are also disadvantages such as the need for large number of cross-drainage structures and protective works against erosion.

Unstable terrain:

1. If possible unstable slopes, areas having frequent landslide problems and benched agricultural fields should be avoided.
2. Mid-slope locations on long, steep, or unstable slopes should be avoided.

Erosion potential:

1. If possible, it is best to avoid areas of high erosion potential. If not, considerable attention is required to dissipate flow in road drainage ditches and culverts and reduce surface erosion. It is also advisable to consult local agricultural experts during the process of route selection to ensure that the selected alignment has a minimum potential for soil erosion and that the project design provides sufficient erosion control measures.

5.4 Site Investigation Procedures

The choice of methods for site investigation is determined by the type of road project and the nature of the issues likely to arise from site conditions, of geology, terrain and climate. A wide variety of procedures are used for site investigation and these may be grouped as follows

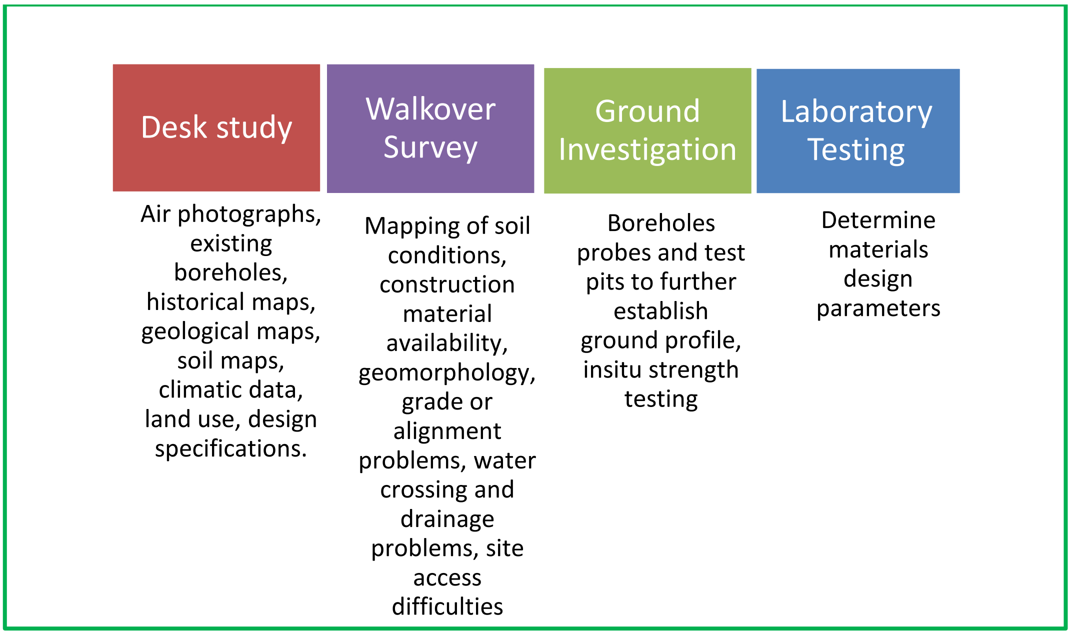


Figure 5.2. General investigation procedures

If an investigation is to be effective, it must be carried out in a systematic way, using techniques that are understood by the local practitioners, relevant to the project in hand, reliable and cost-effective. For low volume roads, investigations should employ relatively standard and simple investigation methods. More sophisticated and expensive procedures should only be employed when a significant geotechnical problem is encountered. Under such circumstances it is advisable to seek specialist assistance.

Site investigation techniques for basic access low volume roads with no significant structures or earthworks can utilise relatively simple sampling and testing techniques. These include visual inspection and description of test pits along the proposed alignment, use of dynamic cone penetrometer testing to assign uniform sections and use of simple on-site material testing kits to assess the grading and plasticity of in-situ soils and borrow materials.

The benefit of utilising the materials test kits is that a large number of simple tests can be conducted in the field relatively quickly and cheaply and the frequency of testing will not be compromised. Verification tests in the laboratory will also be required. Strength, compaction and other types of test can only be conducted by appropriate sampling and laboratory testing.

5.5 Desk Studies

Before any ground survey is carried out and, indeed, before such a survey can be planned and designed, it is vital to study all the relevant information that is available about the project area. This is done through a systematic desk study which entails the collection of detailed information for review and analysis. It allows checking the suitability of all environmental and engineering conditions along different route options. Studying existing documents, including site investigations from earlier project phases, and examining maps and aerial photographs often eliminates an unfavourable route from further consideration, thus saving a considerable amount of time and money. Topographic maps give essential information about the relief of an area, and whether or not there are any existing routes. Aerial photographs provide a quick means for preparing valuable sketches and overlays for reconnaissance/field surveys.

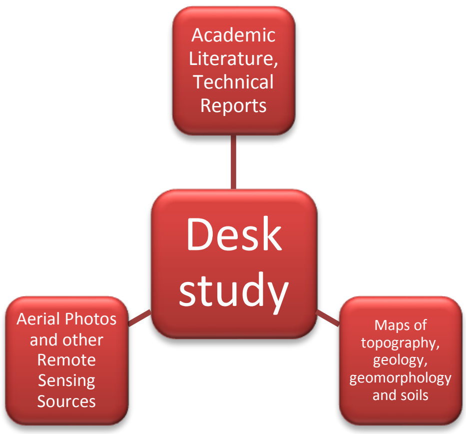


Figure 5.3 Desk study key components

There are a number of very helpful sources of information in South Sudan that can and should be used for this purpose. Table 5.2 summarises data sets that may obtained through desk studies.

The following are some other useful desk-study information sources

Key Ministries:

- Ministry of Roads and Bridges;
- Ministry of Agriculture and Forestry;
- Ministry of Transport;
- State Ministries of Physical Planning.

Useful websites:

www.unsudig.org: United Nations Information Gateway, (Maps, statistics etc)

www.logcluster.org/countries/ssd: European Commission Humanitarian Aid (Maps)

www.usaid.gov/where-we-work/africa/south-sudan:

www.goss.org: Gateway for Ministry websites,

www.cde.unibe.ch: Downloadable maps

Table 5.1 Existing data sources relevant to road construction

Information	Functional Use	Availability	Application
Main Road Design Manuals	Additional data and information on aspects of geometry, drainage, pavement and materials and structural design of roads and bridges in South Sudan.	Ministry of Roads and Bridges (MRB).	More detailed descriptions of procedures and associated standards.
Road and other Engineering Reports	Previous road investigations in the locality will provide a range of data and information such as: soil and rock type, strength parameters, hydro- geological issues, construction materials, information on local road performance and issues.	MRB and NGOs involved in road programmes, UNOPS, USAID, WFP.	Reports may provide geological, hydrological, and geotechnical information for the general area that may reduce the scope or better target the nature of the site investigation.
Remote Sensing	Identifies man-made structures, potential borrow source areas. Provides geologic and hydrological information which can be used as a basis for site reconnaissance; Track site changes over time.	MRB and external sources such as Quick Bird; IKONOS and Google Earth.	Evaluating photographs or satellite images may save time during construction material or geo-hazard surveys.
Topographic Maps	Provides good index map. Allows estimation of site topography. Identifies physical features; Can be used to assess access restrictions.	Topographic maps at 1:50,000 or 1: 250,000. Transport and road type maps. UN Sudan Information Gateway.	Identification of access areas and restrictions, and can estimate cut and fill before visiting the site.
Geologic Reports and Maps	Provides information on nearby soil and rock type and characteristics. Hydro-geological issues. Environmental concerns.	Geological Survey, local Universities. Large scale geological and hydrological maps available on web.	A report on regional geology identifies rock types, fracture, orientation and groundwater flow patterns.
Soil maps	Local soil types. Permeability of local soils. Climatic and geologic information.	Ministry of Agriculture and Forestry;	The local soil survey provides information on near-surface soils to facilitate preliminary borrow source evaluation.
Meteorological and Climatic data	Mean Annual/Monthly; Rainfall and distribution' Max and min temperatures; evaporation.	National Metrological Agency.	Climatic impacts on road environment.

Land use / land cover	Distributional and type of soils; drainage and water courses; agriculture and forest cover.	Ministry of Agriculture and local Administrations. Universities and research institutes.	Identify the physical and biological cover over the land, including water, vegetation, bare soil, and artificial structures.
Local Knowledge	Traffic classification, traffic variation, road user demand, hazards and ground instability, local road performance and maintenance history, accident black spots, water sources, local weather conditions and drainage characteristics.	State and county administrations.	Identification of specific problems and hazards along proposed alignment; Local sources of materials and previous performance.
Statistics and Future Plans	Population data and demographics; Socio-Economic and household survey information; Development Plans.	State and county administrations. MRB and Planning Ministries.	Future activities within vicinity of planned road corridor.

5.6 Walkover Surveys and Geotechnical Mapping

The initial walkover survey should focus on covering, visually, the entire length of the proposed alignment before concentrating on detailed locations. Key walkover objectives are summarised in Figure 5.4.

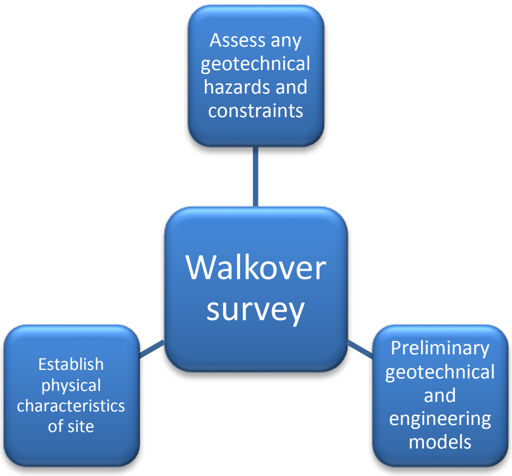


Figure 5.4 Key walkover objectives

The walk-over survey should, in conjunction with the Desk Study, establish the key physical, geotechnical and engineering aspects of the proposed alignment. On some projects basic geotechnical or engineering geological mapping may be required to determine the extent of potential hazards. The location of existing or potential borrow areas or rock quarries for construction materials is an essential element of the walk-over process. Further details on procedures are included in Appendix E.

5.7 Ground Investigations

5.7.1 General

Ground Investigations involve the physical sampling, examination and in situ testing of the soils and rocks underlying and adjacent to the route corridor in order to determine geotechnical and engineering properties relevant to the appropriate design of LVRs.

Ground investigations should provide a description of ground conditions relevant to the proposed works and establish a basis for the assessment of the geotechnical and road engineering parameters relevant for all stages of the Project Cycle. Ground investigations for construction materials determine the nature and extent of proposed construction materials sources as well as their relevant geotechnical parameters. They may also be required to provide relevant information on groundwater needed for geotechnical design and construction. Specialist investigations may be required to collect information about identified geo-hazards.

Figure 5.5 outlines the key objectives of ground investigations which may be undertaken using a variety of sampling and testing techniques, as outlined in Table 5.2.

Table 5.2 Standard ground investigation techniques

Ground Investigation Technique	Purpose	Advantages	Frequency
DCP survey	In-situ test for strength characteristics.	Light and portable, gives information on state of any pavement layers present. Can test both road and shoulder. Test quick and simple.	At minimum 4-10 DCP tests/km should be used for LVRs, 10 tests/km for DC2,3 and 4 roads.
Vane shear test	In-situ shear strength in clays.	Especially good at assessing soft clays. Equipment is easily portable.	Where soft clays are present, 4-10 tests/km should be used.
Cone Penetration Test	In situ strength and compressibility of soils.	Good reliable information in soft to stiff clays and loose to dense sands.	Used in areas under moderate to high embankment and for structure foundation investigations.
Test Pits and trenches	Provides a ground profile and samples for testing subgrade and potential fill material.	Gives an accurate picture of the ground profile.	Dependent on DCP testing. Pits should be at least 0.5 below the natural subgrade level. In cuts this can be reduced to 0.3m. For a new alignment, pits should be at least 2m deep unless rock is present.
Auguring and Boring	Provides in situ information on material present.	Can be used in areas where trial pits are not possible. Can extend to great depth.	Should be used in landslide zones, unconsolidated soils and where existing pavement layers are present.
SPT	Provides in situ test results in most materials and can be used in weak rocks.	Used in conjunction with augering or boring holes.	Used for structure foundation investigation and high earthworks.
Seismic hammer	Can differentiate between loose unconsolidated sediments and intact rock.	Light and portable. A sledge hammer and geophones provide a cheap option.	Can use for key areas where rock head is uncertain and critical for design.

This table presents a list of techniques that may be required for LVRs in general ; the use of any technique or combination of techniques for a specific road will be a function of the scale, nature and geotechnical environment of that road. Ground investigations need to be carefully planned and must take into account the nature of the ground; the nature and phase of the project; and the project design requirements. Results from the Desk Study and Walk-Over should be used in the planning of cost-effective ground investigations.

Further details of ground investigation procedures likely to be used in LVR ground investigations are included in Appendix E to this document

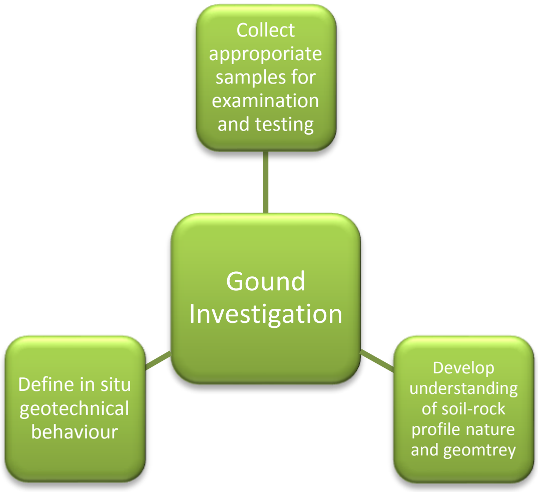


Figure 5.5 Key ground investigation objectives

5.8 Laboratory Test Programmes

Laboratory testing of soil samples recovered during subsurface explorations is the most common procedure to obtain engineering properties necessary for design. Testing programmes vary greatly in size and scope depending on the type and phase of the road project and associated works. Testing should not be commissioned on an arbitrary or ad hoc basis but should be part of a rationally designed programme. Clear objectives should be identified and test procedures and test programmes need to be designed with these in mind. The relationships between in situ conditions and those experienced by the sampled and tested material need to be clearly borne in mind when designing and developing the test regime.

Laboratory tests commonly employed in LVR investigations are detailed in Appendix B.

In the majority of cases no single test procedure will satisfy requirements and a battery of test procedures will be needed. An appropriate test programme will include a logical selection and sequence of tests that is function of the geotechnical environment, the nature of the investigation and the road design requirements.

It is necessary that testing requests be clear and sufficiently detailed. Unless specialised testing is required, the owner should require that all testing be performed in accordance with appropriate specification for laboratory testing in AASHTO and ASTM.

5.9 Investigations for Project Phases

Each phase of a project has specific objective and the site investigation requirements for each phase should be focussed on these objectives. Investigation budgets are likely to be very constrained for most LVR projects and hence the procedures and techniques employed must be carefully selected and planned to obtain maximum information for the least cost. Table 5.4 summarises the general procedures likely to be adopted for each project phase described in the following sections.

Table 5.4 Relative importance of investigation activities during the project life-cycle

Project Phase	Investigation Activity			
	Desk Study	**Walkover - Mapping**	**Ground Investigation**	**Laboratory Testing**
General Planning	A	B	C	C
Feasibility Study	A	A	B	B
Engineering Design	B	B	A	A
Construction	C	B	B	A
Maintenance	C	B	C	C
Rehabilitation	C	A	B	B

A: An essential activity. B: Important support activity C: Minor activity

5.9.1 Identification and general planning

This is the stage at which the need for the project is identified and projects that do not meet selection criteria defined by the appropriate authorities are rejected. It is likely that a desk study and a simple reconnaissance survey will form the basis for this phase of the investigation. Desk studies form a crucial element throughout a site investigation but are particularly crucial in the early phases. Key elements of a General Planning site investigation are likely to be:

- Identification of potential alignments to meet the project task;
- Establishment of general physical environment;
- Identification of any major geological or geotechnical hazards or constraints;
- Development of general geotechnical model.

5.9.2 Pre-feasibility study

In the limited cases where a pre-feasibility study is required this would be the stage where a broad economic and engineering assessment is made. It is at this stage that the main engineering and other constraints affecting the route are identified (for example, environmental and cultural issues) and likely corridors for the proposed road selected.

As part of the pre-feasibility study stage for a major LVR programme it is important to identify and investigate the major technical, environmental, economic and social constraints through a reconnaissance survey in order to obtain a broad appreciation of the viability of the competing alignment options. For low volume roads, one of the most important aspects of the pre-feasibility study is communication with the people who will be affected by the road. Their views are vital for the completion of a successful project and interacting with them is essential right from the outset.

Although not covered in this part of the manual the importance of community participation at this stage, and throughout the project, cannot be over-emphasised as an input to the route selection, design and development of complimentary interventions related to a project.

5.9.3 Feasibility study or preliminary engineering design

At this stage sufficient data are required to identify the final choice of route and the structural design of the road. The feasibility study survey consists, essentially, of mapping the terrain along the centre-line of the viable route or routes identified at the pre-feasibility stage. Data is required that can estimate the likely costs to an accuracy of better than 25%. General costs for similar roads that have been built recently may be used for much of the assessment but the costs for major structures such as bridges and major earthworks need to be estimated sufficiently accurately hence the extent of the site investigation programme is dictated by these requirements.

A feasibility survey provides data that enables specialists to study the advantages and disadvantages of a variety of routes and then to determine which routes should be considered for further investigation. It is an opportunity for checking the actual conditions on the ground and for noting any discrepancies in the maps or aerial photographs. During this survey, it is necessary to make notes of soil conditions, especially potentially soil problems; availability of construction materials; unusual grade or alignment problems, water crossings and potential drainage problems; and requirements for clearing and grubbing. It is also very useful to take photographs or make sketches of reference points, structure sites, landslides, washouts, or any other unusual circumstances.

Simultaneously with the feasibility study or shortly thereafter, a preliminary pavement selection is desirable in order to assess the possible solutions and the approximate needs for pavement construction materials in view of a comparison with the apparent availability of such materials.

For the lower classes of roads predominantly unpaved earth or gravel roads, the information from the feasibility study may be the only available data to assist in the design of the road due to financial constraints, hence, it is important to bear this in mind when designing the survey that is to be undertaken. The outputs of the pre-feasibility study for gravel roads should be a single selected alignment for possible further investigation at the feasibility stage if required. For paved roads, more than one viable alignment option should be available.

After the Feasibility Study there should be sufficient information for the final route alignment to be selected. Minor adjustments to the route alignment(s) may still be necessary during design, but the number of iterations needed to establish the best alignment and confirm the choice of the route should decrease significantly.

In some cases the choice of final route alignment might depend on factors other than just the engineering factors. Considerations such as environmental issues, numbers of people within a minimum distance from the road, proximity to historic, religious or other cultural sites and so on might override the basic economic analysis. Decisions based on some form of multi criteria analysis are available and could be used by those responsible if required.

5.9.4 Final engineering design

The final engineering design requires sufficient design data for preparation of the tender and draft contract documents. This stage requires the most rigorous site investigation and considerably more data will be required than hitherto. An estimate of the requirement for detailed site investigation should be made as part of the feasibility study. The entire process of project design should now be completed with sufficient accuracy to minimise the risk of changes being required after the contracts has been awarded. Detailed investigation will be required to provide technical data on the following:

- Topography;
- Traffic count and loading;
- Alignment soils and construction materials (fill, gravels, rock, potential aggregate, sand and water) – including potential haul and quantities;
- Hydrology and drainage;
- Ground stability, geotechnics and the characteristics of water crossings;
- Socio-environmental considerations.

The scope and extent of the site investigation for final engineering design will depend on the characteristics of the alignment and the type of road under consideration. For many low volume roads the design of the feasibility study should be such that most of the information obtained should be sufficient for final design. The data obtained at the feasibility stage will not be so comprehensive and will not be as robust from a statistical point of view as that obtained from site investigations for DC3 and DC4 roads. However, it should be adequate and reliable and sufficient to provide a competent design for DC1 and DC2 low volume roads. It is likely that some additional detailed survey will be required, particularly for water crossings, within areas of problem soils and unstable terrain.

The quality and level of the site investigation for final design should not be compromised to provide cost savings nor should the level of investigation be necessarily reduced to reflect an anticipated low design class.

The sub-surface investigation for the final design stage is typically performed prior to defining the proposed structural elements or the specific locations of culverts, embankments or other structures. Accordingly, the investigation process includes techniques sufficient to define soil and rock characteristics and the centreline subgrade conditions.

An important assumption is that the topographic survey, based on the preliminary route alignment has been completed prior to the detailed site investigation. It is only against the topographic model that locations of structures and other features of the design can be fixed and estimates made of quantities, haulage and ultimately construction costs.

In general, the site investigation for final design will focus on sampling and testing of materials to provide information on the following reports:

- Characteristics of alignment soils and in-situ materials;
- Location and characteristics of construction materials, volumes available and haulage;
- Earthworks investigations – cut and fill;
- Water sources.

Specific site investigation programmes may be required for associated bridges and other large structures.

5.9.5 Subgrade Characterisation

The subgrade can be defined, in terms of location, as the upper 600mm of the road foundation. The subgrade is required to resist repeated stressing by traffic and to be stable to the stresses imposed by varying climatic and moisture influence.

The character of the subgrade is determined by the geological and weathering characteristics of the rocks that produce the soil and the interaction with the local climate, moisture and drainage regime prevailing in the area. As a general “rule of thumb” better subgrades are found in well drained areas. Clayey soils often predominate in flat areas and along valley floors.

The design of a paved or unpaved road is very strongly dependant on the characteristics of the subgrade and, therefore, so is its potential performance. The desirable properties of a good subgrade include high strength, high stiffness, good drainage characteristics, ease of compaction and low compressibility. A good subgrade is strong enough to resist shear failure and has adequate stiffness to minimise vertical deflection. Stronger and stiffer materials provide a more effective foundation for the pavement layers and are more resistant to stresses from repeated loadings and environmental (moisture) conditions. Most importantly, the stronger the subgrade, the thinner the pavement layers above need to be. Unfortunately the designer usually has very little choice about the subgrade for most of the route.

Because the road design is so dependent on the subgrade, it is vital that the characteristics of the subgrade along the alignment are measured in some detail and understood. In cases where the subgrade materials are unsuitable, either cost effective methods of improving the existing conditions must be identified (eg. improving drainage or stabilisation) or the road alignment must be altered to avoid such areas completely.

5.9.6 Earthworks

Natural slopes, road cuts and existing embankment fill in the vicinity of the planned project provide evidence of expected ground stability and likely requirement for detailed surface and subsurface investigations.

These investigations should consider; the types of materials in the cut; slope stability and the different types of movements that may occur. Scars, anomalous bulges, odd outcrops, broken contours, ridge top trenches, fissures, terraced slopes, abrupt changes in slope or in stream direction, springs or seepage zones all indicate the possibility of past ground movements.

The first indication of possible instability problems can be obtained from a study of the topography. Topographic maps and aerial photographs provide useful data on whether instability is likely to occur or has occurred in the past. Moreover, an understanding of the local geology is essential. Slope failure along road cuts is often associated with pre-existing planes. Survey of the orientation and characteristics of joints and weak zones is therefore essential. In addition, the degree of weathering along these joints should be inspected.

When a visual survey is not enough, it is often useful to excavate a trench. In deep cuts, where interference with existing stability and groundwater conditions is expected, a trench across the face of the slope provides a better understanding of the geology of the area. Trenches are preferable to pits to inspect cuts because of their dimension. Depending on the geology and degree of weathering, up to five trenches are normally enough to investigate a 100m long slope cut. The trenches should be located at places where material changes are expected and range between 1m and 3m in depth. For safety reasons great care needs to be taken by personnel accessing trenches or pits greater the 1m depth. Adequate support to pit or trench walls is essential and any engineers or technicians entering the pits or trenches must be accompanied by surface safety supervision.

Additional information on performance of slopes can also be obtained by inspecting soil and rock exposures along existing road cuts in the region.

A particular difficulty in steep terrain is the disposal of excess material (spoil), therefore every effort should be made to balance the cut and fill. Where this is not possible, suitable stable areas for the disposal of spoil must be identified. Spoil can erode, or may become very wet and slide in a mass. Material is carried downslope and may cause scour of watercourses or bury stable vegetated or agricultural land. Material may choke stream beds causing the stream to meander from side to side, undercutting the banks and creating instability.

High level embankment foundation investigation should, as a minimum, consider; the range of materials and settlement potential; side-slope stability; groundwater; moisture regime and drainage requirements; erosion resistance; haul distance; and environmental impact.

Settlement problems are unlikely if rock is encountered at a shallow depth. However, if the underlying foundation is covered by transported soils, problems are likely as the material may vary from soft alluvial clays to collapsing silts (sands) or expansive clays. It is therefore important to understand the particular transportation history and mechanism and the result that this has on the nature of the soil and its behaviour.

The type of ground investigation will depend on the types of soils encountered. If soils are predominately cohesive, the primary design issues will be bearing capacity, side slope stability, and long-term settlement. These design issues will usually require the collection of undisturbed soil samples for laboratory strength and consolidation testing. The vane shear test can provide valuable in-situ strength data, particularly in soft clays.

Where embankments cross alluvial deposits, there will probably be a stream requiring a structure. Therefore investigations should assess the interaction between these structures, the embankment and the in-situ material. Most embankment problems at streams are a direct result of poor drainage and consequent high pore pressures. During the site investigation it is important that all sources of water along the alignment are identified and their impact on the design assessed.

If groundwater is not identified and adequately addressed early, it can significantly impair constructability, road performance and slope stability. Claims related to unforeseen groundwater conditions often form a significant proportion of contractual disputes. Many of these claims originate from a failure to record groundwater during site investigation.

5.9.7 Construction materials

Sources of road-building materials have to be identified within an economic haulage distance and they must be available in sufficient quantity and of sufficient quality for the purposes intended. Previous experience in the area may assist with this but additional survey is usually essential.

The construction materials investigation often requires an extensive programme of site and laboratory testing, especially if the materials are of marginal quality or occur only in small quantities.

The site investigation must identify and prove that there are adequate and economically viable reserves of natural construction materials. The materials required are:

- Common embankment fill;
- Capping layer / imported subgrade;
- Sub-base and road-base aggregate;
- Road surfacing aggregate;
- Paving stone (eg for cobblestone pavements);
- Aggregates for structural concrete;
- Filter/drainage material;

- Special requirements (eg rock-fill for gabion baskets).

5.10 Investigations for Small Structures

5.10.1 Introduction

The objective of a structures site investigation is to provide a clear picture of the ground conditions to enable a suitable design to be carried out. The level of site investigation clearly depends on the type and complexity of the proposed structure. When bridges are considered site investigations should be undertaken by a suitably qualified engineer and a suitably designed geotechnical survey should be carried out.

The ground underneath a proposed structure should have an adequate bearing capacity to support the load of the structure itself and the vehicles, which pass over it. If the soil has insufficient strength it will compress and the structure will subside, possibly causing failure.

The bearing capacity will depend on a range of different factors including; the proportions of sand clay; organic and other material in the soil; the mineralogy of the clay materials; and the level of the water table. As the type of soil may change with depth it is necessary to dig trial pits at the proposed site to determine the bearing capacity at the proposed foundation level. By identifying and sampling the material excavated from different depths of the trial pits the bearing capacity of the soil can be determined. Bearing capacities are particularly important in the design of structures where large localised loads are expected, (e.g. bridge abutments and piers) as the soil must have a high bearing capacity to support these loads.

5.10.2 Assessment of the problem or need

In order to set priorities it will be necessary to assess the general condition of the road network, highlighting which roads require new or improved structures. This assessment should allow the responsible engineers to:

- Prioritise construction of structures;
- Calculate the structures programme budget requirements;
- Develop work programmes and construction timeframe;
- Identify resource requirements.

This information can then be collated for senior planning engineers to co-ordinate the overall budget and resource requirements for the whole road network. The basis of this work should be an inventory of all structures (or required structures) on the road network. TRL Overseas Road Note 7 provides guidance on the preparation of such inventories.

It is essential that detailed assessments be undertaken at each structure site as structures form a large percentage of the overall cost of the road infrastructure. Assessments undertaken at sites of proposed structure locations should be sufficiently detailed to ensure:

- Enough time is spent identifying the best location for the structure. (If the road is already built and the structure is being upgraded it may not be possible to identify new crossing sites);
- The appropriate type of structure is chosen;
- The structure is adequate for the purpose (traffic type and numbers, water flows and size etc.);
- The design should not need to be significantly changed during construction, as this would result in an increase in the cost of the structure.

5.10.3 Assessment of potential structures

The main issues to be decided during the assessment of new structures are:

- Type of structure - Volume 2 Chapter 4;
- Location of the structure - Volume 2 Chapter 5;
- Size of structure - Volume 2 Chapter 6.

The assessment may be undertaken for either a new structure or the upgrading of an existing structure. In either case the design work will be similar. There are two main stages to be undertaken in the planning and assessment of potential structures; desk study and field study.

5.10.4 Desk study

The desk study should allow the designer to develop an initial idea of the size and possibly type of structure required. The following information should be obtained and assessment made at this stage:

- Obtain a map of the area. Ensure that it shows the important features (roads, villages, watercourses and contours);
- Mark the catchment areas on the map and calculate the catchment size for each structure location;
- Review the topography of the area.

5.10.5 Field study

The following should be undertaken as part of the field study:

- Prepare a sketch map of potential site (s) - plan and x-section;
- Field investigations of the soil conditions and strengths;
- Surface exploration - identify soil types in the water course for potential erosion;
- Sub surface exploration - trial pits;
- Record results in tables or on maps;
- Site survey, including water measurements;
- Determine section and gradient near potential sites by surveying the watercourse;
- Determine area of the waterway for normal and flood flows;
- Check availability of local resources;
- Crosscheck information with local community members regarding flood levels, frequency an duration.

The value of consulting with the local community should not be underestimated, particularly with regard to levels and frequency of flooding and waterborne debris. Also, in generally flat terrain their knowledge of the extent and direction of flood flows is valuable. They should be able to inform regarding local materials and labour/skills resources and any seasonal accessibility problems. The consultation opportunity should also be used to listen to any concerns and allay fears regarding the potential effects or impact of any new or rehabilitated structure.

5.10.6 *Collection of initial design data*

The collection of the initial design data will affect the primary choice of structure. This design data should be gathered during the desk and field studies. Table 5.5 shows the range of data that can be collected in the assessment of the potential structure, which is discussed in more detail in the various chapters. It will not be necessary to collect all the data for the more simple structures. Some of the data may also be collected on a further visit during more detailed survey of the selected structure site.

Table 5.5: Data Requirement

Category	Item	Information required
Local Resources	**Labour**	• Is there an availability of trade skills in the locality eg carpentry, stonemasons? • What is the standard of workmanship available? • Options of: 1 Specialist skills vs. training local labour 2 Time/cost vs. skills transfer and ongoing maintenance potential • Labour wage rates.
	Materials	• What is the availability of local materials (eg masonry stone (rough/dressed), timber, locally manufactured brick and blockwork)? • What is the strength, quality, durability and quantity of local materials? • Steel: what are the imported and delivery costs to site, delays, welding, bending and fixing skills available? • Cement: what are the strengths achievable, delivery/ import delays, types of concrete and experience, quality control and possible testing arrangements? • What are the unit costs of materials?
	Equipment	• What basic specialist equipment is available / would be required for construction AND maintenance (transport, production, loading unloading, mixing, placing, craneage etc.?) What are the costs of equipment (including transport and servicing costs)?
Design Criteria	**General**	• What is the reliability of the collected data? • Is a separate structure needed to allow work to commence further along the road? • What will be the cost for construction AND maintenance? • Do pedestrians, animals or IMTs frequently travel along the road?
	Traffic	• What is the class of road? • Are local standards established for structures on this category of road? • What is the largest type of vehicle that uses the road? • Does vehicle and axle load data exist? • If funds are severely constrained, is a one lane, alternate traffic flow option feasible? • What is the traffic density, does it vary eg seasonally or on market days in the local area? • Review standards used elsewhere and recommend appropriate ones. Will the vehicle size or loading increase if the road or structure is improved (new or re-routed traffic)? • Are any exceptional loads transported? - check for logging, quarries, mining or other industries in the area. What are the possible traffic, economic and safety implications?

Type of Structure	**New**	• Which types of structure would be acceptable?
	Existing Structure	• What is the general condition of the structure? • What was the original design life? • Do as-built records exist? • Are there indications of maximum flood levels on structure? • Are there any signs of post construction settlement? • What are the main problems with the existing structure? • Are there failures in any of the structural elements? • What is the current level of scour around structure? • Indications of excessive loading or abuse? • Dimensions and any possibility of refurbishment or adaptation?
Site Selection	**General**	• Is the depth to firm strata or rock known? • What type of material is available to build on for foundations? • What is the level of the water table? • What is the compressibility or strength of subsoil? • What is the best location of trial pits - to provide the most valuable information? • Is the water / soil chemistry aggressive to building materials? (specialist advice may be required)
Water Parameters	**Watercourse Details**	• Is the stream perennial or seasonal? • What is the type of watercourse? (Meandering, straight, bends, presence of weeds) • Is the watercourse and bed stable, e.g. in rock? • What is the low water level? • What are the minimum or normal flow levels? • What are the maximum flood levels (MFL)? (frequency of occurrence and duration) • What are the watercourse cross sections at potential site? • What is the gradient of watercourse upstream and downstream of the crossing point? • Is there evidence of course/bank or level changes, erosion/deposition at the site, upstream or downstream? Consult with old maps and the community • Is there sometimes floating debris in the water? • What is the water velocity during floods? • What is the longitudinal section or profile along the watercourse? Is the watercourse used for private or commercial traffic with headroom requirements? • Size and amount of sediment supplied from catchment area.
	Catchment Details	• Area of catchment? • Are sudden floods encountered? • Shape of catchment? • Gradient of terrain? • Permeability of soil? • Vegetation coverage and type? • Rainfall intensity? • Is the vegetation coverage changing rapidly e.g. Deforestation?

The importance of collecting accurate information cannot be over emphasised. Although it may prove difficult to collect the required data it is not good practice to make superficial or un-supported assumptions as this will almost invariably result in higher costs due to either additional resources being required to amend the design during construction or the structure being unfit for its purpose.

5.10.7 Field assessment practicalities

To undertake a survey of a new road or site for a structure it is usually necessary to have the following equipment:

- Vehicle - with an odometer;
- Map of the road network;
- Note book;
- Tape measure;
- Ranging rods;
- Graduated line and weight for measuring water depths;
- Hammer, nails, wooden stakes and paint for site survey marks;
- Abney level (or simple survey level) and survey staff (only required for bridges);
- Camera (optional - may be useful for recording potential sites for reference in design office);
- Shovel and pickaxe/mattock for trial holes;
- Materials sample bags;
- Containers for water samples;
- Dynamic Cone Penetrometer (DCP) for soil strength assessment (desirable);
- Water craft for deep water sites;
- GPS.

It is likely that more complex structures will require a second or even third site visit in order to collect the necessary detailed information required. These visits will probably require additional survey equipment to determine more accurate levels. Following initial field investigations along a potential route or rehabilitation/ improvement of an existing route, the field engineer should compile a Table of the structural works, which may be required.

The actual costs of structures will vary according to local resource costs and factors. The benefits of keeping a database of actual and estimated construction costs cannot be overemphasised. Because of the many factors that influence local costs and construction practices it is highly risky to transfer unit cost knowledge from one location to another, and most certainly between regions and countries. There is no substitute for careful consideration of all local cost components and variables.

5.10.8 Foundation bearing capacity

The ground underneath a proposed structure should have an adequate bearing capacity to support the load of the structure itself and the vehicles, which pass over it. If the soil has insufficient strength it will compress and the structure will subside, possibly causing failure.

The bearing capacity will depend on a range of different factors including; the proportions of sand clay; organic and other material in the soil; the mineralogy of the clay materials; and the level of the water table. As the type of soil may change with depth it is necessary to dig trial pits at the proposed site to determine the bearing capacity at the proposed foundation level. By identifying and sampling the material excavated from different depths of the trial pits the bearing capacity of the soil can be determined. Bearing capacities are particularly important in the design of structures where large localised loads are expected, (e.g. bridge abutments and piers) as the soil must have a high bearing capacity to support these loads.

The number of trial pits that should be dug will depend on the complexity of the structure and the uniformity of the soil. Table 5.6 gives a guide to the number and depth of trial pits that should be dug for different structures. If the ground conditions are known to vary over the proposed site, or two trial pits show markedly different results, then further trial pits should be dug as appropriate. The trial pit depth is only given as a guideline figure. If the soil conditions are very poor it may be necessary to increase the depth. Where bedrock exists close to the ground surface this offers the best foundation.

Table 5.5: Trial pits: requirements and locations

Structure	Number	Location	Depth
Drift	Not required.		
Culvert	1	At outlet.	1.5 metres.
Vented ford	2 (only 1 required if ford is shorter than 15 metres).	At each end of the vented section, preferably one on the upstream and one on the downstream side.	1.5 metres.
Large bore culvert	2 (additional pits at each pier location if required).	At each abutment and each pier.	2.5 metres (deeper in poor ground conditions).
Bridge	2 (additional pits at each pier location if required).	At each abutment and each pier.	To firm strata (minimum of 3m).

References

TRL, 1988. ORN 7- Volume 1. *A guide to bridge inspection and data systems for district engineers.*

USAID, 2006. *Site Investigation Manual*. Louis Berger Group for the Ministry of Transport and Roads (now Ministry of Roads and Bridges)

6 GEOMETRIC DESIGN

6.1 Introduction

Geometric design is the process whereby the layout of the road through the terrain is designed to meet the needs of all the road users. The geometric standards are intended to meet two important objectives namely to provide minimum levels of safety and comfort for drivers by provision of adequate sight distances, coefficients of friction and road space for manoeuvres; and to minimise earthworks to reduce construction costs.

Geometric design covers road width; cross-fall; horizontal and vertical alignments and sight lines; and the transverse profile or cross-section. The cross-sectional profile includes the design of the side drainage ditches, embankment heights and side slopes, and is a vital part of geometric design for low volume roads. The cross-section essentially adapts the pavement or roadway to the road environment and is part of the drainage design. For example, for paved roads, wide, sealed shoulders and high camber or cross-fall can significantly improve the operating environment for the pavement layers by minimising the ingress of surface water. For unpaved roads the geometrics are the principal influence on the performance of these roads. Sub-surface water is a problem in low-lying flood-prone areas and whenever the road is in cut. Again, the height of embankment and the depth and type of drainage ditch have very significant effects. Some of these aspects are dealt with in the Drainage Chapter (Chapter 9).

This Chapter introduces and presents the rationale, considerations and selection procedure for appropriate geometric designs for a particular route and sets out the various Geometric Standards to be used for LVR in South Sudan.

6.1.1 Principal factors affecting geometric standards

The principal factors that affect the appropriate geometric design of a road are:

- Cost and level of service;
- Terrain;
- Safety;
- Pavement type;
- Traffic volume and composition;
- Roadside population (open country or populated areas);
- Soil type;
- Climate;
- Construction technology; and
- Administrative or functional classification.

The cost of a road is usually the most critical factor. It is also the most difficult parameter to include in the setting of the design standards. The standard of a road is essentially an index of its ‘service level’ but ‘service level’ is a rather imprecise term that means different things to different people. However, most would agree that its main components include; speed of travel, safety, comfort, ease of driving, stopping and parking, and reliable trafficability or passability. The chosen service level is directly associated with traffic volume and, hence, is not treated as a separate variable. The standards for service level simply increase from the lowest road class to the highest, remaining relatively constant within each class (see Table 1.2 and supporting text in Chapter 1).

Since these factors differ for every road, the geometric design of every road could, in principle, be different. This is impractical and it is therefore normal practice to identify the main factors and to design a fixed number of geometric standards to cope with the range of values of these key factors.

For LVRs in South Sudan four basic standards DC1 to DC4 are defined based on traffic levels (Table 6.1).

Table 6.1 : Proposed categorisation for geometric design of roads

Traffic Grouping	Geometric Standards	Intended Level of Service	AADT
High Volume (HVR)	Refer to South Sudan Geometric Design Manual 2006	A and B	>300
Low Volume LVR)	DC4	C	150 - 300
	DC3		75 – 150
	DC2		25 – 75
	DC1	D	<25
	Track		-

These are then modified, sometimes quite considerably, to cater for the other key factors. The most important of these are:

- Terrain;
- Traffic composition (including pedestrians and non-motorised vehicles);
- Roadside land use – activities and population density;
- Safety;
- Pavement type (paved or unpaved).

Varying standards of geometric design do not exist to cater specifically for climate and soil type. However, these factors are taken into account in the design of the drainage features of the road (Chapter 9) and affect the road cross-section thereby contributing to the geometric design.

The designer, therefore, has a very wide range of standards from which to choose, ensuring that a suitable standard is available for almost all situations. However, there will be cases where it is impossible to meet any of the standards, often because of extremely severe terrain conditions. Under such circumstances the standards must be relaxed and road users must be warned of the reduction with suitable and permanent signage.

6.1.2 How the standards are used

A national 'standard' is not a specification, although it could, and often is, incorporated into specifications and contract documents. Rather, a standard is a specific level of quality that should be achieved at all times and nationwide. Amongst other things this ensures consistency across the country. For the geometric standards, this means that road users know exactly what to expect. Drivers, for example, are not 'surprised' by unexpected changes in quality. Thus they will not unexpectedly find that a road is too narrow, or that they have to alter their speed drastically to avoid losing control of their vehicle. Thus standards are a guarantee of a particular quality level and, for roads, this is vital for reasons of safety.

It is important to note that there is no reason why a higher standard than the standard appropriate to the traffic and conditions should not be used in specific circumstances. For example, for reasons of national and international prestige or for strategic or military reasons, a road may be built to a higher standard than would normally be justified e.g. a road to an international sports facility (where the traffic is low for most of the time but can be quite high for short periods), the road to an airport, and roads to military establishments. Thus higher standards can be used if required but lower standards should not be used except in exceptional circumstances, for example, in particularly difficult terrain.

Figure 6.1 shows how the appropriate geometric standards are selected.

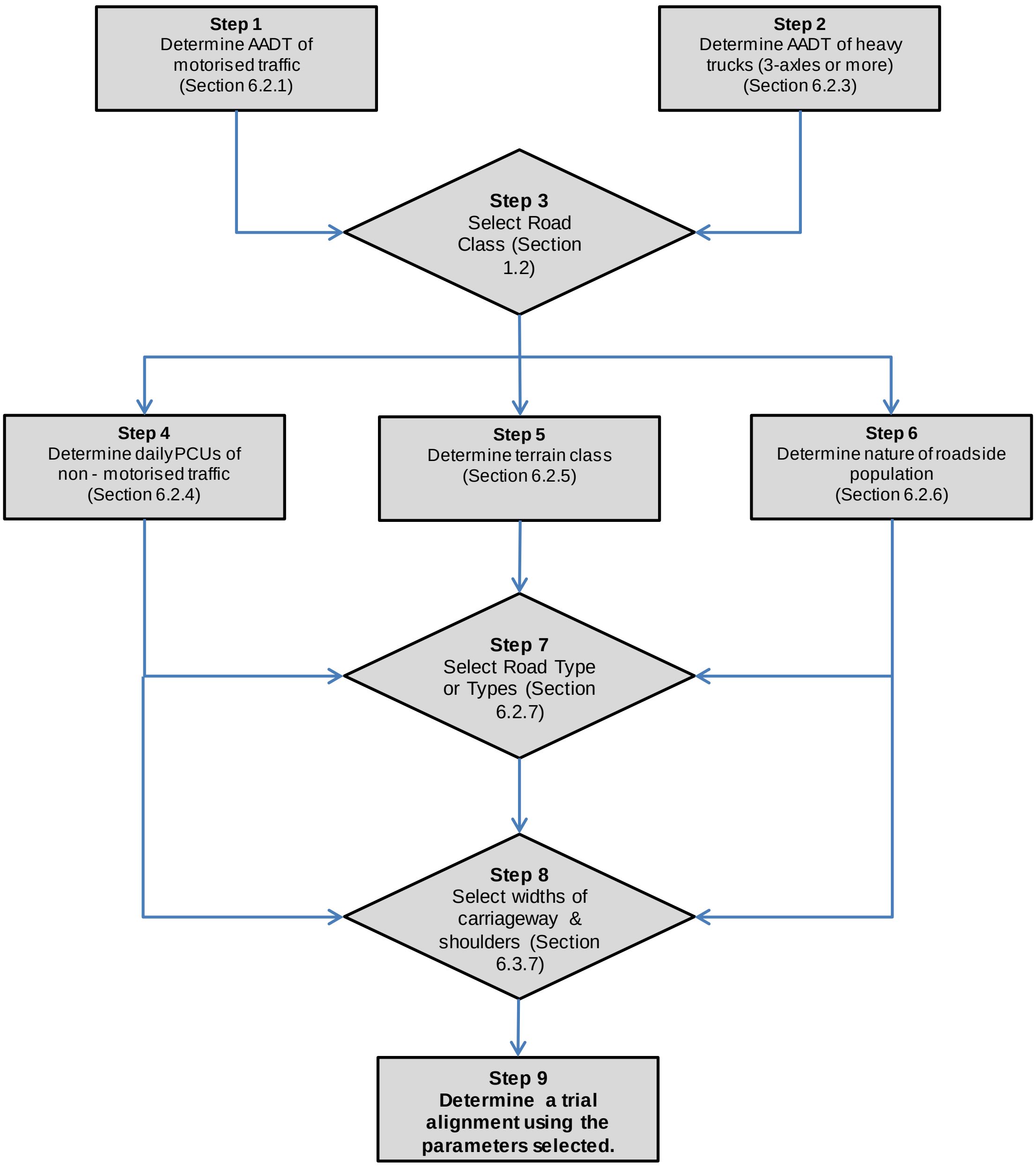


Figure 6.1: Selection procedure for appropriate geometric standards

Step 1: The first step is to determine the basic traffic level because this defines the road class (see Section 6.2.1 and 6.2.3). At this point, the proportion of heavy vehicles in the traffic stream is also determined (**Step 2**). This step is not specific to the geometric design and will usually have been done by the time it is necessary to determine the geometric characteristics of the road. However, more details of the traffic are required for the geometric design in terms of the other road users such as pedestrians, bicycles, motor cycles, motor cycle taxis and animal drawn vehicles. These are taken into account in Step 8.

Step 3: Select Road Class

Step 4: The numbers and characteristics of all the other road users are considered (see Section 6.2.4). It is here that the road layout may be altered and additional widths provided for safety and to improve serviceability for all road users (e.g. reduce congestion caused by slow moving vehicles).

Step 5: The terrain class; flat, rolling, mountainous and escarpment is determined (see Section 6.2.5).

Step 6: The 'size' of the villages or other settlements through which the road passes is evaluated to determine whether they are large enough to require parking areas and areas for traders (see Section 6.2.6).

Step 7: For most road classes there are options for road type and therefore the next step is to decide which type will be built (Section 6.2.7) In many cases the adoption of an EOD policy will mean that different parts of the road may be designed with a different surfacing. The process for selecting the choice of road surfacing and paving is described in Chapter 7.

Step 8: From the available data the widths of carriageway and shoulders should be determined (see Section 6.3.7). At this stage additional factors that affect the geometric standards are also considered such as additional road safety features and the construction technology to be employed.

Once the basic parameters have been determined, the appropriate table from Tables 6.17 to Table 6.23 (Section 6.14) is selected. This provides details of the other geometric factors that are needed to carry out the geometric design.

Step 9: The completion of the process is the design of a trial alignment as a check to ensure that all the standards have been met. If not, alternative alignments should be tried. In extreme conditions it may not be possible to adhere to all the standards at all points along the road. In such cases engineering judgement or additional technical advice may be needed. The pre-feasibility study should have shown that the costs of the road are likely to be acceptable. However, at this stage it may be found that the engineering problems are more costly to solve than anticipated. This needs to be checked and a final alignment selected. If the costs are too high then the project will need to be reviewed.

6.2 The Principal Factors Determining the Choice of Geometric standard

6.2.1 Traffic volume

Roads are designed to provide good service for many years and therefore the traffic level to be used in the design process must take into account traffic growth. Designing for the current traffic will invariably lead to inadequate standards in the future unless the traffic growth rate is extremely low. To deal with these uncertainties it is generally expected that there is a strong correlation between traffic level, traffic growth rates and the functional classification of a road and therefore such a classification is often seen as a suitable alternative to represent traffic.

However, although traffic levels often increase in line with the functional classification, this is not always true and, furthermore, the traffic levels and growth rates are likely to differ considerably between different areas and different regions of the country. For example, the traffic on a ‘collector’ road in one area of the country might be considerably more than on a ‘main access’ road in another area. The design of the road, and therefore the standards adopted, should reflect the traffic level. In addition, traffic growth rates are often expected to be considerably higher on roads connecting local centres than on roads connecting villages but this is not always the case.

In general it is expected that growth rates on roads that do not have ‘through’ traffic (essentially feeder roads) will have lower traffic growth rates than the higher classes of road but each situation should be treated on its own merits taking into account any expected future developments.

For geometric design it is the daily traffic that is important. The approach recommended for estimating the traffic for geometric design purposes is based on the estimated traffic level at the middle of the design life period and this therefore requires an estimate of the traffic growth rate This method eliminates the risk of under-design that may occur if the initial traffic is used and the risk of over-design if traffic at the end of the design life is used.

A design life of 15 years is recommended for paved roads and 10 years for unpaved roads.

Normally a general growth rate is assumed or is provided by government (Planning Dept.) based on the growth in registered vehicles during previous years. However, such data may be incomplete or may need to be augmented with other activity indicators. Local development plans may indicate higher growth rates in some places. Plans for new exploitation of agricultural areas, forestry or mineral resources or quarries would significantly affect both traffic and axle loading. Similarly new settlement or re-settlement plans would affect future traffic levels.

Where there is no existing road, estimating the initial traffic is difficult and estimating future traffic even more so. However, in many cases where a new road is proposed there is likely to be pedestrian traffic and therefore some information on the likely vehicular traffic after the road is constructed. In some cases an economic evaluation may have been carried out to justify the road in the first place. This will have provided an estimate of the amount of goods transported by pedestrians and the likely amount that will be carried by vehicles. In the unlikely event that there is no information available, the lowest class of engineered road (DC1) should be designed. Historical growth rates of similar roads in any specific area should be considered if available. It should be noted that the issue of road classification to determine the standards to be applied is not difficult. A maximum of four different standards are defined for LVRs (DC1 to DC4 in Table 6.1) and each will be applicable over a specific traffic range. These ranges are therefore quite wide and little difficulty should normally be experienced in assigning a suitable standard to a new road project.

Where the expected traffic is near to a traffic class boundary, it would be prudent to use a higher classification.

6.2.2 The design vehicle

For geometric design it is the physical dimensions of a vehicle that are also important. A truck requires more space than a motorcycle, for example, and this does not depend on whether the truck is empty or fully loaded.

The way that vehicle size influences the geometric design of low and high volume roads is fundamentally different. When the volume of traffic is high, the road space occupied by different types of vehicle is an essential element in designing for capacity (i.e. the number of vehicles that the road can carry in a unit of time - vehicles per hour or per day). For example, at the highest traffic levels, when congestion becomes important, traffic volume dictates how many traffic lanes need to be provided.

For LVRs the volume of traffic is sufficiently low that congestion issues do not arise from traffic volume but from the disparity in speed between the variety of vehicles and other road users which the road serves. In other words the traffic composition is the key factor; traffic capacity is not the problem. Nevertheless it is the size of the largest vehicles that use the road that dictates many aspects of geometric design. Such vehicles must be able to pass each other safely and to negotiate all aspects of the horizontal and vertical alignment. Trucks of different sizes are usually used for different standards – the driver of a large 5 or 6-axle truck would not expect to be able to drive through roads of the lowest standards.

In some countries the truck population in rural areas is predominantly one or two types and sizes of vehicle. This makes it relatively easy to select a typical vehicle for setting geometric standards. Conversely, some countries have a wide variety of truck sizes and selecting a suitable truck size for geometric design is more difficult.

Good information on the vehicle fleet in South Sudan is lacking but, in view of the low density of roads and, hence, lack of alternative routes, together with the limited choice of vehicle for many transporters, it is prudent to be conservative in choosing the design vehicle for each class of road so that the maximum number of vehicle types can use them. In South Sudan four different design vehicles have been used as shown in Table 6.2 and Table 6.3. However there is very little difference between design vehicles DV2 and DV3. Roads designed for the single unit truck will be suitable for the bus provided the front and rear overhangs of the bus are taken into account when designing curves; and this can be done with suitable curve widening where required as described later. The standard for only the lowest class of road is insufficient for DV2 and DV3.

Diagrams showing the full minimum swept out path of the design vehicle are shown in the SS Geometric Design Manual (2006).

Table 6.2: Design vehicle characteristics

Design vehicle	Designation	Height (m)	Width (m)	Length (m)	Front overhang (m)	Rear overhang (m)	Wheelbase (m)	Minimum Turning Radius (m)
4x4 Utility	DV1	1.3	2.1	5.8	0.9	1.5	3.4	7.3
Single unit truck	DV2	4.1	2.6	11.0	1.5	3.0	6.5	12.8
Single Unit bus	DV3	4.1	2.6	12.1	2.1	2.4	7.6	12.8
Truck and Semi-trailer	DV4	4.1	2.6	15.2	1.2	1.8	4.8 + 8.4 = 13.2	13.7

Table 6.3: Design vehicle for each LVR class

Design standard	Design vehicle
DC4	DV4
DC3	DV3
DC2	DV3
DC1	DV1

6.2.3 Traffic composition – proportion of heavy vehicles

The density of roads in South Sudan is very low and rural vehicle ownership is low. One of the consequences of this is that the proportion of heavy vehicles in the traffic stream on LVRs is often quite high. Design standards DC2, DC3 and DC4 include a modification to cater for this.

For DC4, if the number of 'large' vehicles, defined as 3-axled (or more) trucks with GVWs (Gross Vehicle Weights) potentially greater than 12 tonnes, is greater than 40, the width of the paved surface is increased to 7.0m and the shoulders reduced to 1.0m. If there are more than 80 large vehicles then the standard for DC5 (as defined in the current Geometric Design Manual) should be used instead of DC4.

For DC3, if the number of large vehicles is greater than 25, design standard DC4 should be used and, for DC2, if the number of large vehicles exceeds 10 then DC3 should be used.

6.2.4 Traffic composition - use of Passenger Car Units (PCUs)

In order to quantify traffic for normal capacity design the concept of equivalent PCUs is often used. Thus a typical 3-axle truck requires about 2.5 times as much road space as a typical car hence it is equivalent to 2.5 PCUs. A motor cycle requires less than half the space of a car and is therefore equivalent to 0.4 PCU's.

The PCU concept is very useful where traffic congestion is likely to be a problem and it was not originally intended for use in the geometric design of LVRs. However, vehicles that move slowly cause congestion problems because of their speed rather than because of their size. In effect, they can be considered to occupy more road space than would be expected from their size alone. The actual PCU rating of a vehicle is affected by the function of a road (i.e. the nature of the other traffic) and varies as the traffic mix varies and as the traffic volume and traffic speeds vary. Nevertheless, in situations where the number of slow moving vehicles, both motorised and non-motorised, is significant, in order to retain the level of service appropriate to the traffic level of motorised vehicles, the road standard should be improved by reducing congestion and this is best done by widening the shoulders. Thus when the PCU level of the slow moving and intermediate forms of transport reaches a certain level, shoulder widening is justified.

The PCU concept is also useful for identifying the need for additional safety features where the numbers of pedestrians and slow moving vehicles are high.

The PCU values for South Sudan are shown Table 6.4. Motorcycle taxis (e.g. Bajaj) are expected to become popular in urban situations as experienced elsewhere in the region, and it is only anticipated that these IMTs will spread to more rural areas and become adapted for freight as well as for passenger transport.

Table 6.4: PCU values

Vehicle	PCU value
Pedestrian	0.15
Bicycle	0.2
Motor cycle	0.25
Bicycle with trailer	0.35
Motor cycle taxi (bajaj)	0.4
Motor cycle with trailer	0.45
Animal drawn cart	0.7
Bullock cart	2.0
All based on a passenger car = 1.0	

6.2.5 Terrain

Terrain has the greatest effect on road construction costs therefore it is not economical to apply the same standards in all terrains. Fortunately drivers of vehicles are familiar with this and lower standards are expected in hilly and mountainous terrain.

Four categories have been defined which apply to all roads as follows:

Flat: 0-10 five-metre contours per km. The natural ground slopes perpendicular to the ground contours are generally below 3%.

Rolling: 11-25 five-metre contours per km. The natural ground slopes perpendicular to the ground contours are generally between 3 and 25%.

Mountainous: 26-50 five-metre contours per km. The natural ground slopes perpendicular to the ground contours are generally above 25%.

Escarpment: Escarpments are topographic features that require special geometric standards because of the engineering problems involved. Typical gradients are greater than those encountered in mountainous terrain.

Hilly terrain: An important aspect of geometric design concerns the ability of vehicles to ascend steep hills. Roads that need to be designed for very heavy vehicles or for animal drawn carts require specific standards to address this, for example, special climbing lanes. Fortunately the technology of trucks has improved greatly over the years and, provided they are not grossly overloaded (which is a separate problem) or poorly maintained, they do not usually require special treatment. On the other hand, animal drawn vehicles are unable to ascend or descend relatively low gradients safely, and catering for them in hilly and mountainous terrain is rarely possible. Climbing lanes cannot be justified on LVRs and nor can the provision of very low maximum gradients. The maximum gradients allowable for different road classes are shown in Tables 6.17 to Table 6.23 (Section 6.14).

Mountainous and escarpment terrain: In mountain areas the geometric standard for LVRs takes account of the constraints imposed by the difficulty and stability of the terrain. This design standard may need to be reduced locally in order to cope with exceptionally difficult terrain conditions. Every effort should be made to design the road so that the maximum gradient does not exceed the standards shown in Tables 6.17 to Table 6.23. But where higher gradients cannot be avoided, they should be restricted in length. Gradients greater than 12% should not be longer than 250m and relief gradients are also required as indicated in the Tables. Horizontal curve radii of as little as 13m may be unavoidable, even though a minimum of 15m is specified.

6.2.6 Roadside population (open country or populated areas)

The more populated areas in village centres are not normally defined as 'urban' but in any areas having a reasonable sized population or where markets and other business activities take place, the geometric design of the road needs to be modified to ensure good access and to enhance safety. This is done by using:

- A wider cross section;
- Specifically designed lay-byes for passenger vehicles to pick up or deposit passengers;
- Roadside parking areas.

It may be appropriate to pave the parking areas in non-bituminous surfacing if there is a risk of substantial oil, fuel or lubricant droppings from poorly maintained vehicles, as this can cause surface deterioration of bituminous surfaces.

6.2.7 Pavement type

For a similar 'quality' of travel there is a difference between the geometric design standards required for an unpaved road (gravel or earth) and for a paved road. This is because of the very different traction and friction properties of the two types of surfaces and the highly variable nature of natural materials. For some characteristics higher geometric standards are required for unpaved roads (because of the lower road friction levels). A road that is to be sealed at a later date should be designed to the higher geometric road standards. Further guidance on surfacing and paving is provided in Chapter 7.

6.2.8 Soil type and climate

Soil type affects the ideal geometric design, principally in terms of cross-section rather than in terms of the width of the running surface or road curvature. With some problem soils the cross-section can be adjusted to minimise the severity of the problem by, for example, minimising the speed of water flow; minimising the likelihood of excessive water inundation or penetration into the carriageway; and/or moving problems areas further away from the carriageway itself. These aspects are dealt with in the drainage section (Chapter 9) of the manual and in the pavement design section (Chapter 7).

Ideally maximum gradients for unpaved roads should also depend on soil types but this is usually impracticable because, in most climatic regions, almost any gradient causes problems for unpaved roads. Unpaved road gradients of more than 6% should be avoided as rainfall induced erosion would be excessive.

6.2.9 Safety

Experience has shown that simply adopting 'international' design standards from developed countries will not necessarily result in acceptable levels of safety on rural roads. The main reasons include the completely different mix of traffic, including relatively old, slow-moving and usually overloaded vehicles; a large number of pedestrians, animal drawn carts and, possibly, motorcycle-based forms of transport and other IMTs; poor driver behaviour; and poor enforcement of regulations. In such an environment, methods to improve safety through engineering design assume paramount importance.

Although little research has been published on rural road safety in South Sudan, the following factors related to road geometry are known to be important:

- Vehicle speed;
- Horizontal curvature;
- Vertical curvature;
- Width of shoulders.

These factors are all inter-related and part of geometric design. In addition, safety is also affected by:

- Traffic level and composition;
- Inappropriate public transport pick-up/set-down areas;
- Poor road surface condition (e.g. potholes);
- Dust (poor visibility);
- Slippery unsealed road surfaces.

The last three factors are related to structural design covered in Chapter 7

Conflicts between motorised vehicles and pedestrians are always a major safety problem on many rural roads where separation is generally not economically possible. The World Bank Basic Access document (World Bank, 2001) considers that there are sound arguments based on safety for keeping traffic speeds low in mixed traffic environments rather than aiming for higher design speeds, as is the case for major roads. The use of wider shoulders is also suggested. These considerations have been incorporated into this manual.

Traffic level and composition are both considered. A considerable number of conflict situations can arise when the number of PCUs of non-motorised traffic is large even though the number of two (or more)-axled motorised traffic is quite low. Furthermore, the proportion of heavy vehicles on the LVRs of South Sudan can also be high, leading to more serious conflict situations. The overall traffic class standards are based on the number of two (or more)-axled motorised vehicles but additional safety features are based on:

- The number of PCUs of non 2-axled motorised vehicles and pedestrians;
- The proportion of heavy vehicles in the motorised stream.

Pedestrians (and draft animals) find it very uncomfortable to walk on poorly graded gravel shoulders containing much oversized material, especially in bare feet. They usually choose to walk on a paved running surface, if available, despite the greatly increased safety risk. Thus, provision of a wider unsurfaced shoulder does not ensure greater safety. On the approaches to market villages, where the pedestrian traffic increases greatly on market days, provision of a separate footpath is the best solution provided that the soil is suitable.

A checklist of engineering design features that affect road safety is given in Figure 6.2. Not all are suitable for rural roads but the general philosophy of design for safety is emphasised.

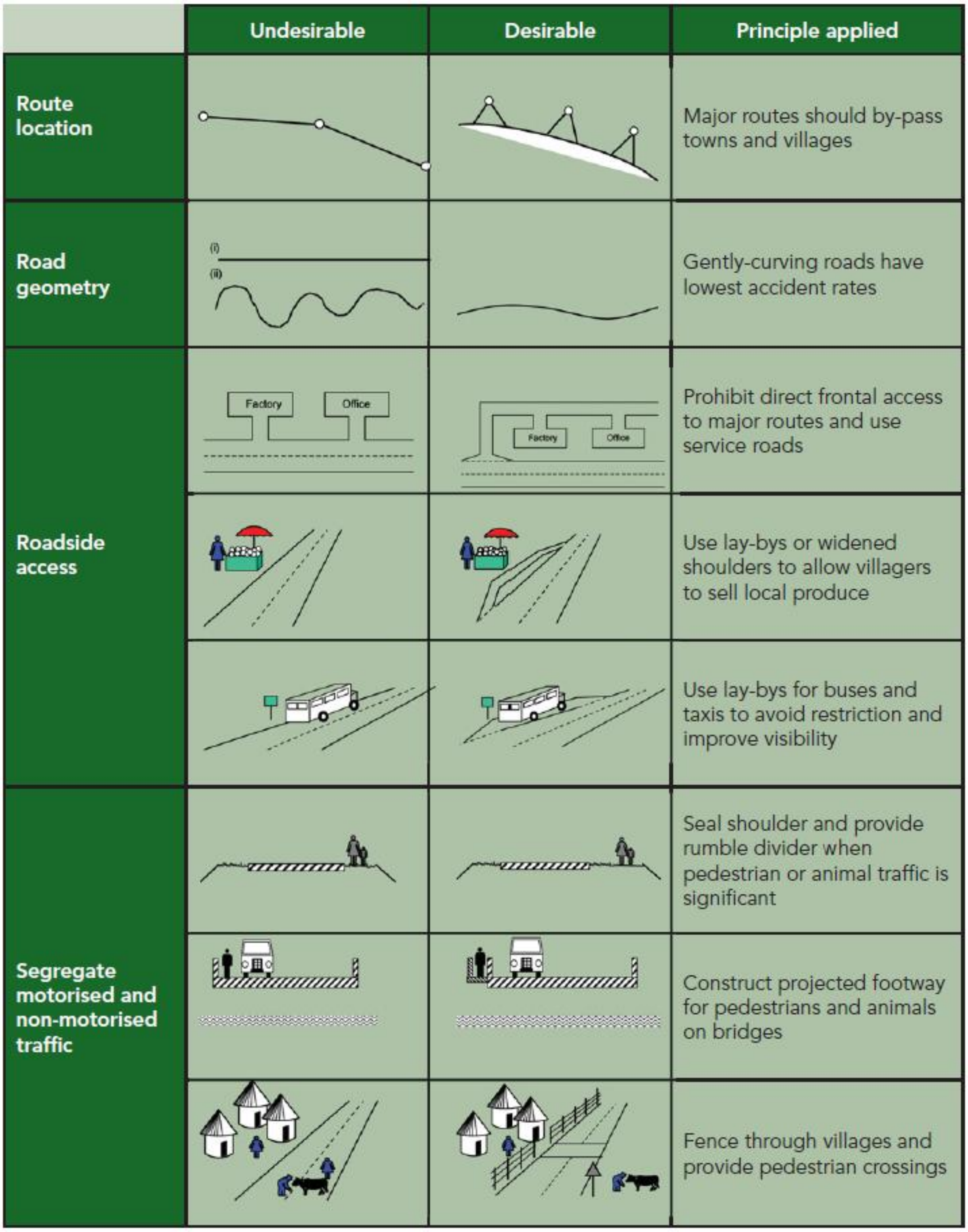


Figure 6.2: Examples of effects of engineering design on road safety

The following factors should be considered when designing for safety:

1. Wherever possible, non-motorised traffic should be segregated by physical barriers, such as raised kerbs (through villages and peri-urban areas).

2. Designs should include features to reduce speeds in areas of significant pedestrian activity, particularly at crossing points. Traffic calming may need to be employed (see Section 6.8.1).
3. To minimise the effect of a driver who has lost control and left the road, the following steps should be taken.
    a. Steep open side-drains should be avoided since these increase the likelihood that vehicles will overturn. (See Section 6.3.1).
    b. Trees should not be planted immediately adjacent to the road.
4. Guard rails should only be introduced at sites of known accident risk because of their high costs of installation and maintenance.
5. Junctions and accesses should be located where full safe stopping sight distances are available (see Section 6.4).

6.2.10 Construction technology

In the case of labour-based construction the choice of technology might affect the standards that can be achieved, especially in hilly and mountainous areas. This is because:

- Maximum cuts and fills will need to be small;
- Economic haul distances without equipment will be limited to those achievable using wheel-barrows;
- Mass balancing will need to be achieved by transverse rather than longitudinal earth movements;
- Maximum gradients will need to follow the natural terrain gradients;
- Horizontal alignments may need to be less direct.

The standards in hilly and mountainous terrain are always lower than in flat terrain but this reduction in standards need not necessarily be greater where labour-based methods are used. Following the contour lines more closely will make the road longer but the gradients can be less severe. Every effort should be made to preserve the same standards in the particular terrain encountered irrespective of construction method.

Side and turn-out drain construction and maintenance standard is usually a V-ditch if equipment based methods are used. This shape is unsuited to labour based methods, for which trapezoidal profiles are easier to construct and maintain. The added benefit is that trapezoidal profiles are less susceptible to erosion.

6.2.11 Administrative function

In many countries it is necessary to take account of the administrative or functional classification of roads because a certain standard may be expected for each functional class of road irrespective of the current levels of traffic. Generally the hierarchy of administrative classification broadly reflects the traffic levels observed but anomalies are common where, for example, traffic can be lower on a road higher in the hierarchy. It is recommended that the standards selected should be appropriate to the task or traffic level of the road in question but a minimum standard for each administrative class can also be defined if it is policy to do so.

6.2.12 Matrix of standards

For each of the basic standards based on traffic level there are four standards to cope with terrain (flat, rolling, mountainous and escarpment), a further two standards (for DC4, DC3 and DC2) to cater for roadside population/activities and three standards to cater for traffic composition, essentially the number of PCUs of non-motorised traffic (including pedestrians) and the percentage of heavy vehicles in the traffic stream. These additional standards for traffic composition and roadside activities are essentially standards to enhance safety.

Once these factors have been taken into account, safety alone no longer affects the number of road standards because an acceptable level of safety must be applied to each road class. This will differ between classes (greater safety features for higher traffic) but not within classes. The administrative classification does not add to the number of standards either. If the traffic level indicates that a lower standard than would normally be acceptable based on administrative classification is sufficient, the road can be built to the minimum standard appropriate to its administrative classification.

Aspects of geometric design outlined in the following sections require particular consideration because they have a major influence on the life-cycle costs of rural roads. The basis for developing the standards is also discussed in these sections.

In contrast to the judgements required for quantifying traffic, the standards themselves are largely dictated by the selected design speed and form a continuous range as design speed increases.

6.3 Cross Sections

The cross section of a road is essentially a geometric design feature but is also intimately related to drainage issues as well as slope stability and erosion problems in hilly and mountainous areas. The cross section includes the shape and size of the running surface; shoulders; the side slopes of embankments; side slopes to drainage ditches; drainage ditches themselves; and slopes to the batter.

The basic cross sections for LVRs are shown in Section 6.14. Some aspects of cross sectional design are concerned with drainage and further details concerning this aspect are discussed in Chapter 9.

The cross-section of a road may need to vary over a route but it is essential that any changes take place gradually over a transition length. Abrupt and isolated changes lead to increased hazards and reduced traffic capacity.

A common situation arises at bridge and water crossing points where the existing structure is narrower than desired. In such situations warning signs must be erected to alert drivers. Fortunately many such crossings are visible well in advance but if not, extra signage may be required.

6.3.1 Slopes of shoulders, side slopes, embankments

Side slopes should be designed to ensure the stability of the roadway and, on low embankments, to provide a reasonable opportunity for recovery if a vehicle goes out of control across the shoulders. In addition, the position of the side drain invert should be a reasonable distance away from the road to minimise the risk of infiltration of water into the road if the drain should be full for any length of time.

Figure 6.3 illustrates the general cross section and defines the various elements.

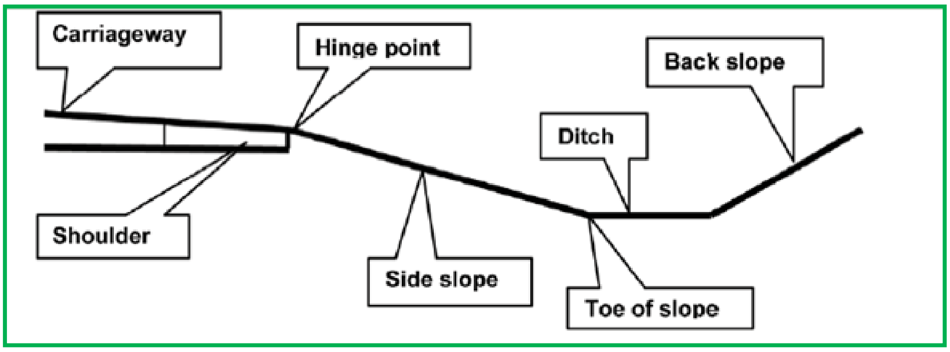


Figure 6.3: Details of the road edge elements

The side slope is defined as 'recoverable' when drivers can generally recover control of their vehicles should they encroach over the edge of the shoulder. Side slopes of 1:4 or flatter are recoverable. Research has also shown that rounding at the hinge point and at the toe of the slope is also beneficial.

A non-recoverable slope is defined as one that is traversable but from which most drivers will be unable to stop safely or return to the roadway easily. Vehicles on such slopes can be expected to reach the bottom. Slopes of between 1:3 and 1:4 fall into this category.

A critical slope is one on which the vehicle is likely to overturn and these will have slopes of greater than 1:3.

The selection of side slope and back slope is often constrained by topography, embankment height, height of cuts, drainage considerations, right of way limits and economic considerations. For rehabilitation and upgrading projects, additional constraints may be present such that it may be very expensive to comply fully with the recommendations provided in this manual.

6.3.2 Roadside ditches

Detailed information concerning roadside ditches is provided in Chapter 9.

Substantial side drains should be avoided when the road traverses areas of expansive clays, with preference for the roadway to be constructed on a low embankment. Water should be discharged uniformly along the road. Where side drains cannot be avoided they should be a minimum distance of 4m from the toe of the embankment and should be shallow and trapezoidal in shape.

6.3.3 Clear zones

The discussion in Section 6.3.1 highlights the safety aspects of embankment side slopes. However, many accidents are made more severe because of obstacles that an out-of-control vehicle may collide with. The concept of clear zones identifies these obstacles and attempts to eliminate such hazards.

The most common hazards are headwalls of culverts and road signage. The clear zone defined for high volume roads is substantial (15m is typical) but for LVRs this is impractical. Ideally it should extend at least to the toe of the embankment and should always be greater than 1.5 m from the edge of the carriageway.

At existing pipe culverts, box culverts and bridges the clear zone cannot be less than the carriageway width. If this criterion cannot be met, the structure must be widened. New pipe and box culverts must be designed with a 1.5m clearance from the edge of the shoulder. Horizontal clearance to road signs and marker posts must also be an absolute minimum of 1.5m from the edge of the carriageway.

6.3.4 Right-of-way

Right-of-way (or the road reserve) is provided to accommodate road width and the drainage requirements; to enhance safety; to improve the appearance of the road; to provide space for non-road travellers; and to provide space for upgrading and widening in the future. The width of the right-of-way depends on the cross-sectional elements of the highway, topography and other physical controls; plus economic considerations. Although extended rights-of-way are convenient, right-of-way widths should be limited to a practical minimum because of their effect on local economies.

Rights-of-way are measured equally each side of the centre line. Recommended Road Reserve widths applicable for the different road classes are shown in Table 6.6. In mountainous terrain where large cuts are required, the total width can exceed the right-of-way width.

Table 6.6: Recommended right-of-way widths

Road Class	Total Right of Way (m)
DC4	50
DC3	30
DC2	30
DC1	20

6.3.5 Shoulders

The shoulders of a road must fulfil the following functions:

- A provide structural support;
- Allow wide vehicles to pass one another without causing damage to the shoulder;
- Provide safe room for temporarily stopped or broken down vehicles;
- Allow pedestrians, cyclists and other vulnerable road users to travel in safety;
- Allow water to drain from within the pavement layers;
- Reduce the extent to which water flowing off the surface can penetrate into the pavement (often done by extending a seal over the shoulder).

Shoulders have an important structural function which is often overlooked in the provision of LVRs. They act as edge supports to contain the running carriageway; without adequate shoulders the road will move laterally and deform. Therefore, there is a minimum width of shoulder that is required to perform this function. Depending on the properties of the material and the traffic, this can range from 0.5 to 1.5m.

Shoulders also have to perform an important traffic carrying function for non-motorised vehicles and pedestrians. Wider shoulders are required when this traffic is high enough. In addition, wider shoulders are provided for some classes of road when the proportion of heavy vehicles in the traffic stream exceeds certain values.

When the road passes through denser areas of population, additional width is provided for parking and for other roadside activities. This widening may be considered to be shoulder widening although the need to provide access to shops and market areas means that the construction is usually of an extra carriageway.

Where the carriageway is paved, the shoulder may be gravel or may be sealed with a bituminous surface treatment. The structural advantages of a sealed shoulder are discussed in Chapter 7. However, sealing the shoulders whenever the numbers of non-motorised traffic exceeds a critical value is recommended in order to encourage the travellers to use the shoulders rather than the carriageway. On the approaches to villages and towns the local traffic builds up quite quickly and therefore consideration should be given to extending the sealed shoulders for considerable distances each side of the town/village. No standard guidance can be given; each situation should be treated on its merits.

Shoulders constructed with the same material as the carriageway (earth or gravel) should have the same cross-fall as the carriageway. If the shoulders are gravel and the carriageway is paved the cross-fall of the shoulder should be 1.5 - 2.0 % steeper than that of the carriageway.

Shoulder widths in mountainous terrain and escarpments are reduced to minimise the high cost of earthworks. Usually the design of the overall cross-section in such terrain will include significant drainage and erosion control features and the shoulder will form an important component of this (Chapter 9).

6.3.6 Single lane roads and passing places

There is good agreement internationally about the recommended carriageway width for single-lane roads, namely 2.5m to-3.5m, depending on traffic volume and mix. Passing places maybe required, depending on the traffic level and provision for other traffic and pedestrians will need to be introduced (wider shoulders) if the numbers of other road users exceed specified levels. The increased width should allow two vehicles to pass at slow speed and hence depends on the design vehicle.

Passing places should normally be provided every 300m to 500m depending on the terrain and geometric conditions. Care is required to ensure good sight distances and the ease of reversing to the nearest passing place, if required. Passing places should be built at the most economic places rather than at precise intervals provided that the distance between them does not exceed the recommended maximum. Ideally, the next passing place should be visible from its neighbour.

The length of passing places is dictated by the maximum length of vehicles expected to use the road, indicating the need to define a design vehicle. The design vehicle DV3 is 12.8m long therefore passing places of twice this length should be provided. In most cases, a length of 25m will be sufficient for rural roads.

A suitable width depends upon the width of the road itself. The criterion is to provide enough overall width for two design vehicles to pass each other safely at low speed. Therefore, a total trafficable minimum width of 6.3m is required (providing a minimum of 1.1m between passing vehicles). Allowing for vehicle overhang when entering the passing bay, a total road width of 7.0m is suitable.

6.3.7 Width standards

Road width (running surface and shoulders) is one of the most important geometric properties since its value is very strongly related to cost and to safety.

A review of international standards showed that some countries have adopted road widths that are intermediate between single lane and two lane requirements. Such roads are considered to be dangerous because vehicles try to pass each other at speed. Since there is not enough room to do so they are forced onto the shoulder area and dangerously close to the road edge. If the road is paved, the edge of the paved area becomes damaged very quickly.

The standards for South Sudan do not include such intermediate widths. However, for all standards except DC1, shoulders are widened if the number of road users other than 2-axled (and more) motorised vehicles exceeds levels that cause too much interaction with the motorised traffic or if the proportion of heavy vehicles in the traffic stream is high. For DC1 the traffic levels are so low that dangerous interactions will be rare and drivers will expect other road users to have priority.

Tables 6.17 to 6.23 show the standard road widths for each road class with the widths of running surface and shoulder given for the paved road classes. The road width of unpaved roads shown in the tables includes the widths of the shoulder as the surfacing of gravel or earth for these roads spreads across the whole surface to the edge of the road making it difficult to define the shoulder for these roads. The shoulder widths for paved roads are also varied for different terrains; for roadside population/activities; and for traffic composition.

The lowest class (DC1) is a single lane road and the shoulder is effectively 0.75m wide. For DC2 the minimum shoulder width is not specifically defined for the unpaved option but, for this class, the traffic is effectively less than 5 vehicles per hour in each direction which will invariably travel down the centre of the road unless another vehicle is seen approaching. Therefore, the effective shoulder width for most of the time is 1.5m. For this class, two vehicles can normally pass each other safely using the shoulder but if one of the largest vehicles is involved the vehicles may need to slow down. If there are sufficient of these larger vehicles, then class DC3 should be used.

A similar argument applies to DC3. The unpaved option for DC3 is wider than DC2 and allows easier passing but the level of service is not commensurate if there are a large number of the larger vehicles in the traffic stream. In this case, the next higher class (DC4) is recommended. For DC4 the shoulders are at least 1.0m wide.

Additional shoulder widths are provided if there is a high number of PCUs of non-motorised vehicles (defined as more than 300 PCUs per day on average).

Other variations are also sometimes needed, for example, where certain problem soils are encountered or in areas that are particularly wet and where the road is likely to be inundated and needs to be raised on a higher embankment. Where spot improvements are made which involve a short length of paved surfacing (e.g. on a steep incline) then the width used should be that shown in the respective Tables for paved surfaces.

The width standards for each classification are summarised in Section 6.14. For some of the cells in the Tables the values quoted will never be a limitation. For example, in flat terrain there will be no need to be concerned about the criteria for maximum gradient and paved road sections will be rare at the lowest traffic levels. Nevertheless, for completeness all the cells have been filled.

6.4 Design Speed and Geometry

Design speed is defined as effectively the maximum (actually the 85th percentile) safe speed that can be maintained over a specified section of road when conditions are so favourable that the design features of the road govern the speed. Design speed is used as an index that essentially defines the geometric standard of a road, linking many of the factors that determine the road's service level, namely traffic level; terrain; pavement type; safety/population density; and road function, to ensure that a driver is presented with a consistent speed environment.

The concept of design speed is most useful because it allows the key elements of geometric design to be selected for each standard of road in a consistent and logical way. For example, design speed is relatively low in mountainous terrain to reflect the necessary reductions in standards required to keep road costs to manageable proportions. The speed is higher in rolling terrain and highest of all in flat terrain.

In practice the speed of motorised vehicles on many roads in flat and rolling terrain will only be constrained by the road geometry over relatively short sections but it is important that the level of constraint is consistent for each road class and set of conditions.

In view of the mixed traffic that occupies the rural roads of South Sudan and the cost benefit of selecting lower design speeds, it is prudent to select values of design speed towards the lower end of the internationally acceptable ranges. The recommended values are shown in Table 6.7.

Table 6.7: Design speeds

Design Standard	Design speed (km/h)				
	Flat	Rolling	Mountain	Escarpment	Urban
DC4	70	60	50	40	50
DC3	70	60	50	30	50
DC2	60	50	40	30	50
DC1	50	40	30	20	40

Changes in design speed, if required because of a change in terrain, should be made over distances that enable drivers to change speed gradually. Thus changes should never be more than one design step at a time and the length of the sections with intermediate standards (if there is more than one change) should be long enough for drivers to realise there has been a change before another change in the same direction is encountered (i.e. considerably more than one single bend). Where this is not possible, warning signs should be provided to alert drivers to the changes.

6.4.1 Stopping sight distance

In order to ensure that the design speed is safe, the geometric properties of the road must meet certain minimum or maximum values to ensure that drivers can see far enough ahead to carry out normal manoeuvres such as overtaking another vehicle in safe circumstances or stopping safely if there is an object in the road.

The distance a vehicle requires to stop safely is called the stopping sight distance. It mainly affects the shape of the road on the crest of a hill (vertical alignment) but if there are objects near the edge of the road that restrict a driver's vision on approaching a bend, then it also affects the horizontal curvature.

The driver must be able to see any obstacle in the road hence the stopping sight distance depends on the size of the object and the height of the driver's eye above the road surface. The driver needs time to react and then the brakes of the vehicle need time to slow the vehicle down, hence stopping sight distance is extremely dependant on the speed of the vehicle. The surface characteristics of the road also affect the braking time so the values for unpaved roads differ from those of paved roads, although the differences are small for design speeds below 60km/h.

The stopping distance also depends on the gradient of the road; it is harder to stop on a downhill gradient than on a flat road because a component of the weight of the vehicle acts down the gradient in the opposite direction to the frictional forces that are attempting to stop the vehicle.

Full adherence to the required sight distances is essential for safety reasons. On the inside of horizontal curves it may be necessary to remove trees, buildings or other obstacles to obtain the necessary sight distances. If this cannot be done, the alignment must be changed. In rare cases where it is not possible and a change in design speed is necessary, adequate and permanent signage must be provided.

Recommended stopping sight distances for paved and unpaved roads at different design speeds are shown in Table 6.8.

Table 6.8: Stopping sight distances (m)

Design speed (km/h)	**20**	**30**	**40**	**50**	**60**	**70**	**80**
Unpaved roads (1)	20	30	50	70	95	125	160
Paved roads (1)	18	30	45	65	85	110	135

Note

1. In rolling and mountainous terrain these values should be increased by 10%

6.4.2 Stopping sight distance for single lane roads (meeting sight distance)

For single lane roads, adequate sight distances must be provided to allow vehicles travelling in the opposite direction to see each other and to stop safely if necessary. This distance is normally set at twice the stopping sight distance recommended in Table 6.8 for a vehicle that is stopping to avoid a stationary object in the road. An extra safety margin of 20-30 metres is also sometimes added.

Although a vehicle is a much larger object than is usually considered when calculating stopping distances, these added safety margins are used partly due to the very severe consequences of a head-on collision; and partly because it is difficult to judge the speed of an approaching vehicle, which could be considerably greater than the design speed. However, single lane roads will have a relatively low design speed, hence meeting sight distances should not be too difficult to achieve.

6.4.3 Intersection sight distance

Intersection sight distance is similar to stopping sight distance except that the object being viewed is another vehicle that may be entering the road from a side road or crossing the road at an intersection. The required safe sight distance for trucks in metres is about 3 times the vehicle speed in km/hr. On straight sections of road many vehicles will exceed the road's design speed but, being straight, sight distances should be adequate.

6.4.4 Passing sight distances

Factors affecting the safe sight distances required for overtaking are more complicated because they involve the capability of a vehicle to accelerate and the length and speed of the vehicle being overtaken. Assumptions are usually made about the speed differential between the vehicle being overtaken and the overtaking vehicle but many road authorities have simply based their standards on empirical evidence. For South Sudan, with a mix of Left and Right Hand Drive vehicles in the national fleet, the issue is further complicated. Passing sight distance criteria should be reviewed in the light of experience over the coming period of expected significant network and traffic growth.

For single lane roads, overtaking manoeuvres are not possible and passing manoeuvres take place only at the designated passing places. On the lower classes of 2-lane roads, passing sight distances are based on providing enough distance for a vehicle to safely abort a passing manoeuvre if another vehicle is approaching. The recommended values are shown in Table 6.9.

Table 6.9: Passing sight distances (m)

Design speed (km/h)	30	40	50	60	70	80
Recommended values	80	135	180	230	270	310

6.4.5 Camber and cross-fall

Camber and cross-fall are essential to promote surface drainage. Ponding of water on a road surface quickly leads to deterioration. There is general agreement that camber or cross-fall should be 3% on paved LVRs (2.5% is sometimes advocated but this is insufficient).

Drainage is less efficient on rough surfaces and unpaved surfaces change shape in use due to traffic and weather between surface maintenance operations. Therefore the minimum design camber or cross-fall needs to be higher on earth and gravel roads. However, if the soil or gravel is susceptible to erosion, high values of camber or cross-fall can cause erosion problems. Values that are too high can also cause driving problems but, on the lower standards of rural roads where traffic is low and the road is a single carriageway, vehicles will generally travel in the middle of the road. Therefore, high levels of camber are not as much of a problem for drivers as poor surfaces due to inadequate cross-fall. The design of LVRs makes use of this fact so that higher camber is used where appropriate. As a result, the optimum value of cross-fall/camber varies considerably, but it normally lies between 4% and 7%, with 6% maximum being the usual recommendation in the absence of additional information concerning the erosion potential of the soil/gravel. It is important that the maintenance regime is capable of keeping the unpaved road camber between these limits.

Shoulders having the same surface as the running surface should have the same slope. Unpaved shoulders on a sealed road should have shoulders that are about 2% steeper, in other words 5% if the running surface is 3%.

6.4.6 Adverse cross-fall

Adverse cross-fall arises on curves when the cross-fall or camber causes vehicles to lean outwards when negotiating the curve. This affects the cornering stability of vehicles and is uncomfortable for drivers, thereby affecting safety. The severity of its effect depends on vehicle speed, the horizontal radius of curvature of the road and the side friction between tyres and road surface. For reasons of safety it is recommended that adverse cross-fall is removed where necessary (see Table 6.10) on all roads regardless of traffic.

Table 6.10: Adverse cross-fall to be removed if radii are less than shown

Design speed (km/h)	Minimum radii (m)	
	Paved	**Unpaved**
<50	500	700
60	700	1000
70	1000	1300
85	1400	
100	2000	

Some cross-fall is necessary for road surface drainage and hence flat carriageway cross sections are not allowed, except at the exact point of cross-fall transition. Instead, a single value of cross-fall is retained on the inner half of the carriageway through curves, and the outer carriageway cross-fall is rotated about the centre line until a straight cross-fall across the carriageway is achieved. (i.e. all camber is removed as shown in Figure 6.4). The straight cross-fall is usually 3 or 4% for paved roads. For unpaved roads the recommended straight cross-fall should also be the same as the normal camber or cross-fall value of 4 - 6%.

To remove adverse cross-fall the basic cambered shape of the road is gradually changed as the road enters the curve until it becomes simply cross-fall in one direction at the centre section of the curve.

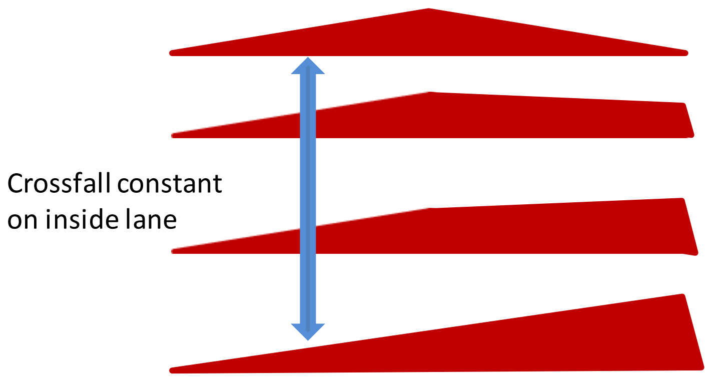


Figure 6.4: Removal of adverse camber

For paved roads the simple removal of adverse camber may not be sufficient to ensure good vehicle control when the radius of the horizontal curve becomes too small. In such a situation additional straight cross-fall may be required. This is properly referred to as super-elevation but it has become common practice to refer to all additional elevation as super-elevation and this convention will be used here.

6.4.7 *Superelevation*

For small radius curves and at the higher speeds of paved sections of road, the removal of adverse cross-fall alone will be insufficient to reduce sideways frictional needs to an acceptable level and cross-fall should be increased by the application of superelevation. A minimum radius is reached when the maximum acceptable frictional and superelevation derived forces have been developed. These minimum radii values are identified in Figure 6.5 for levels of superelevation of up to 10 per cent. Although this maximum percentage is rather arbitrary, it is widely considered to be a value above which drivers may find it difficult to remain centred in lane as they negotiate a bend.

On paved roads with unsealed shoulders, the outer shoulder should drain away from the paved area to avoid loose material being washed across the road.

On unpaved roads, the cross-fall is designed to remove rainwater quickly and effectively, and will be dependent on local conditions and materials. Values of superelevation lower than the minimum value of the cross-fall (4%) would fail to drain the surface, whist higher values than 6% will be likely to result in lateral erosion. On unpaved roads, the maximum superelevation will therefore be the elimination of adverse cross-fall (see Table 6.10) to 6%. On superelevated sections the whole of the carriageway is drained to the inner shoulder and side drain. This increases the risk of erosion and therefore consideration should be given to paving such sections under an EOD strategy.

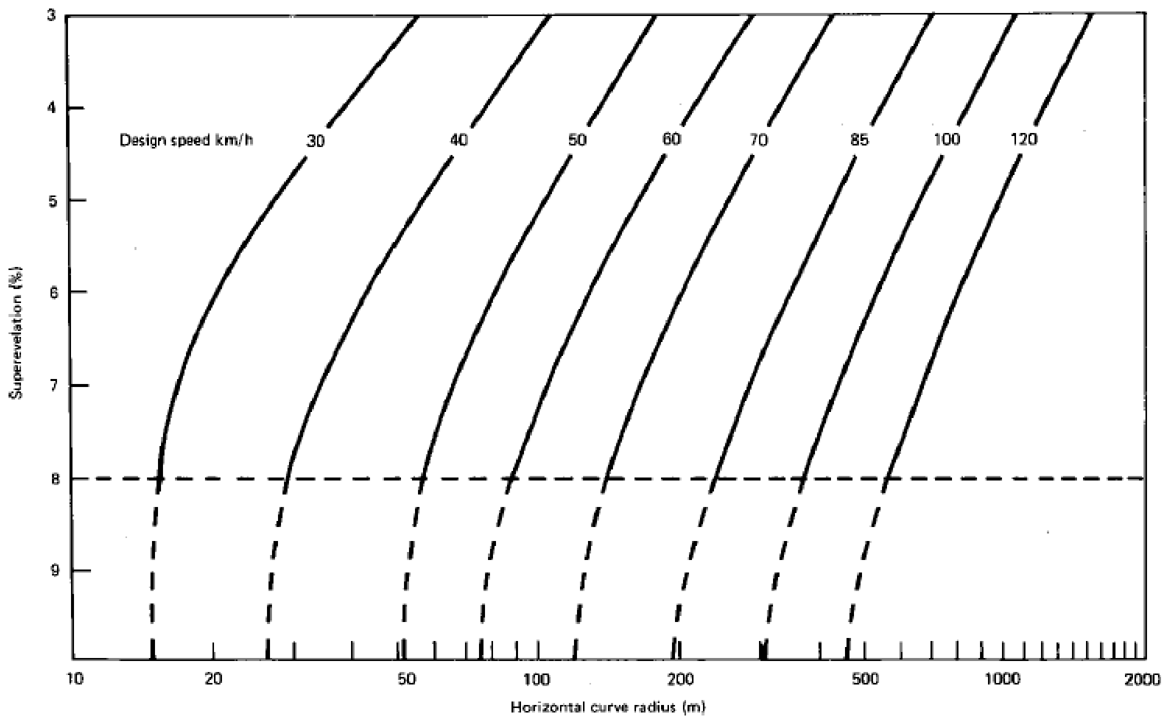


Figure 6.5: Superelevation design curves

The change from normal cross-section on straight sections of road to a super-elevated section should be made gradually. The length over which super-elevation is developed is known as the super-elevation development length. Two-thirds of the development length should be provided before the curve begins. The development depends on design speed as shown in Table 6.11. Between 50% and 75% of the super-elevation should be achieved by the tangent point. 66% is usually used.

Table 6.11: Superelevation development lengths

Design speed (km/h)	Development length (m)
30	25
40	30
50	40
60	55
70	65
80	80

6.5 Horizontal Alignment

The horizontal alignment consists of a series of straight sections (tangents) connected to circular curves. The horizontal curves are designed to ensure that vehicles can negotiate them safely. The alignment design should be aimed at avoiding sharp changes in curvature, thereby achieving a safe uniform driving speed. On higher speed roads, transition curves are introduced between straight sections of road and circular curves whose radius changes continuously from infinity (tangent) to the radius of the circular curve (R) to reduce the abrupt introduction of centripetal acceleration that occurs on entering the circular curve. Transition curves are not required when the radius of the horizontal curve is large and are normally not used on the lower classes of road. In South Sudan their use is confined to roads where the design speed is 80km/hr or greater and therefore they are not required for LVRs.

In order for a vehicle to move in a circular path an inward radial force is required to provide the necessary centripetal acceleration or, in other words, to counteract the centrifugal force. This radial force is provided by the sideways friction between the tyres and the road surface assisted by the cross-fall or super-elevation.

The sideways friction coefficient is considerably less than the longitudinal friction coefficient. Its value decreases as speed increases but there is considerable disagreement about representative values, especially at the lower speeds. For paved roads it ranges from between 0.18 and 0.3 at 20km/h down to between 0.14 and 0.18 at 80km/h. For unpaved roads it can be considerably less. The design speed is therefore one of the main design parameters in consideration of horizontal curves. Values of design speed for each class of road under each of its operating conditions have been set as shown in Table 6.7.

For both sealed and unsealed roads there are also constraints on the maximum cross-fall, as described in Section 6.4.5 to 6.4.6. These constraints translate directly into minimum values of horizontal radii of curvature.

The recommended minimum values of horizontal curvature are shown in Table 6.12 and Table 6.13. As indicated in the Tables, the use of a higher value of super-elevation (Section 6.4.7) makes it possible to introduce a smaller horizontal curve based on the same design speed. This can be used for paved roads but not for unpaved roads.

Table 6.12: Recommended minimum horizontal radii of curvature: paved roads (m)

Design speed (km/h)	20	25	30	40	50	60	70	80
Super-elevation = 4%	15	19	30	55	95	145	215	300
Super-elevation = 6%	15	18	27	50	85	135	195	270
Super-elevation = 8%	15	17	25	50	80	120	175	240
Super-elevation = 10%	15	16	25	45	75	110	160	220

Table 6.13: Recommended minimum horizontal radii of curvature: unpaved roads (m)

Design speed (km/h)	20	25	30	40	50	60	70	80
Side Friction Factor	0.19	0.17	0.165	0.15	0.14	0.12	0.11	0.10
Super-elevation = 4%	15	25	35	65	115	175	255	355

6.5.1 Curve length

For reasons of safety and ease of driving, curves near the minimum for the design speed should not be used at the following locations:

- On high fills, because the lack of surrounding features reduces a driver's perception of the alignment;
- At or near vertical curves (tops and bottoms of hills) because the unexpected bend can be extremely dangerous, especially at night;
- At the end of long tangents or a series of gentle curves, because actual speeds will exceed design speeds;
- At or near intersections and approaches to bridges or other water crossing structures.

There are conflicting views about curve lengths. One school of thought maintains that the horizontal alignment should maximise the length of road where adequate sight distances are provided for safe overtaking. Overtaking is difficult on curves of any radius and hence the length of curved road should be minimised. This requires curve radii to be relatively close (but not too close) to the minimum for the design speed to maximise the length of straight sections. This view is the currently accepted best practice for roads except in very flat terrain but care should be exercised to ensure the curves are not too tight. This view is also supported in the circumstances of South Sudan with the vehicle fleet mix of LHD and RHD vehicle, with the added overtaking manoeuvre risks.

The alternative view is that very long straight sections should be avoided because they are monotonous and cause headlight dazzle at night. A supposedly safer alternative is obtained by a winding alignment with tangents deflecting 5 to 10 degrees alternately from right to left. Straight sections should have lengths (in metres) less than 20 x design speed in km/h. Such 'flowing' curves restrict the view of drivers on the inside carriageway and reduce safe overtaking opportunities, therefore such a winding alignment should only be adopted where the straight sections are very long. In practice this only occurs in very flat terrain. The main aspect is to ensure that there are sufficient opportunities for safe overtaking and therefore, provided the straight sections are long enough, a semi-flowing alignment can be adopted at the same time. If overtaking opportunities are infrequent, maximising the length of the straight sections is the best option.

For small changes of direction it is often desirable to use a large radius of curvature. This improves the appearance and reduces the tendency for drivers to cut corners. In addition, it reduces the length of the road segment and therefore the cost of the road provided that no extra cut or fill is required.

6.5.2 Curve widening

Widening of the carriageway where the horizontal curve is tight is usually necessary to ensure that the rear wheels of the largest vehicles remain on the road when negotiating the curve; and, on two lane roads, to ensure that the front or rear overhang of the vehicle does not encroach on the opposite lane. Widening is therefore also important for safety reasons. Any curve widening that is considered should only be applied on the inside of the curve.

Vehicles need to remain centred in their lane to reduce the likelihood of colliding with an oncoming vehicle or driving on the shoulder. Sight distances should be maintained as discussed previously. The levels of widening shown in Table 6.14 are recommended except for roads carrying the lowest levels of traffic (DC1). Widening should be applied on the inside of the curve and introduced gradually.

Widening on high embankments is often recommended for the higher classes of road. The steep drops from high embankments can unnerve some drivers and the widening is primarily for psychological comfort although it also has a positive effect on safety. Such widening is not recommended for LVRs.

Table 6.14: Curve Widening Recommendations (m)

	Single lane roads				Two lane roads			
Curve radius	20	30	40	60	<50	51 - 150	151 - 300	301 - 400
Increase in width	1.5 (1)	1.0	0.75	0.5	1.5	1.0	0.75	0.5

Notes:
1. See Section 6.6.4 dealing with hairpin stacks

6.6 Vertical Alignment

The two major elements of vertical alignment are the gradient, which is related to vehicle performance and level of service; and the vertical curvature, which is governed by safe sight distances and comfort criteria.

The vertical alignment of a road seems more complicated than the horizontal alignment but this is simply because of difficulties in presentation due to the inclusion of the algebraic difference in gradient (G %) between the uphill and downhill sides. In addition, the equation of the vertical curve is a parabola rather than a circle.

The required sight distance for safety is the basic stopping sight distance (Table 6.8).

6.6.1 Crest curves

The minimum length of the curve (L metres) over the crest of the hill between the points of maximum gradient on either side is related to G and to the stopping-sight distance; and therefore to the design speed. Note that although drivers would like to overtake on hills, the required sight distance for safe passing on crests is much too large to be economical on LVRs.

The minimum value of the L/G ratio can be tabulated against the stopping sight distance (Table 6.8), and therefore the design speed, to provide the designer with a value of L for any specific value of G. The international consensus provides the values shown in Table 6.15.

Table 6.15: Minimum values of L/G for crest curves

Design speed(km/h)	30	40	50	60	70	80
Paved roads	2	5	10	17	30	45
Unpaved roads	2	6	11	20	35	58

6.6.2 Sag curves

Sag curves are the opposite of crest curves in that vehicles first travel downhill and then uphill. In daylight the sight distance is normally adequate for safety and the design criterion is based on minimising the discomforting forces that act upon the driver and passengers when the direction of travel changes from downhill to uphill. On rural roads such considerations are somewhat less important than road safety issues. However, at night time the problem on sag curves is the illumination provided by headlights to see far enough ahead. This depends on the height of the headlights above the road and the angle of divergence of the headlight beams.

To provide road curvature that allows the driver to see sufficiently far ahead using headlights while driving at the design speed at night is usually too expensive for LVRs. In any case, the driving speed should be much lower at night on such roads. As a result of these considerations it is recommended that the minimum length of curve is determined by the driver discomfort criterion. The results are shown in Table 6.16.

Table 6.16: Minimum values of L/G for sag curves

Design speed(km/h)	**30**	**40**	**50**	**60**	**70**	**80**
Minimum L/G	2.5	4	6.5	9	12	16

In practice a minimum length of curve of 75m will cope with almost all situations on LVRs. For example, on a steep down-hill of 10% followed by an up-hill of the same slope, the required minimum curve length at a speed of 50km/h is 2.2 x (10 + 10) = 44m and 3.5 x (10+10) = 70m at 60km/h.

6.6.3 Gradient

For four-wheel drive vehicles, it is reported that the maximum traversable gradient is about 18%. Two wheel drive trucks can cope with gradients of 15%, except when heavily laden. Bearing in mind the likelihood of heavily laden small trucks, international rural road standards have a general recommended limit of 12%, but with an increase to 15% for short sections (< 250m) in areas of difficult terrain for paved roads. Slightly higher standards are recommended for DC4 with a preferred maximum of 10% and an absolute maximum of 12% on escarpments where relief gradients of less than 6% are required for a distance of 250m following a gradient of 12%.

For driving consistency, and hence safety, in terrains other than mountainous terrains and escarpments, limiting values of gradient are also often specified. In flat terrain a maximum gradient of 7% is appropriate for LVRs. In rolling terrain a maximum of 10% is appropriate.

6.7 Harmonisation of Horizontal and Vertical Alignment

6.7.1 Situations to avoid

When designing the horizontal alignment of a road, the designer must ensure that the other elements of the design are complementary to each other. It is therefore important to note that there are a number of design situations that could produce unsatisfactory combinations of elements despite the fact that the design standards have been followed for the particular class of road in question. These are designs that could provide surprises for drivers by presenting them with unfamiliar conditions. They are therefore comparatively unsafe.

Avoiding such designs is more important for the higher classes of road because design speeds are higher, traffic is much greater and, consequently, any accidents resulting from poor design are likely to be more severe and more frequent. However, in many cases, avoidance of such designs does not necessarily impose a significant cost penalty and therefore the principles outlined below should be applied to roads of all classes.

Multiple curves

In the more hilly and mountainous terrains, horizontal curves are required more frequently and have small radii because the design speeds are low. The tangent sections become shorter and a stage can be reached where successive curves can no longer be dealt with in isolation. There are three situations that should be avoided if possible.

Reverse curves

A curve is followed immediately by a curve in the opposite direction. In this situation it is difficult for the driver to keep the vehicle in its proper lane. It is also difficult for the designer to accommodate the required super-elevation within the space available.

Broken back curves

This is the term used to describe two curves in the same direction connected by a short tangent. Drivers do not usually anticipate that they will encounter two successive curves close to each other in the same direction. There can also be problems fitting in the correct super-elevation in the space available.

Compound curves

Compound curves occur when one curve connects to another of different radius. These can be useful in fitting the road to the terrain but in some circumstances they can be dangerous. Drivers do not usually expect to be confronted by a change in radius, and therefore in design speed, hence if, the change is too great, some drivers are likely to be travelling too fast when entering the tighter part of the compound curve from the larger one. Compound curves should be avoided where curves are sharp and where the difference in radii is large. Thus, in any compound curve the smaller radius should not be less than 67% of the larger one.

Isolated and long curves

An isolated curve close to the minimum radius connected by long straight sections is inherently unsafe. Irrespective of the design speed, actual speeds on long straight sections will be relatively high and therefore a curve of minimum radius will require a significant reduction in speed for most vehicles. It is good practice to avoid the use of minimum standards in such situations. An added bonus is that, provided no extra cutting of filling is required, the use of a larger radius of curvature results in a shorter and less expensive road. Curve widening can help to alleviate this problem if a higher radius curve cannot be used.

The same argument is true, but to a much lesser extent, for any small radius curve that is very long (i.e. the road is turning through a large angle). Drivers can negotiate a short curve relatively safely at speeds in excess of the design speed but they cannot do so if the curve is long hence a large radius should be used in such situations.

6.7.2 Balance

It can be seen that there are several competing factors in providing the optimum horizontal alignment. Small radii curves maximise the length of straight sections and optimise overtaking opportunities. This should be the controlling factor where the terrain is such that overtaking opportunities are infrequent and actual speeds are close to the design speeds. However, in more gentle terrain where overtaking is less of a problem and vehicles generally travel at speeds higher than the design speed, the use of larger radius curves is preferred for the reasons outlined previously.

In summary, engineering choice plays a part in the final design which is essentially a balance between competing requirements.

6.7.3 Phasing

The horizontal and vertical alignment should not be designed independently. Hazards can be concealed by inappropriate combinations of horizontal and vertical curves and therefore such combinations can be very dangerous. Some examples of poor phasing are as follows:

A sharp horizontal curve following a pronounced crest curve. The solutions are to;

- Separate the curves;
- Use a more gentle horizontal curve;
- Begin the horizontal curve well before the summit of the crest curve.

Both ends of the vertical curve lie on the horizontal curve. If both ends of a crest curve lie on a sharp horizontal curve the radius of the horizontal curve may appear to the driver to decrease abruptly over the length of the crest curve. If the vertical curve is a sag curve the radius of the horizontal curve will appear to decrease. The solution is to make both ends of each curve coincide or to separate them completely.

A vertical curve overlaps both ends of a sharp horizontal curve. This creates a hazard because a vehicle has to turn sharply while sight distance is reduced on the vertical curve. The solution is to make both ends of each curve coincide or to separate them completely.

6.7.4 Junctions and Intersections

The result of an accident is likely to be that one or more vehicles will leave the road. Hence, where possible, a safe ‘run-off’ environment should be created and good sight distances provided. Intersections should therefore not be located on high embankments; near to bridges or other high level water crossings; on small radius curves; or on super-elevated curves. To ensure good visibility, vegetation should be permanently cleared from the area surrounding the junction.

It is also advisable to avoid building intersections on gradients of more than 3% or at the bottom of sag curves. This is because:

- Stopping sight distances are greater on downhill descents and drivers of heavy vehicles have more difficulty in judging them;
- It is advantageous if heavy vehicles are able to accelerate as quickly as possible away from the junction.

The ideal angle that intersecting roads should meet is 90^o because this provides maximum visibility in both directions but visibility is not seriously compromised as long as the angle exceeds 70^o.

Where two roads have to cross each other, a simple X-cross junction is adequate for LVRs. However, where possible, it is preferable to provide two staggered T-junctions as illustrated in Figure 6.6 rather than one X-cross junction since there is unlikely to be a cost penalty in doing so. The most heavily trafficked road is retained as a direct through route. The minor road is then split so that traffic has to enter the major road by making a left turn across the traffic stream onto the major road and then a right turn to re-enter the minor road. This method halves the number of possible manoeuvres where the traffic from the minor road has to cross the traffic stream on the major road. The entry points of the two arms of the minor road should ideally be spaced about 100m apart.

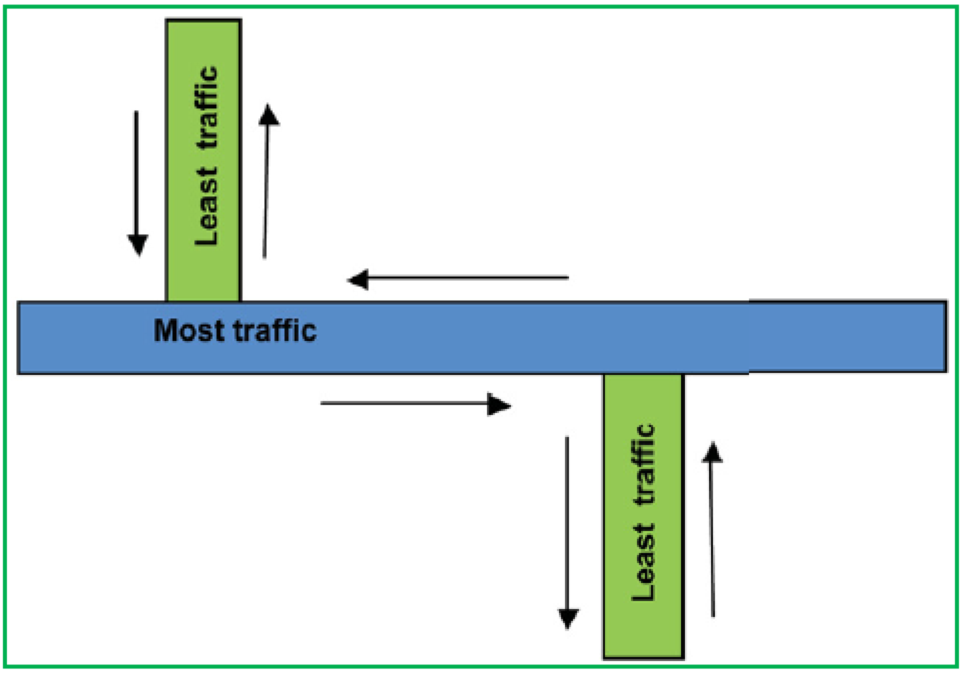


Figure 6.6: Preferred intersection design (for driving on the right hand side of carriageway)

6.8 Safety

The regional road accident statistics, in common with many other countries in Africa, show that death rates from road accidents are 30 to 50 times higher than in the countries of Western Europe. The numbers of serious injuries resulting from road accidents are equally alarming. Economic analysis has shown conclusively that this high level of road accidents has economic consequences for the country that is equivalent to a reduction of 2-3% of GDP. This is a very significant drain on the economy. Furthermore, the consequences of the road accidents impose a great deal of grief and anguish on a considerable proportion of the population. Every effort should therefore be made to reduce the number of serious accidents.

The geometric design of the roads has an important part to play in this endeavour and road safety aspects have been highlighted throughout this manual. Road and shoulder widths have been increased to accommodate pedestrians, NMTs, and intermediate forms of transport (IMTs); moderate design speeds have been used for elements of road alignment; parking places and lay-byes for buses have been included in populated areas; account has been taken of reduced friction on unpaved roads; adequate sight distances have been provided; and much more (see Figure 6.2 for example).

However there are a number of other steps that could be taken to improve safety. These include:

- Traffic calming measures to reduce speeds in populated area;
- Road markings, signage and lighting;

- Segregating pedestrians and motorised vehicles in populated areas;
- Providing safety barriers at dangerous locations;
- Providing a professional safety audit at the design stage.

6.8.1 Traffic calming

The seriousness of road accidents increases dramatically with speed and hence very significant improvements to road safety are possible if traffic can be slowed down. This process is called traffic calming and various techniques are used on paved roads. All such methods have their advantages and disadvantages and the effectiveness of the methods also depends on aspects of driver behaviour that can vary considerably from country to country. Therefore research needs to be carried out in South Sudan to identify the most cost effective approaches.

The effect of any traffic calming measure on all the road users should be carefully considered before they are installed. Some are unsuitable if large buses are part of the traffic stream; some are very harsh on bicycles, motorcycles and motor cycle taxis; and some are totally unsuitable when there is any animal drawn transport.

The three most common methods are:

- Chicanes;
- Rumble strips; and
- Speed reduction humps.

Chicanes: These are designed to produce artificial congestion by reducing the width of the road to one lane for a very short distance (3-5m) at intervals (typically 300m) along the road section to be treated. They are usually built on alternate sides of the road. They cause drivers to slow down provided that the traffic level is high enough to make it very probable that they will meet an oncoming vehicle. The method is obviously unacceptable if traffic flow is high because the congestion that is causes will be severe. For safety, they must be illuminated at night.

Rumble strips: These are essentially a form of artificial road texture that causes considerable tyre noise and vehicle vibrations if the vehicle is travelling too fast. They are used in two ways. The first is to delineate areas where vehicles should not be. They are effectively a line running parallel to the normal traffic flow so that if a vehicle inadvertently strays onto or across the line the driver will receive adequate warning. Secondly they are used across the road where they are placed in relatively narrow widths of 2 to 4m but at intervals along the road of typically 50 to 200 metres. They are uncomfortable to drive across at speed hence they are usually effective in slowing down the traffic. They do not need to be illuminated at night.

Speed reduction humps and cushions: These are probably the most familiar measures used to slow traffic. They are essentially bumps in the road extending uniformly from one side to the other. Unlike rumble strips, speed reduction humps are quite high and, if they are designed badly, they can cause considerable vehicle damage. They are often used in villages where they are placed at intervals of between 50m and 200m. They are very effective but usually unpopular with drivers.

The shape of the hump is important to reduce the severity of the shock when a vehicle drives over it. Ideally they should cause driver discomfort but not vehicle damage. The height of the bump is usually 50 or 75mm but the width should be at least 1.5m (2.0m is better) and the change in slope from the roadway onto the hump should be gradual. The top of the hump can be rounded or flat. Pipes that are almost buried are completely unsuitable. The surface drainage arrangements adjacent to a hump require consideration to ensure that all surface water drains away effectively and standing water is avoided.

Based on a similar principle to the speed hump, speed reducing cushions are more versatile. They are essentially very similar to the speed hump but the hump is not continuous across the road carriageway. The width of a two lane road is usually covered by two or three cushions with considerable gaps between them. The idea is that large vehicles will not be able to pass without at least one wheel running over one of the humps but bicycles and motorcycles can pass between them without interference. If suitably designed, the wheels of animal drawn carts could also avoid the humps.

6.8.2 Road markings, signage and lighting

Theft of metallic signs is a problem in some areas and therefore painting signs on permanent features such as buildings, rocks and purpose built masonry should be considered where necessary.

The extent to which road markings, signs and other road furniture is required depends on the traffic volume, the type of road, and the degree of traffic control required for safe and efficient operation. For low volume roads the primary purpose is to improve road safety hence not all of the features of road furniture and signage described in typical Road Furniture and Markings manuals will be used on LVRs.

The main elements are:

- Traffic signs provide essential information to drivers for their safe and efficient travel and manoeuvring on the road;
- Road markings to delineate the pavement centre line and edges to clarify the paths that vehicles should follow (particularly important at night);
- Marker posts to indicate the alignment of the road ahead and, when equipped with reflectors, provide optical guidance at night;
- Lighting in settlements to improve the safety of a road at night time.

6.9 Traffic Signs

Traffic signs are of three general types:

- Regulatory Signs: indicate legal requirements of traffic movement and are essential for all roads;
- Warning Signs: indicate conditions that may be hazardous to road users;
- Information Signs: convey information of use to the driver.

6.9.1 Warning signs

The physical layout of the road must sometimes be supplemented by effective traffic signing to inform and to warn drivers of any unexpected changes in the driving conditions. Some of the common situations are mentioned below but each situation is unique and the severity of any particular situation can vary considerably. It is therefore recommended that the judgement of an experienced road safety expert is obtained at the road design stage.

For an existing road that is to be upgraded, the hazardous locations should be identified at an early stage and, ideally, should be corrected in the new design. If this is not possible, then suitable road signs should be installed.

The most common situation occurs when the geometric standards for a particular class of road have been changed along a short section of road. This is usually caused by a constraint of some kind that has prevented the standard from being applied continuously and therefore causes an unexpected and potentially dangerous situation. Examples are a sharp bend, a sudden narrowing of the road, or an unexpectedly steep gradient.

A similar situation arises in easy terrain where, despite the fact that the geometric standard of the road has been applied, a hazard such as a bend occurs after a long section of road where drivers are easily able to exceed the design speed of the road by a considerable margin.

As well as changes in the geometric standard of the road, many other relatively unexpected hazards can occur and also need to be signed. For example an unexpected school crossing, a ford or other structure that is not clearly visible from a safe distance – there are many examples too numerous to list. Once again, engineering judgement is required.

Speed humps are a particular problem because they are often not sufficiently visible from a reasonable distance, and sometimes they have been badly designed and provide more of a jolt to the vehicle than intended. It is therefore good practice to provide warning signs for these, especially on roads that are likely to be used by traffic unfamiliar to the area. This will include classes DC3 and DC4 and many DC2 roads.

An important consideration on unpaved roads is that the road markings that are used on paved roads to improve safety cannot be used on unpaved roads. This means that if drivers need to be warned of a hazard that is traditionally done by means of road markings, on unpaved roads this will have to be done by means of traffic signs.

6.9.2 Information signs

Information signs are less vital on the lower classes of road frequented primarily by local people. However, for road classes DC3 and DC4 on which a considerable proportion of drivers will not be local, information signs are desirable. They obviate the need for drivers to stop in populated areas to ask questions of pedestrians and hence improve safety, but in most cases this effect is very marginal, especially if the road standards that should be provided in populated areas have been applied. Hence the convenience of some information signs is part of the provision of a particular level of service to the traveller.

6.10 Road Markings

Road markings on some types of paved roads either supplement traffic signs and marker posts or serve independently to indicate certain regulations or hazardous conditions. There are three general types of road markings in use namely pavement markings, object markings and road studs.

6.10.1 Pavement markings

Pavement markings consist primarily of centre lines, lane lines, no overtaking lines and edge lines. Not all of these are possible, or justified, on low volume roads. However, on a paved, two lane a centre line is desirable. Such a road is not likely to have been built unless the traffic justifies it and hence, for safety reasons, a centre line is recommended.

Other pavement markings such as 'stop', pedestrian crossings and various word and symbol markings may supplement pavement line markings. However, it is obvious that such markings can only be applied to paved roads and then not to all surfacings. In cases where a warning is deemed necessary for safety reasons but road markings cannot be used, road signs must be used instead if applicable.

6.10.2 Object markers

Physical obstructions in or near the carriageway should be removed in order to provide the appropriate clear zone. Where removal is impractical, such objects should be adequately marked by painting or by use of other high-visibility material.

6.10.3 Road studs

Road studs are used on more heavily trafficked roads and in urban areas. They are unlikely to be used on low volume roads but if necessary advice can be found in Road Furniture and Markings manuals.

6.10.4 Marker posts

There are two types of marker posts in use namely guideposts and kilometre posts. Guideposts are intended to make drivers aware of potential hazards such as abrupt changes in shoulder width and alignment, or approaches to structures for example. They are unlikely to be used on a low volume road, except on high embankments adjacent to structures. Kilometre posts are a usual feature provided on main roads and are therefore only likely to be needed on some roads of class DC4.

6.11 Lighting

Lighting of low volume rural roads is seldom justified except at intersections, railway level crossings, narrow or long bridges, tunnels, sharp curves, and areas where there is high level activity adjacent to the road (e.g. markets).

6.12 Safety Barriers

Safety barriers are expensive and seldom justified on low volume roads. The geometric design of such roads should be done to eliminate the need for such barriers but sometimes they might be required in highly dangerous situations, for example, on some bends on an escarpment road that cannot be made safe by other means, or high embankments adjacent to structures. Expert advice should be sought. Safety barriers are expensive to procure and install and they must be installed properly otherwise they are not likely to be fit for purpose.

6.12.1 Segregating vulnerable road users

Where possible, non-motorised vehicles and pedestrians should be physically segregated from the motorised vehicles. While this is not specifically part of the geometric design of the road itself, if the terrain and local conditions are suitable for the construction of parallel pathways wide enough for NMTs, then some of the geometric features of the roadway designed to accommodate this traffic will not be necessary and hence considerable savings may be possible. However if traffic does travel on such pathways, sufficient connections need to be made to the roadway itself to enable access in either direction.

6.12.2 Safety audits

The subject of road safety is remarkably complex in that, although many unsafe practices are glaringly obvious, there are many situations where it is difficult to identify what is likely to be unsafe, especially if the project is a new road and one is working from drawings. The history of road safety is full of ideas that were thought to improve road safety but often had no discernible effect or even made situations worse. The problem has always been lack of reliable data; there is no substitute for a systematic method of recording the characteristics of road accidents and analysing the data when there is sufficient for reliable conclusions to be drawn.

Professional road safety auditing is the next best thing and is regularly undertaken on every road project in some countries in an attempt to improve the safety design from the very beginning. It is anticipated that this practice will be introduced in South Sudan, especially for road projects located in populated areas.

6.13 Using the Geometric Standards

There are three design situations for applying the LVR Geometric Design Standards, namely:

- Upgrading from a lower class of road to a higher class;
- Designing a road to replace an existing track; and
- Designing a completely new road where nothing existed before.

Careful consideration needs to be paid to alignment issues as it is likely that any re-alignment or route upgrade will require additional land and may encroach on land already occupied or used by others. The necessary legal land consultations and acquisition procedures will need to be followed.

6.13.1 Upgrading an existing road

The basic alignments will already exist but the standards of the existing road will normally be those applicable to a road of lower class. The new road will require higher standards which may involve a wider cross section, higher design speeds and therefore larger horizontal and vertical radii of curvature. In flat and rolling terrain, larger horizontal radii of curvature are usually achieved by means of minor realignments at the curves themselves. Larger vertical radii of curvature are usually more difficult but, depending on the terrain, can often be achieved by additional fill rather than deeper cutting. In more severe mountainous terrain it may be necessary to make substantial realignments to avoid deep cuts, for example, following a contour more closely to avoid a steep hill with inadequate sight distances over a crest.

The most difficult aspect is likely to occur in mountainous terrain when substantial widening is required. Under these circumstances it may not always be possible to meet the standards of the new road class and therefore adequate warning signs will need to be employed to alert drivers to the lower standards. In general, however, the main improvements, apart from overall widening, are essentially spot improvements and do not require sophisticated design methods.

6.13.2 Designing a road to replace an existing track

In this case the existing geometric standards will be very much lower than those required hence some substantial re-alignments may be necessary, especially in hilly and mountainous terrain. However, the basic route selection has been carried out by virtue of the fact that there is an existing track and the main control points along the alignment will already be defined. Although re-alignments may be substantial, an experienced Engineer could adopt a design-by-eye approach in many cases, especially for lower category LVRs. However, it is anticipated that, in general, the designs will be done with the help of computer programs based on accurate topographical and other survey data (see Chapter 5 on route selection).

6.13.3 Designing a new road

Designing a geometric alignment for an entirely new road where nothing existed before is a considerably more complex process because of the many different route alignments that are possible and the relative lack of information available at the beginning of the process. In many cases there will need to be a prefeasibility study to identify possible corridors for the road and to decide whether the project is likely to be viable. This will then need to be followed by a feasibility study to determine the best routes within the best corridors and, finally, a detailed design study based on the route selected. The level of detail in this process depends critically on the class of road being designed and the terrain through which it will pass. Errors at this stage can be costly and, once the road is built, can also impose serious burdens in the future if the road requires excessive maintenance.

The principles of route selection are outlined in Chapter 5. They are based on surveys of various focus that provide information about all the likely technical engineering issues related to the new road, but also surveys concerned with environmental and social issues as well. The final design will inevitably be a compromise between many competing factors and there is no formal way of resolving all of them to everyone's satisfaction. Engineering judgement and consensus will be required to arrive at a satisfactory alignment.

6.14 LVR Geometric Design Standards

The foregoing sections of Chapter 6 provide the background and rationale for the various Geometric Standards for LVRs. The Geometric Design process is summarised in Figure 6.1 and this section 6.14 includes further guidance and the detailed Standards tables and diagrams not already included in the previous text.

6.14.1 Traffic composition

The proportion of heavy vehicles in the traffic stream on LVRs is often quite high. The Geometric Design standards for DC2, DC3 and DC4 include a modification to cater for this. In order to quantify traffic for normal capacity design the concept of equivalent PCUs is used. The PCU values are shown Table 6.4.

6.14.2 Geometric design standards for LVRs

The design standards are shown in Tables 6.17 to 6.23. In these Tables 'large vehicles' are defined as trucks with three or more axles and gross vehicle weights greater than 10 tonnes.

Two sets of tables are shown for each class of route; one for paved roads and one for unpaved roads.

Sometime there will be cases where it is impossible to meet some of the standards mainly due to severe terrain conditions. Under such circumstances the standards must be relaxed at the discretion of the Engineer and suitable permanent signage used to warn road users.

Table 6.17: Geometric design standards for Paved DC4 (1) (AADT 150-300)

Design Element	Unit	Flat	Rolling	Mountain	Escarp -ment	Populated areas
Design Speed	km/hr	70	60	50	25	50
Width of running surface	m	6.5 (2)	6.5 (2)	6.5	6.5	6.5 (1)
Width of shoulders	m	1.25 (2)	1.25 (2)	0.5	0.5	1.25 (3)
Total width	m	9.0	9.0	7.5	7.5	9.0
Min. stopping sight distance	m	110	90	70	25	65
Min. horizontal radius for SE=4%	m	195	135	85	15 (4)	85
Min. horizontal radius for SE=7%	m	170	120	75	17 (4)	NA
Min. horizontal radius for SE=10%	m	150	105	70	22 (4)	NA
Maximum desirable gradient	%	4	7	10	12	4
Maximum gradient	%	7	10	12 (5)	12 (5)	6
Minimum crest vertical curve	K	21	12	7	4	7
Minimum sag vertical curve	K	4.8	3.5	2.2	1.3	2.2
Normal cross-fall	%	3	3	3	3	3
Shoulder cross-fall	%	6	6	3	3	6

Notes

1. If there are more than 80 large vehicles AADT then DC5 should be used.
2. If the number of large vehicles AADT is >40 then running surface width should be increased to 7.0m and shoulders reduced to 1.0m.
3. Parking lanes and footpaths may be required.
4. On hairpin stacks the minimum radius may be reduced to 15m.
5. Length not to exceed 200m and relief gradients required (<6% for minimum of 200m).

Table 6.18: Geometric design standards for Unpaved DC4 (1) (AADT 150-300)

Design Element	Unit	Flat	Rolling	Mountain	Escarp -ment	Populated areas
Design Speed	km/hr	70	60	50	25	50
Road width	m	7.0 (3)	7.0 (3)	7.0	7.0	7.0 (2,3)
Min. stopping sight distance	m	125	105	75	28	70
Min. horizontal radius	m	245	175	110	23 (4)	110
Maximum desirable gradient	%	4	6	6	6	4
Maximum gradient	%	6	9	9	9	6
Maximum super elevation	%	6	6	6	6	6
Minimum crest vertical curve	K	34	19	11	6	11
Minimum sag vertical curve	K	4.8	3.5	2.2	1.3	2.2
Normal cross-fall (5)	%	6	6	6	6	6

Notes

1. If there are more than 80 large vehicles AADT then DC5 should be used.

1. Parking lanes and footpaths may be required.
2. If the number of large vehicles AADT is >40 then width should be increased to 7.5m.
3. On hairpin stacks the minimum radius may be reduced to 15m.
4. Cross-fall can be reduced to 4% where warranted (e.g. poor gravel (for safety), low rainfall).

Table 6.19: Geometric design standards for Paved DC3 (1) (AADT 75-150)

Design Element	Unit	Flat	Rolling	Mountain	Escarp -ment	Populated areas
Design Speed	km/hr	70	60	50	25	50
Width of running surface	m	6.0	6.0	6.0	6.0	6.0
Width of shoulders	m	1.0	1.0	0.5	0.5	1.0 (2)
Total width	m	8.0	8.0	7.0	7.0	8.0
Min. stopping sight distance	m	110	90	70	25	65
Min. horizontal radius for SE=4%	m	195	135	85	20 (3)	85
Min. horizontal radius for SE=7%	m	170	120	75	18 (3)	NA
Min. horizontal radius for SE=10%	m	150	105	70	16 (3)	NA
Maximum desirable gradient	%	4	7	10	12	4
Maximum gradient	%	7	10	12 (4,5)	12 (4,5)	6
Minimum crest vertical curve	K	21	12	7	2	7
Minimum sag vertical curve	K	4.8	3.5	2.2	1.3	2.2
Normal cross-fall	%	3	3	3	3	3
Shoulder cross-fall	%	6	6	3	3	6

Notes

1. If there are more than 30 large vehicles AADT then DC4 should be used.
2. Parking lanes and footpaths may be required.
3. On hairpin stacks the minimum radius may be reduced to 15m.
4. Length not to exceed 200m and relief gradients required (<6% for minimum of 200m).
5. If the number of large vehicles AADT is <20 this can be increased to 15%.

Table 6-20: Geometric design standards for Unpaved DC3 (1) (AADT 75-150)

Design Element	Unit	Flat	Rolling	Mountain	Escarp -ment	Populated areas
Design Speed	km/hr	70	60	50	25	50
Road width	m	7.0	7.0	6.5	6.5	7.0 (2)
Min. stopping sight distance	m	125	105	75	28	70
Min. horizontal radius	m	245	175	110	23 (4)	110
Maximum desirable gradient	%	4	6	6	6	4
Maximum gradient	%	6	9	9	9	6
Maximum super elevation	%	6	6	6	6	6
Minimum crest vertical curve	K	34	19	11	3	11
Minimum sag vertical curve	K	4.8	3.5	2.2	1.3	2.2
Normal cross-fall (3)	%	6	6	6	6	6

Notes

1. If there are more than 30 large vehicles AADT then DC4 should be used.

2. Parking lanes and footpaths may be required.
3. Cross-fall can be reduced to 4% where warranted (e.g. poor gravel (for safety), low rainfall).
4. On hairpin stacks the minimum radius may be reduced to 15m.

Table 6-21: Geometric design standards for Paved DC2 (1) (AADT 25-75)

Design Element	Unit	Flat	Rolling	Mountain	Escarp -ment	Populated areas
Design Speed	km/hr	60	50	40	20	50
Width of running surface	m	3.3	3.3	3.3	3.3	3.3
Width of shoulders	m	1.5	1.5	1.0	1.0	1.5 (2)
Total width	m	6.3	6.3	5.3	5.3	6.3
Min. stopping sight distance	m	85	70	50	17	65
Min. horizontal radius for SE=4%	m	135	85	50	15 (3)	85
Min. horizontal radius for SE=7%	m	120	75	45	15 (3)	NA
Min. horizontal radius for SE=10%	m	105	70	40	15 (3)	NA
Maximum desirable gradient	%	4	7	10	12	4
Maximum gradient	%	7	10	12 (4)	15 (4)	6
Minimum crest vertical curve	K	12	7	4	2	7
Minimum sag vertical curve	K	3.5	2.2	1.3	0.7	2.2
Normal cross-fall	%	3	3	3	3	3
Shoulder cross-fall	%	6	6	3	3	6

Notes

1. If there are more than 20 large vehicles AADT then DC3 should be used.
2. Parking lanes and footpaths may be required.
3. On hairpin stacks the minimum radius may be reduced to 13m.
4. Length not to exceed 200m and relief gradients required (<6% for minimum of 200m).

Table 6.22: Geometric design standards for Unpaved DC2 (1, 2) (AADT 25-75)

Design Element	Unit	Flat	Rolling	Mountain	Escarp -ment	Populated areas
Design Speed	km/hr	60	50	40	20	50
Road width (5)	m	6.0	6.0	6.0	6.0	6.0 (3)
Min. stopping sight distance	m	95	75	55	20	70
Min. horizontal radius	m	175	110	70	15 (4)	110
Maximum desirable gradient	%	4	6	6	6	4
Maximum gradient	%	6	9	9	9	6
Maximum super elevation	%	6	6	6	6	6
Minimum crest vertical curve	K	19	11	6	3	11
Minimum sag vertical curve	K	3.5	2.2	1.3	0.7	2.2
Normal cross-fall	%	6	6	6	6	6

Notes

1. If there are more than 20 large vehicles AADT then DC3 should be used.
2. If there are less than 10 large vehicles AADT then DC1 may be used.

3. Parking lanes and footpaths may be required.
4. On hairpin stacks the minimum radius may be reduced to 13m.
5. Road widths may be reduced at the discretion of the engineer and approval of the client to address specific local conditions, especially in mountainous areas.

Table 6.23: Geometric design standards for DC1 (AADT 1-25)

Design Element	Unit	Flat	Rolling	Mountain	Escarp -ment	Populated areas
Design Speed	km/hr	50	40	30	20	40
Road width	m	4.5	4.5	4.5	4.5	4.5
Min. stopping sight distance	m	70	55	35	18	50
Min. horizontal radius	m	110	70	35	15 (1)	70
Maximum desirable gradient	%	4	6	6	6	4
Maximum gradient	%	12 (2)	12 (2)	12 (2)	12 (2)	6
Minimum crest vertical curve	K	11	6	3	2	6
Minimum sag vertical curve	K	2.2	1.3	0.7	0.5	1.3
Normal cross-fall	%	6	6	6	6	6

Notes

1. On hairpin stacks the minimum radius may be reduced to 13m.
2. Length not to exceed 200m and relief gradients required (<6% for minimum of 200m).

For the lowest category of road it may sometimes be necessary to adopt a basic access only approach. For such roads it may be too expensive to provide a design speed but minimum absolute standards must be applied. These are summarised in Table 6.24.

Table 6.24: Minimum standards for Basic Access

Characteristic	Minimum requirements	
Radius of horizontal curvature	12m absolute but up to 20m depending on expected vehicles	
Vertical curvature K value for crests K value for sags	 2.5 0.6	
Maximum gradients Open to all vehicles Open only to cars and pick-ups	 14% 16%	
Minimum stopping sight distance	Flat and Rolling terrain Mountainous Escarpments	50m 35m 20m

For Basic Access, Longitudinal Gradients of >6% should be considered for paving due to the excessive longitudinal erosion caused by rainfall surface runoff under an EOD Spot Improvement Strategy.

6.14.3 Design-by-eye

The design-by-eye method is best suited to rehabilitation or upgrading projects where a road alignment already exists and is the preferred method for developing a design for a track or undesignated road under a community roads programme where a walking track is being improved to enable it to carry occasional vehicles. Nevertheless, considerable experience and skill is needed to carry out the design-by-eye method and the approach should only be used under the guidance and supervision of an experienced Engineer.

6.14.4 Typical cross sections

Typical cross sections for a range of conditions are shown in Figures 6.7 to 6.18. They include:

- Roads on flat terrain;
- Roads on rolling terrain;
- Roads on mountainous terrain;
- Roads on escarpments;
- Roads through populated areas;
- Roads on expansive soils.

Unpaved and Paved options are shown.

Slope dimensions for the various conditions are summarised in Table 6.25.

Table 6.25: Slope Ratio Table – Vertical to Horizontal

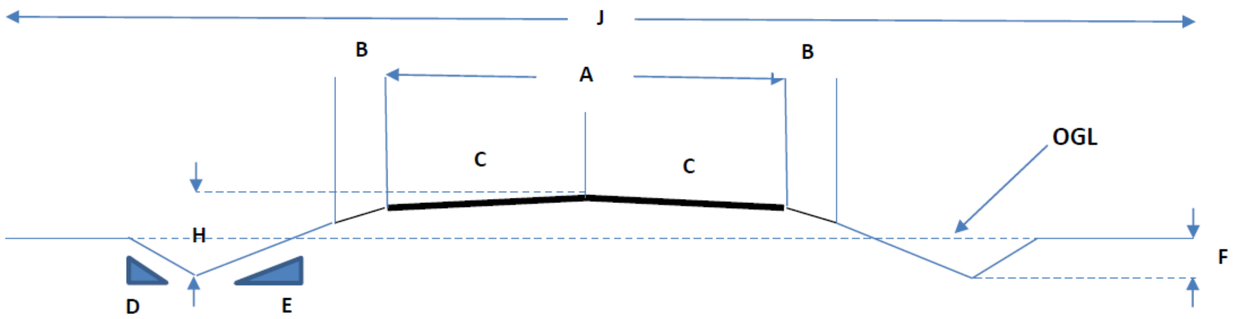
Material	Height of Slope (m)	Side Slope (V:H)		Back Slope
		Fill	Cut	
Earth Soil	0.0 – 1.0	1:3	1:2	1:3
	1.0 – 2.0	1:2		1:2
	>2.0	2:3		2:3
Strong Rock	0.0 – 2.0	4:5		2:1
	>2.0	1:1		4:1
Weathered Rock	0.0 – 2.0	2:3		2:1
	>2.0	1:1		3:1
Decomposed Rock	0.0 – 1.0	1:3		1:3
	2.0 – 2.0	1:2		1:2
	>2.0	2:3		2:3
Black Cotton Soil (expansive clays)(1)	0.0 – 2.0	1:6	-	-
	>2.0	1:4		

Note

1. Move ditch away from road as shown in Figures 6.17 and 6.18

This Table should be used as a guide only, particularly because applicable standards in rock cuts are highly dependent on costs. Also certain soils that may be present at subgrade level may be unstable at 1:2 side slopes and therefore a higher standard will need to be applied for these soils. Slope configuration and treatments in areas with identified slope stability problems should be addressed as a final design issue.

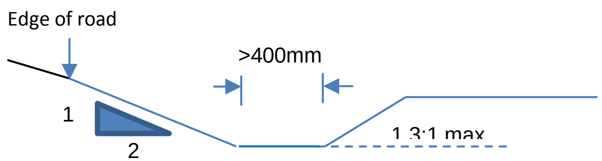
Figure 6.7: Typical cross section, DC1 – 4, Flat Terrain, Unpaved



Label	Design Criteria	Design Classes			
		DC1	DC2	DC3	DC4
A	Carriageway width (m)	3.3	5.0	5.5	6.0
B	Shoulder width (m)	0.6	0.5	0.75	0.75
C	Min Crossfall/Camber (%)	4	4	4	4
D	Backslope of ditch (v:h ratio)	See Table 6.25			
E	Side slope of ditch (v:h ratio)				
F	Depth of Side ditch (m)	Varies			
H	Crown height (m)	0.35	0.35	0.5	0.5
J	Cleared width (m)	15	20	20	20

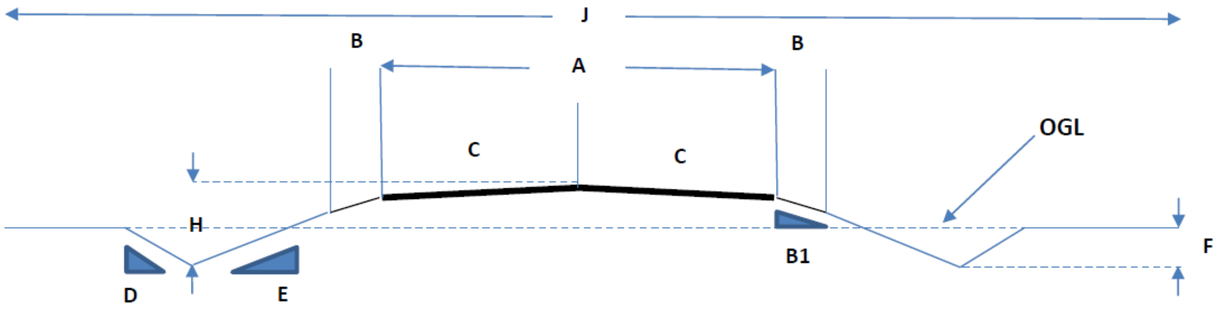
Notes:

1. Section not drawn to scale;
2. V-shape is the standard shape of the drainage ditch constructed and maintained by motor or towed grader;
3. Trapezoidal drains are commonly used and are much easier to dig and clean using labour-based methods. The minimum recommended width is 400mm and the typical cross-section is shown below;



4. Rectangular drains need to be lined with rock, brick stone masonry or concrete to maintain their shape;
5. More detail on side drains is provided in Chapter 9.

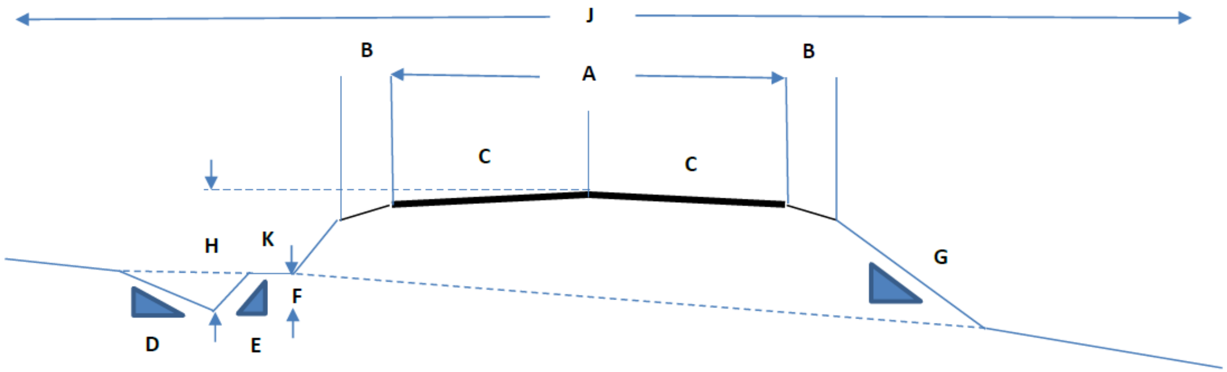
Figure 6.8: Typical cross section, DC1 – 4, Flat Terrain, Paved



Label	Design Criteria	Design Classes			
		DC1	DC2	DC3	DC4
A	Carriageway width (m), minimum		3.3	6.0	6.5
B	Shoulder width (m)		1.5	1.0	1.25
B1	Shoulder Crossfall (%)		6	6	6
C	Crossfall/Camber (%)		3	3	3
D	Backslope of ditch (v:h ratio)		See Table 6.25		
E	Side slope of ditch (v:h ratio)				
F	Depth of side ditch (m)		Varies		
H	Crown height (m)		0.75	0.75	0.75
J	Cleared width (m)		20	20	20

Notes:
1. Section not drawn to scale;
2. V-shape is the standard shape of the drainage ditch constructed and maintained by motor or towed grader;
3. Trapezoidal drains are commonly used and are much easier to dig and clean using labour-based methods. The minimum recommended width is 500mm;
4. Rectangular drains need to be lined with rock, brick stone masonry or concrete to maintain their shape;
5. More detail on side drains is provided in Chapter 9.

Figure 6.9: Typical cross section, DC1 – 4, Rolling Terrain, Unpaved

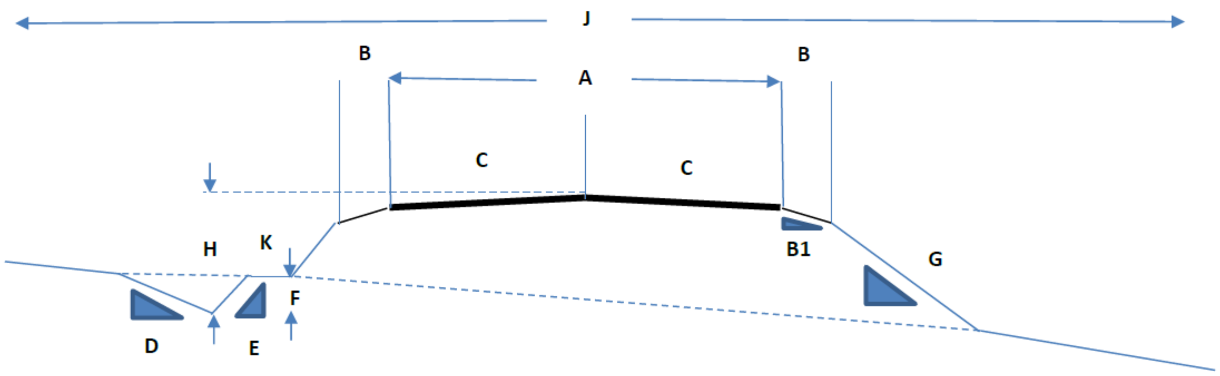


Label	Design Criteria	Design Classes			
		DC1	DC2	DC3	DC4
A	Carriageway width (m)	3.3	5.0	5.5	6.0
B	Shoulder width (m)	0.6	0.5	0.75	0.75
C	Min Crossfall/Camber (%)	4	4	4	4
D	Backslope of ditch (v:h ratio)	See Table 6.25			
E	Side slope of ditch (v:h ratio)				
F	Depth of Side ditch (m)	Varies			
G	Side slope (v:h ratio)	See Table 6.25			
H	Crown height (m)	0.35	0.35	0.5	0.5
J	Cleared width (m)	15	20	20	20
K	Embankment toe (m)	Varies			

Notes:

1. Section not drawn to scale;
2. See Figure 6.7 for trapezoidal and other ditch options.

Figure 6.10: Typical cross section, DC1 – 4, Rolling Terrain, Paved

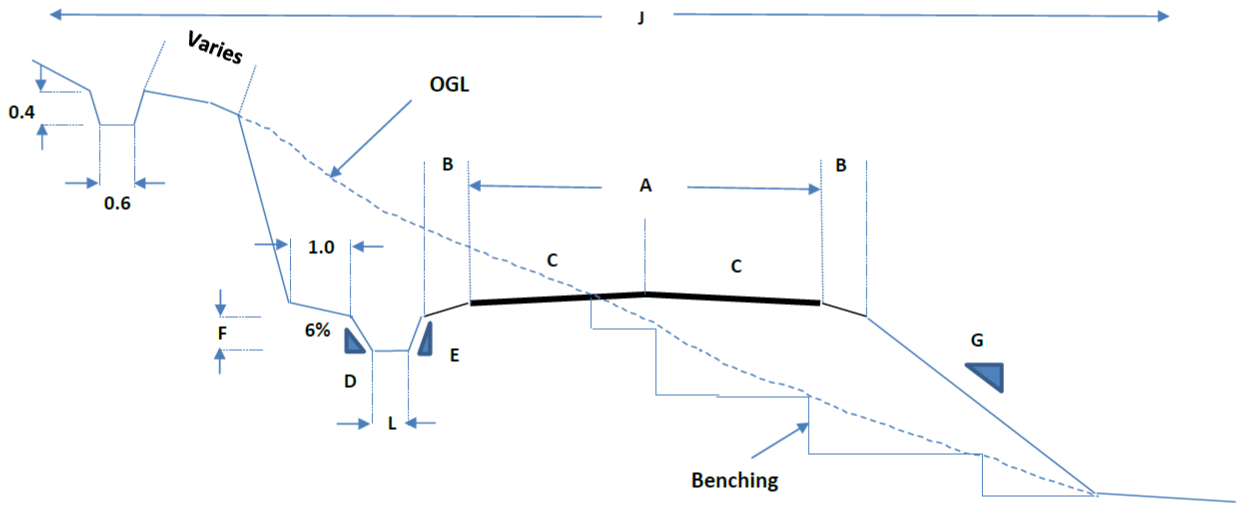


Label	Design Criteria	Design Classes			
		DC1	DC2	DC3	DC4
A	Carriageway width (m)		3.3	6.0	6.5
B	Shoulder width (m)		1.5	1.0	1.25
B1	Shoulder Crossfall (%)		6	6	6
C	Crossfall/Camber (%)		3	3	3
D	Backslope of ditch (v:h ratio)		See Table 6.25		
E	Side slope of ditch (v:h ratio)				
F	Depth of side ditch (m)		Varies		
G	Side slope		See Table 6.25		
H	Crown height (m)		0.75	0.75	0.75
J	Cleared width (m)		20	20	20
K	Embankment toe (m)	Varies			

Notes:

1. Section not drawn to scale;
2. See Figure 6.7 for trapezoidal and other ditch options.

Figure 6.11: Typical cross section, DC1 – 4, Mountainous Terrain, Unpaved

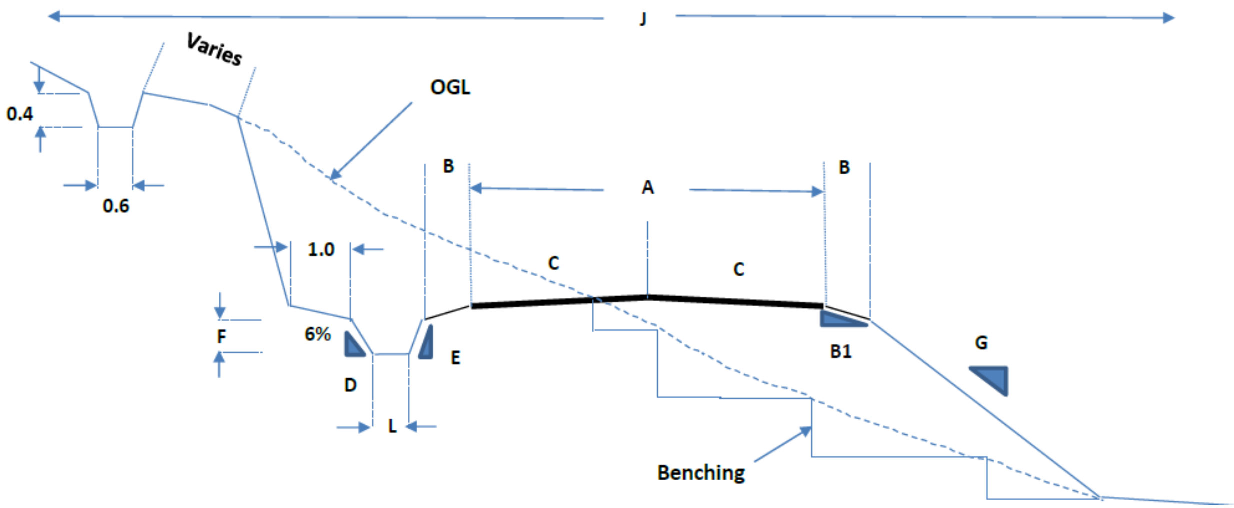


Label	Design Criteria	Design Classes			
		DC1	DC2	DC3	DC4
A	Carriageway width (m)	3.3	5.0	5.5	6.0
B	Shoulder width (m)	0.6	0.5	0.5	0.5
C	Min Crossfall/Camber (%)	4	4	4	4
D	Backslope of ditch (v:h ratio)	See Table 6.25			
E	Side slope of ditch (v:h ratio)				
F	Depth of Side ditch (m)	0.35			
G	Side slope (v:h ratio)	See Table 6.25			
J	Cleared width (m)	15	20	20	20
L	Ditch width (m)	Varies			

Notes:

1. Section not drawn to scale

Figure 6.12: Typical cross section, DC1 – 4, Mountainous Terrain, Paved

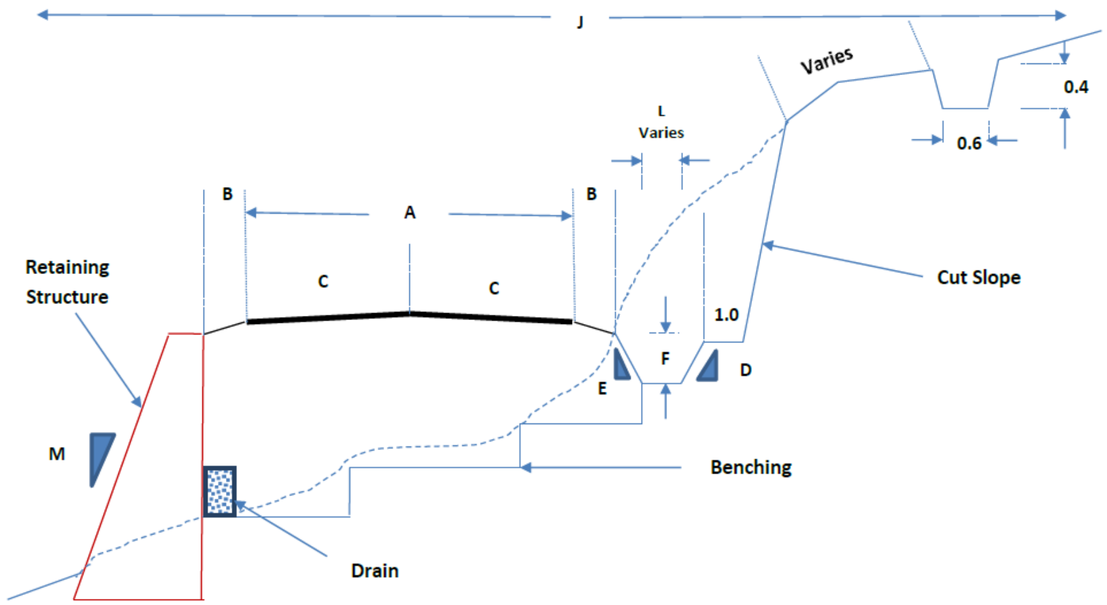


Label	Design Criteria	Design Classes			
		DC1	DC2	DC3	DC4
A	Carriageway width (m)		3.3	6.0	6.5
B	Shoulder width (m)		1.0	0.5	0.5
B1	Shoulder crossfall (%)		3	3	3
C	Crossfall/Camber (%)		3	3	3
D	Backslope of ditch (v:h ratio)		See Table 6.25		
E	Side slope of ditch (v:h ratio)				
F	Depth of Side ditch (m)		0.5		
G	Side slope (v:h ratio)		See Table 6.25		
J	Cleared width (m)		20	20	20
L	Ditch width (m)		Varies		

Notes:

1. Section not drawn to scale

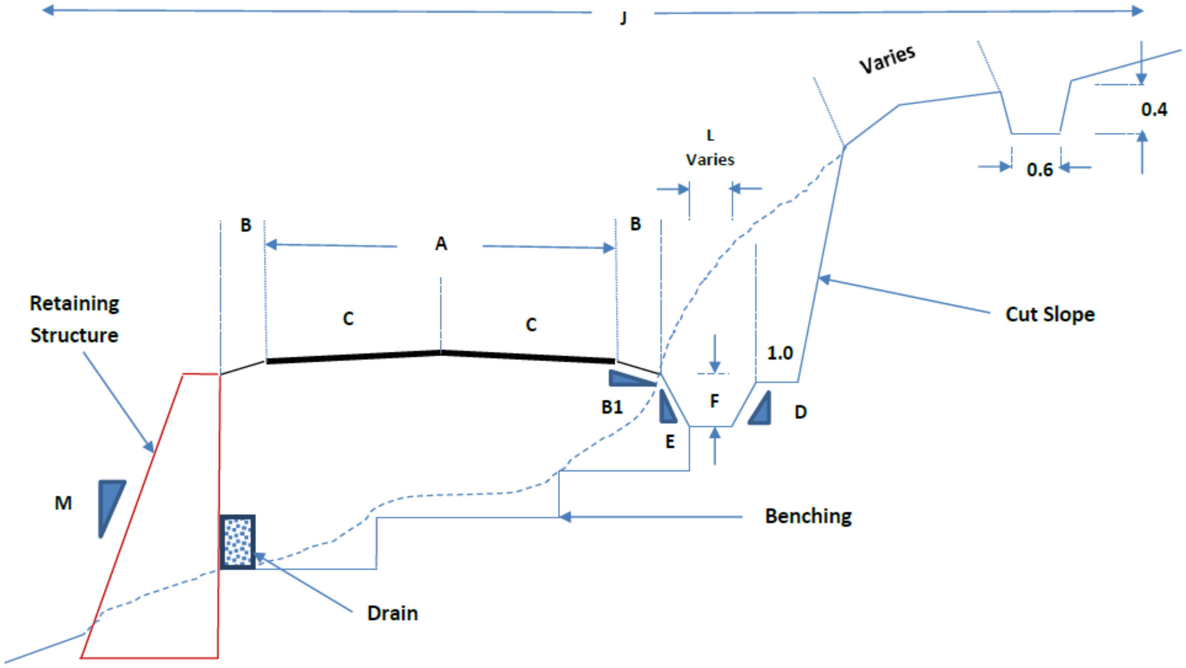
Figure 6.13: Typical cross section: DC1 – 4, Escarpment Terrain, Unpaved



Label	Design Criteria	Design Classes			
		DC1	DC2	DC3	DC4
A	Carriageway width (m)	3.3	5.0	5.5	6.0
B	Shoulder width (m)	0.6	0.5	0.5	0.5
C	Min Crossfall/Camber (%)	4	4	4	4
D	Backslope of ditch (v:h ratio)	See Table 6.25			
E	Side slope of ditch (v:h ratio)				
F	Depth of Side ditch (m)	Min 0.35			
J	Cleared width (m)	15	20	20	20
L	Ditch width (m)	Varies			
M	Slope of retaining structure	Varies			

Notes: 1. Section not drawn to scale

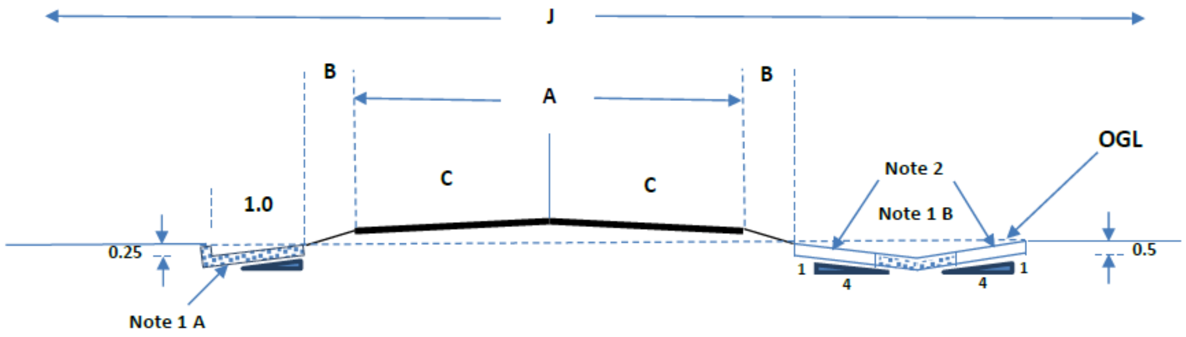
Figure 6.14: Typical cross section: DC1 – 4, Escarpment Terrain, Paved



Label	Design Criteria	Design Classes			
		DC1	DC2	DC3	DC4
A	Carriageway width (m)		3.3	5.5	6.5
B	Shoulder width (m)		1.0	0.5	0.5
B1	Shoulder crossfall (%)		3	3	3
C	Crossfall/Camber (%)		3	6	3
D	Backslope of ditch (v:h ratio)		See Table 6.25		
E	Side slope of ditch (v:h ratio)				
F	Depth of Side ditch (m)		Min 0.5		
J	Cleared width (m)		20	20	20
L	Ditch width (m)		Varies		
M	Slope of retaining structure		Varies		

Notes: 1. Section not drawn to scale

Figure 6.15 Typical cross section, DC1 – 4, Populated areas, Unpaved

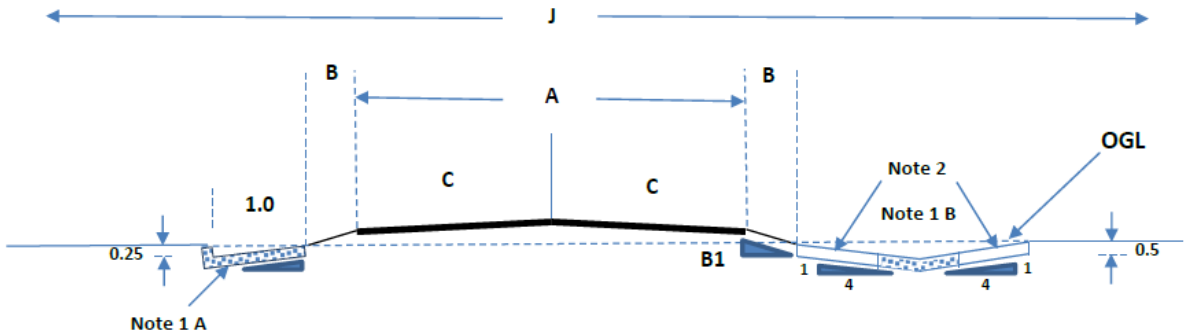


Label	Design Criteria	Design Classes			
		DC1	DC2	DC3	DC4
A	Carriageway width (m), minimum	3.3	5.0	5.5	6.0
B	Shoulder width (m)	0.6	0.5	0.75	0.75
C	Min Crossfall/Camber (%)	4	4	4	4
J	Cleared width (m)	15	20	20	20

Notes:

1. Open channel type A – 25 cm thick mortared stone pitching
   Open channel type B – 25 cm thick mortared stone pitching
2. Wearing course
3. Choice of open channel dependent on local conditions
4. Provide lined channels only where maintenance of road surface and camber at original levels is guaranteed.

Figure 6.16: Typical cross section, DC1 – 4, Populated areas, Paved

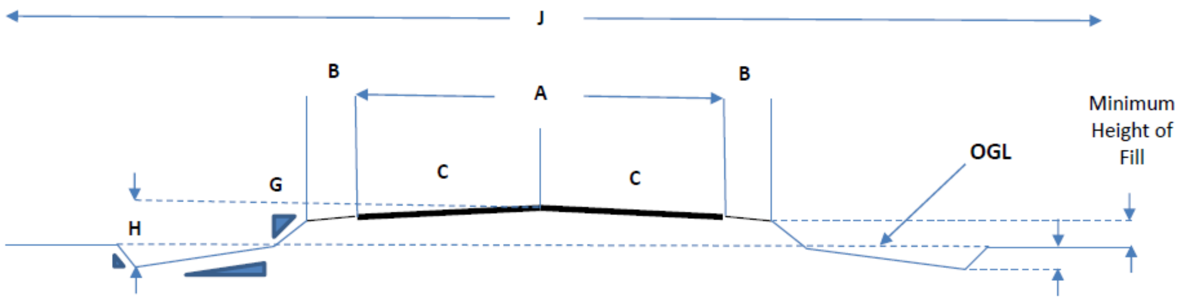


Label	Design Criteria	Design Classes			
		DC1	DC2	DC3	DC4
A	Carriageway width (m), minimum		3.3	6.0	6.5
B	Shoulder width (m)		1.5	1.0	1.25
B1	Shoulder Crossfall (%)		6	6	6
C	Crossfall/Camber (%)		3	3	3
J	Cleared width (m)		20	20	20

Notes:

1. Open channel type A – 25 cm thick mortared stone pitching
   Open channel type B – 25 cm thick mortared stone pitching
2. Choice of open channel dependent on local conditions
3. Surfacing of shoulder recommended.

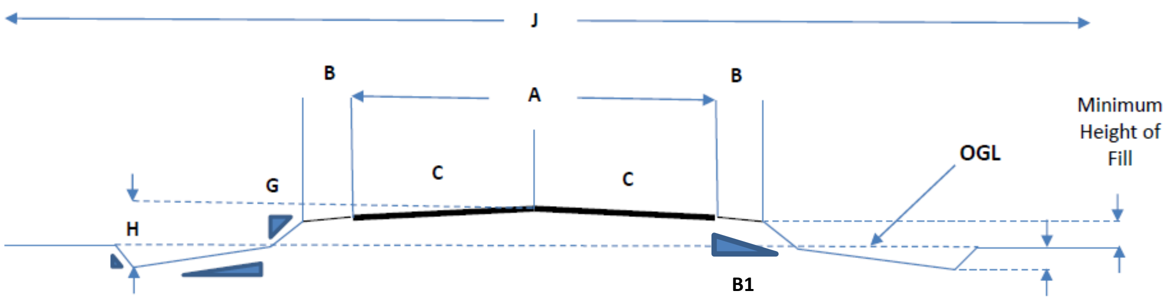
Figure 6.17: Typical cross section, DC1 – 4, Flat Terrain, Expansive soils, Unpaved



Label	Design Criteria	Design Classes			
		DC1	DC2	DC3	DC4
A	Carriageway width (m)	3.3	5.0	5.5	6.0
B	Shoulder width (m)	0.6	0.5	0.75	0.75
C	Min Crossfall/Camber (%)	4	4	4	4
D	Backslope of ditch (v:h ratio)	See Table 6.25			
E	Side slope of ditch (v:h ratio)				
F	Depth of Side ditch (m)	Varies			
G	Side slope	See Table 6.25			
H	Crown height (m)	0.35	0.35	0.5	0.5
J	Cleared width (m)	15	20	20	20

Notes: 1. Section not drawn to scale.

Figure 6.18: Typical cross section, DC1 – 4, Flat Terrain, Expansive soils, Paved



Label	Design Criteria	Design Classes			
		DC1	DC2	DC3	DC4
A	Carriageway width (m), minimum		3.3	6.0	6.5
B	Shoulder width (m)		1.5	1.0	1.25
B1	Shoulder Crossfall (%)		6	6	6
C	Crossfall/Camber (%)		3	3	3
D	Backslope of ditch (v:h ratio)		See Table 6.25		
E	Side slope of ditch (v:h ratio)				
F	Depth of side ditch (m)		Varies		
G	Side slope		Varies		
H	Crown height (m)		0.75	0.75	0.75
J	Cleared width (m)		20	20	20

Notes: 1. Section not drawn to scale.

6.14.5 Roadside population and non-motorised vehicles

If the road is passing through a village or large settlement, an extra carriageway width of 3.5m is provided in each direction for parking and for passenger pick-up and a 2.5m pedestrian footpath is also specified. The latter is essentially the road shoulder (Tables 6.17 and 6.18). In addition, the main running surface is paved and is 7.0m wide.

When passing through a minor settlement a 2.5m paved shoulder is specified but no additional footpath, though one could be provided if considered to be required. The carriageway is also increased to 7.0m and therefore the standard is very similar to DC4 but with wider shoulders.

These standards are not justified for the lower traffic levels of DC1, which is a single carriageway, unless the road is passing through a particularly well populated area but where additional traffic may be expected. In such circumstances the shoulders should be widened to 2.5 metres for the extent of the populated area.

Additional shoulder widths are also provided if there is a high number of PCUs of non-motorised vehicles, (defined as more than 300 PCUs per day on average (Tables 6.26 and 6.27).

Table 6.26: Increased 'shoulder' widths (each side) for unpaved LVRs

Design standard	Basic shoulder widths (m)				Populated areas	High PCUs
	Flat	Rolling	Mountainous	Escarpment		
DC4 unpaved	Shoulders not defined for unpaved roads. The figure is for increased width each side, but DC1 is unlikely in populated areas.				+ 3.5	+ 2.0
DC3 unpaved					+ 3.5	+ 1.5
DC2 unpaved					+ 2.5	+ 1.25 (1)
DC1					+ 2.0	

Notes

1. DC1 is effectively a single carriageway hence less extra width is needed for PCUs.

Table 6.27 Shoulder widths (each side) for paved LVRs

Design standard	Basic shoulder widths (m)				Populated Section for parking	High PCUs
	Flat	Rolling	Mountainous	Escarpment		
DC4 paved	1.25	1.25	0.5	0.5	3.5	+ 2.0
DC3 paved	1.0	1.0	0.5	0.5	3.5	+ 1.5
DC2 paved (1)	1.5	1.5	1.0	1.0	2.5	+ 1.25 (2)
DC1 (1)					2.0	

Notes

1. Paved sections are single carriageway resulting in a wider shoulder.
2. DC1 and DC2 paved are effectively a single carriageway, hence less extra width is needed for high PCUs.

References

Lebo J. & Schelling D. 2001. *Design and appraisal of rural transport infrastructure. Ensuring basic access for rural communities*. World Bank Technical paper 496.

USAID, 2010. *Geometric Design Manual*. MRB, GoSS.

7 SURFACING AND PAVEMENT DESIGN

7.1 Introduction to Paving and Surfacing Options for LVR

There are a large number of proven bituminous and non-bituminous paving and surfacing options available for use on Low Volume Roads. These surface options fulfil a variety of functions which, collectively, preserve the integrity of roadway and any pavement layers and improve the functionality of the road in service. The basic locally available materials of natural soils/gravels, stone, sand, fired clay brick can be used with or without a range of binders and sealers to offer a range of attributes which need to be matched to such factors as expected traffic levels and loading, locally available materials and skills, construction and maintenance regimes and the environment. Careful consideration should therefore be given to all these factors in order to make a judicious, cost-effective choice of paving and surface to provide satisfactory performance and minimise life cycle costs.

This section provides an overview of the various types of paving and surfacings available and appropriate for use in South Sudan in relation to a range of local factors. The section provides information on the constituents and performance characteristics of the surfacings, the factors affecting their choice and the general approach to their design.

The subsequent sections of the Chapter provide guidance on the selection and design process for the various paving and surfacing options.

7.1.1 Types of surfacings

LVR surfacings suitable for application in South Sudan may be grouped according to their main constituents as follows:

Basic

S-01: Engineered Natural Surface (ENS)

S-02: Natural gravel

Stone Paving

S-03: Waterbound/Drybound Macadam (WBM - DBM)

S-04: Hand Packed Stone (HPS)

S-05: Stone Setts or Pavé (SSP and MSSP)

S-06: Mortared Stone (MS)

S-07: Dressed stone/cobble stone (DS, CS, MDS, MCS)

Fired Clay Brick

S-08: Unmortared/mortared joints (CB, MCB)

Bituminous

S-09: Sand Seal

S-10: Slurry Seal

S-11: Chip Seal

S-12: Cape Seal

S-13: Otta Seal

Concrete

S-14: Non-reinforced concrete (NRC)

An outline description of the above surfacing types is presented in the following pages. Many of the paving and surfacing techniques have beneficial attributes with regard to good use of local resources and labour based methods. Some of the options have low energy and carbon footprint attributes with low levels of imported components. The surface options vary significantly in their maintenance liability attributes, which must be an important consideration in the design process.

7.1.2 Basic surfacings

S-01: Engineered Natural Surface (ENS)

An Engineered Natural Surface using the compacted in situ soil at the road location to form a basic surface for traffic. Essential provisions are a compacted camber (4-6%), side drains and an effective drainage system. Typically soils with an in service CBR of a minimum of about 15% or more can provide a year round running surface for light motor traffic. Route sections with steep gradients, or weak or problematic soils can be improved in situ by upgrading to higher standard surface under a spot improvement or EOD strategy to improve their traffic carrying capacity throughout the year.

S-02: Natural Gravel

One or more layers of natural gravel placed directly on the existing shaped earth formation and compacted with an appropriate surface camber (typically 4-6%). The layers could be mechanically stabilised or blended with other material to improve the material properties.

7.1.3 Stone paving

These are a number of proven techniques to use natural stone to provide satisfactory paving for LVRs.

S-03: Waterbound/Drybound Macadam

A Macadam layer essentially consists of a stone skeleton of single sized coarse aggregate in which the voids are filled with finer material. The stone skeleton, because of its single size large material will contain considerable voids but will have the potential for high shear strength if confined properly. The stone skeleton forms the “backbone” of the macadam and is largely responsible for the strength of the constructed layer. The material used to fill the voids provides lateral stability to the stone skeleton but adds little bearing capacity.

In Waterbound Macadam (WBM) the aggregate fines are washed or slushed into the coarse skeleton with water. Dry-bound macadam is a similar technique to the original WBM, however instead of water and deadweight compaction being used in the consolidation of fine material, a vibrating roller is used. The development of small vibrating rollers has made the use of this technique attractive for labour based rural road works in some locations.

WBM or DBM are commonly used as layers within a sealed flexible pavement, but in the appropriate circumstances may be used as an unsealed option with a suitably cohesive material being used as the fines component. The WBM or DBM may be constructed as a low cost, initial surface to be later sealed and upgraded in a ‘stage construction’ strategy.

S-04: Hand-packed stone

Hand Packed Stone is a proven labour based technique. The surfacing consists of a layer (typically 150 – 300 mm thick) of large broken stones pieces, laid by hand and tightly packed together and wedged in place with smaller stone chips rammed by hand into the joints using hammers and steel rods. The remaining voids are filled with sand. The Hand Packed Stone is normally bedded on a thin layer of sand or gravel. For use by heavy traffic, the layer should be compacted with a vibrating or heavy non-vibrating roller. An edge restraint or kerb constructed of large or mortar jointed stones improves durability and lateral stability.

S-05: Stone setts or pavé

Stone sett surfacing or Pavé is an historically well-established labour based technique that has been adapted successfully as a robust option on low volume rural roads where there is a good local supply of suitable stone. It consists of a layer of roughly cubic (100mm) stone setts laid on a bed of sand or fine aggregate within mortared stone or concrete edge restraints (kerbs). The individual stones should have at least one face that is fairly smooth, to be the upper or surface face when placed. Each stone sett is adjusted with a small (mason's) hammer and then tapped into position to the level of the surrounding stones. Sand or fine aggregates is brushed into the spaces between the stones and the layer then compacted with a roller.

S-06: Mortared stone

Mortared Stone Paving is another labour based technique that consists of a layer of natural selected stones, laid on a bed of loose sand or fine aggregate with the joints filled with sand–cement mortar. The stones do not need to be dressed to a regular shape. The individual stones should have at least one face that is fairly smooth and even, to be the upper or surface face when placed. Stone size is typically from 100 – 300mm. The bedding sand around each stone is adjusted with a small hammer and the stone is then tapped into position and to the final level of the surrounding stones. Sand–cement mortar and small stones are used to fill the joints between the individual stones. When the mortar has set the layer should be covered in sand or other moisture retaining material and kept wet for a few days to aid curing. Mortared Stone paving should not be trafficked until 7 days after laying.

S-07: Dressed stone/cobble stone paving

Dressed or Cobble Stone Paving has been used for centuries as a strong, durable road surface using labour based methods. The technique is similar to Stone Setts or Pavé, however the individual stones are larger; normally of size 100 – 300mm. They are cut from suitable hard rock and 'dressed' manually to a cubic shape with a smooth, flat finish on at least one face using hammers and chisels. The dressed stones are laid on a bedding sand layer (20 – 70mm) and tapped into final position with a hammer. Sand is brushed into the joints between the stones. Temporarily covering with loose sand and compacting with a heavy roller can improve durability. The excess sand is removed after compaction. An edge restraint or kerb constructed (for example) of large or mortared stones is required for durability. Sand-cement mortar joints and bedding can be used to improve durability and prevent water penetrating to moisture susceptible foundation layers and weakening them.

7.1.4 Fired clay brick

S-08: Fired clay brick - unmortared or mortared joints

Bricks suitable for road surfacing can be produced by firing clay in large or small scale kilns using coal, wood or some agricultural wastes as a fuel. The bricks must achieve certain strength, shape and durability requirements. The fired bricks are generally laid on edge to form a layer of typical 100mm thickness on sand or sand-cement bedding layer and jointed similarly. Kerbs or edge restraints are necessary and can be provided by sand-cement bedded and mortared fired bricks. The fired bricks are normally laid in a herring bone or other approved pattern to enhance load spreading characteristics. Un-mortared brick paving is compacted with a plate compactor and the jointing sand is topped up if necessary. For mortar-bedded and jointed-fired clay brick paving, no compaction is required. When the mortar has set the layer should be covered in sand or other moisture retaining material and kept wet for a few days to aid curing. If mortared bedding and jointing are used the surface should not be trafficked until 7 days after laying.

7.1.5 Bituminous surfacings

Bituminous surfacings or surface treatments generally comprise an admixture of different proportions of stone or sand, and bitumen. The bitumen may be a penetration grade, cutback or emulsion (the last being particularly suitable for labour based methods of construction as heating is avoided; or for small scale works). The bituminous surfacings usually require good quality, screened or crushed stone or sand, but lower quality aggregate may be used for some types of seals (e.g. Otta Seal).

An effective bond between the surface treatment and the surface of the roadbase is essential for good performance. This can be achieved through the use of an appropriate grade of bitumen (the prime or prime coat) before the start of construction of the surface treatment.

Some typical types of bituminous surface treatment are shown in Figure 7.1.

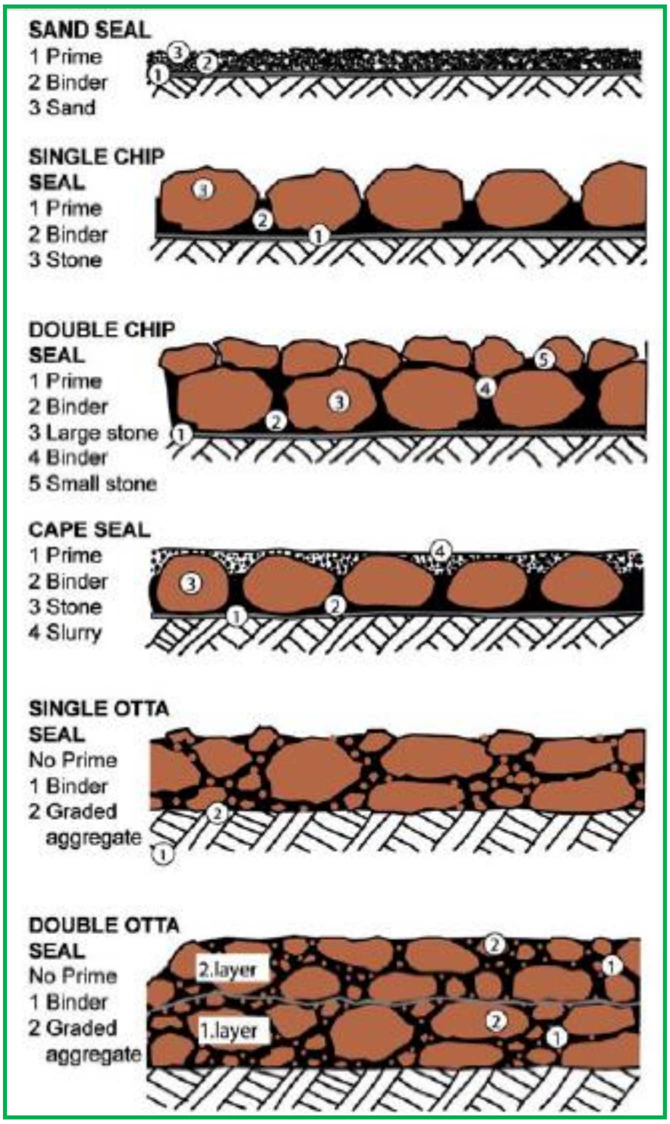


Figure 7.1: Examples of typical bituminous surface treatments

S-09: Sand seal

This seal consists of a spray of bituminous binder followed by the application of a coarse, clean sand or crusher dust as aggregate. This surfacing is used on low-volume roads, especially in drier regions, but can also be used for maintenance resealing, or for temporary by-passes or diversions. Single sand seals are generally not a recommended option. For new construction, two layers are usually specified as single layers tend not to be durable. There is an extended curing period (typically 8 – 12 weeks) between the first and second seal applications to ensure complete loss of volatiles from the first seal and thus minimise the risk of bleeding.

S-10: Slurry seal

A Slurry Seal consists of a homogeneous mixture of pre-mixed materials comprising fine aggregate, stable-mix grade emulsion (anionic or cationic) or a modified emulsion, water and filler (cement or lime). The production of a slurry can be undertaken in simple concrete mixers and laid by hand, or more sophisticated purpose-designed machines which mix and spread the slurry.

Slurry Seals can be used for treating various defects on an existing road surface carrying relatively low traffic for which the following are typical applications:

- Arrest loss of chippings;
- Restore surface texture;
- Reduce unevenness because of bumps, slacks and/or ruts;
- Rectify low activity surface cracking;
- New construction as a grout seal following a single Chip Seal or in multiple layers directly on the roadbase of low traffic roads;
- A component of a Cape Seal.

S-11: Chip seal

This seal (single or double) consists of a spray(s) of bituminous binder followed by the application of a layer(s) of aggregate (stone chippings). The binder acts as a waterproofing seal preventing entry of surface water into the road structure while the chippings protect this film from damage by vehicle tyres.

Chip Seals can be used for a number of purposes, including:

- New construction (normally double surface dressings only);
- Temporary by-passes or diversions (normally single surface dressings);
- Maintenance resealing (normally single surface dressing);
- First layer of a Cape Seal.

S-12: Cape seal

A Cape Seal consists of a single 13mm or 19mm aggregate, penetrated with a binder and covered with a slurry seal. If 19mm aggregate is used, the slurry is applied in two layers. The function of the slurry is to provide a dense void filler to enhance the stability of the single-sized coarse aggregate layer. The coarse aggregate is left proud to provide the macro texture for skid resistance.

S-13: Otta seal

An Otta Seal is a sprayed bituminous surfacing comprising a mixture of graded aggregates ranging from natural gravel to crushed rock with relatively soft (low viscosity) binder, with or without a sand cover seal. This type of seal contrasts with the single sized crushed aggregate and relatively hard (high viscosity) binders used in Chip seals. Otta seals can be single or double (two layers).

Otta Seals can be used for a variety of purposes, including:

- New construction (single or double Otta Seals with/without sand seal);
- Temporary seal (normally single Otta Seal - diversions, haul roads, temporary accesses, etc.);
- Maintenance reseal (normally single Otta Seal).

Performance characteristics of Bituminous Seals

The mechanism of performance of surface treatments varies in relation to the composition of their constituents as illustrated in Figure 7.2 and described below.

Type A: (e.g. sand seal and Otta seal):

These seal types, like hot-mix asphalt, rely to varying extents on a combination of mechanical particle interlock and the binding effect of bitumen for their strength. Early trafficking and/or heavy rolling are necessary to develop the relatively thick bitumen film coating around the particles. Under trafficking, the seal acts as a stress-dispersing mat comprising the bitumen/aggregate mixture.

Type B: (e.g. ship seal, cape seal):

These seal types rely on the binder to “glue” the aggregate particles to the roadbase. Where shoulder-to-shoulder contact between the stones occurs, some mechanical interlock is mobilised. Under trafficking, the aggregate is in direct contact with the tyre and requires relatively high resistance to crushing and abrasion to disperse the stresses without distress.

Figure 7.2: Differing mechanisms of performance of surface treatments

Typical service lives

The life of a bituminous surfacing treatment can vary widely in relation to a number of factors as indicated below:

- **Climate:** Very high temperatures cause rapid binder hardening through accelerated loss of volatiles, while low temperatures can lead to brittleness of the binder leading to cracking or aggregate loss resulting in reduced surfacing life.
- **Pavement strength:** Lack of underlying pavement stiffness will lead to fatigue cracking and reduced surfacing life.
- **Base materials:** Unsatisfactory roadbase performance and absorption of binder into certain base materials (e.g. pedogenic materials) will lead to reduced surfacing life.
- **Binder durability:** The lower the durability of the binder, the higher the rate of its hardening, and the shorter the surfacing life.
- **Design and construction of surfacing:** Improper design and poor construction techniques (e.g. inadequate prime, uneven rate of binder application or ‘dirty’ aggregates) will lead to reduced surfacing life.
- **Traffic:** The higher the volume of heavy traffic the shorter the surfacing life.
- **Stone polishing:** The faster the polishing of the stone, the earlier the requirement for resurfacing.

Typical service lives of bituminous surface treatments are given in Table 7.1.

Table 7.1: Typical bituminous surfacing service lives [(1)]

Type of surfacing	Typical service life (years)
Double sand seal (DSS)	3 - 6
Slurry seal (SIS)	2 - 4
Single chip seal (SCS)	3 - 5
Double chip seal (DCS)	7 - 10
Single Otta seal (SOS)	6 - 10
Single Otta seal plus sand seal (SOS+SS)	8 - 12
Cape seal (13mm + single slurry) (CS13)	6 - 10
Cape seal (19mm + double slurry) (CS19)	8 - 14
Double Otta seal (DOS)	12 - 16

Note

1. Assumes that timeous routine and periodic maintenance are carried out.

Factors affecting choice of bituminous surface treatments

The various factors affecting the choice of surface treatments in relation to the operational requirements are indicated in Table 7.2.

Table 7.2: Selected factors affecting choice of bituminous surface treatments

Parameter	Degree	Type of Surfacing						
		SS	SIS	SCS	DCS	CS	SOS+ SS	DOS
Service life required (years)	Short (<5)	✓	✓	✓	?	?	?	?
	Medium (5-10)	X	X	X	✓	✓	✓	?
	Long (>10)	X	X	X	?	?	?	✓
Traffic level (AADT)	Light (<100)	✓	✓	✓	?	?	?	?
	Medium (100-300)	X	X	X	✓	✓	✓	?
	Heavy (>300)	X	X	X	✓	✓	✓	✓
Impact of traffic turning action	Low (no trucks)	✓	✓	✓	?	?	?	?
	Medium (trucks)	X	X	X	✓	✓	✓	?
	High (3-axle trucks)	X	X	X	?	?	?	✓
Gradient	Mild (<5%)	✓	✓	✓	✓	✓	✓	?
	Moderate (5-10%)	X	X	X	✓	✓	✓	?
	Steep (>10%)	X	X	X	✓	✓	✓	✓
Material Quality	Poor	X	X	X	X	X	✓	✓
	Moderate	?	?	?	?	?	✓	✓
	Good	✓	✓	✓	✓	✓	?	?

Existing pavement and base quality	Poor	X	X	X	?	?	?	✓
	Moderate	?	?	?	✓	✓	✓	✓
	Good	✓	✓	✓	✓	✓	✓	✓
Suitable for labour-based methods		✓	✓	✓	✓	✓	X	X
Contractor experience/ capability	Low	?	?	X	X	X	✓	✓
	Moderate	✓	?	?	?	?	✓	✓
	High	✓	✓	✓	✓	✓	✓	✓
Maintenance capability	Low	X	X	X	X	X	✓	✓
	Moderate	X	X	X	✓	✓	✓	✓
	High	✓	✓	✓	✓	✓	✓	✓

Key

✓	**Suitable/preferred**	?	OK, but maybe not optimal	X	Not suitable/applicable
SS	Sand seal	**SIS**	Slurry seal	**SCS**	Single chip seal
DCS	Double chip seal	**CS**	Cape seal	**SOS**	Single Otta seal
DOS	Double Otta seal				

The final choice of a surface treatment should be based on the Surfacing Decision Management System (SDMS) described in Section 7.2 of this Chapter and a life-cycle cost analysis in which the various factors discussed above, as well as the service life of the treatment, should all be taken into account.

7.1.6 Concrete surfacing

Non-reinforced concrete slab surfacing

Un-reinforced or reinforced cement concrete slab pavements can be used to provide a high strength, durable road surface with very low maintenance requirements. The concrete must have a minimum strength of 20MPa. Joints are required to accommodate thermal expansion and contraction and particular care is required to construct them properly. When the concrete has set the layer should be covered in sand or other moisture retaining material and kept wet for a few days to aid curing. Concrete surfaces should normally not be trafficked until 7 days after casting.

Reinforced concrete slab paving: It will be difficult to justify normal reinforced concrete paving for LVRs, so that design of such pavements is not included in this Manual.

Concrete brick paving: Concrete brick or block paving (including the use of geo-cell on-site formers) may be used for LVR roads and design and construction requirements are similar to Fired Clay brick incremental paving.

7.2 Choice of Pavement and Surfacing

The various factors that typically affect the choice of a paving and surfacing can be grouped under the following headings:

- Available materials;

- Operational environment;
- Road task;
- Natural environment.

These factors are illustrated in Figure 7.3.

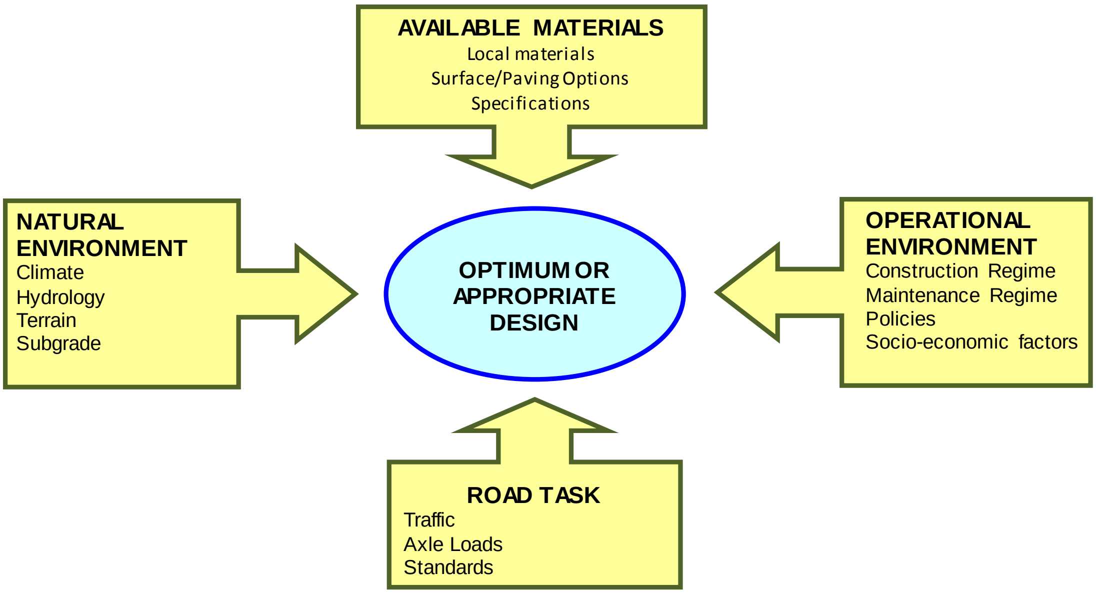


Figure 7.3: General Road Surface selection factors

The final selection of surfacing should then be made on the basis of life-cycle costing.

7.2.1 Evaluation framework

A rational method is required for the selection of the most appropriate surface or paving structure for a particular section of low volume rural or urban road. The Surfacing Decision Management System (SDMS) provides such a procedure for assessing the various factors that influence the suitability of surface-paving options for a specific section of rural road. When ENS or natural gravel are considered to be unsuitable options, the separate Matrices of Surfacing and Paving Options (Tables 7.5 to 7.8) will further guide the user to identify the most appropriate options.

The key objective is the elimination of unsuitable or high risk options using a series of road environment related “screens” before proceeding to Final Engineering Design (FED) for the surfacing/paving and their Whole Life Costing. Figure 7.4 shows the basic steps in the SDMS procedure.

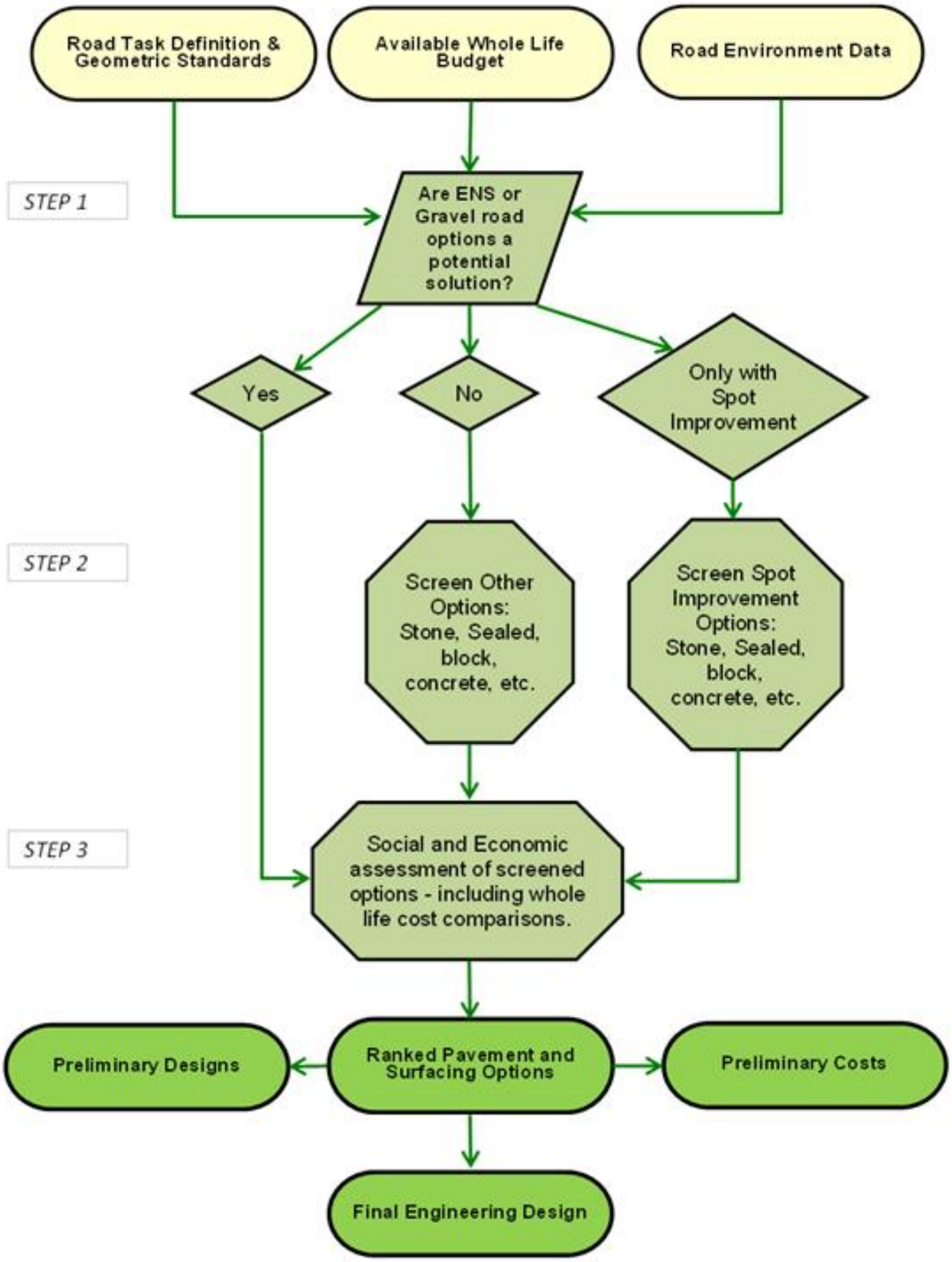


Figure 7.4: Overview of the SDMS procedure

7.2.2 SDMS Procedure

Step 1 of the three-step SDMS procedure is illustrated in Figure 8.5 while each of the explanatory sheets (Sheets 1-3) supporting the sequential activities are presented in Figures 7.6 to 7.8.

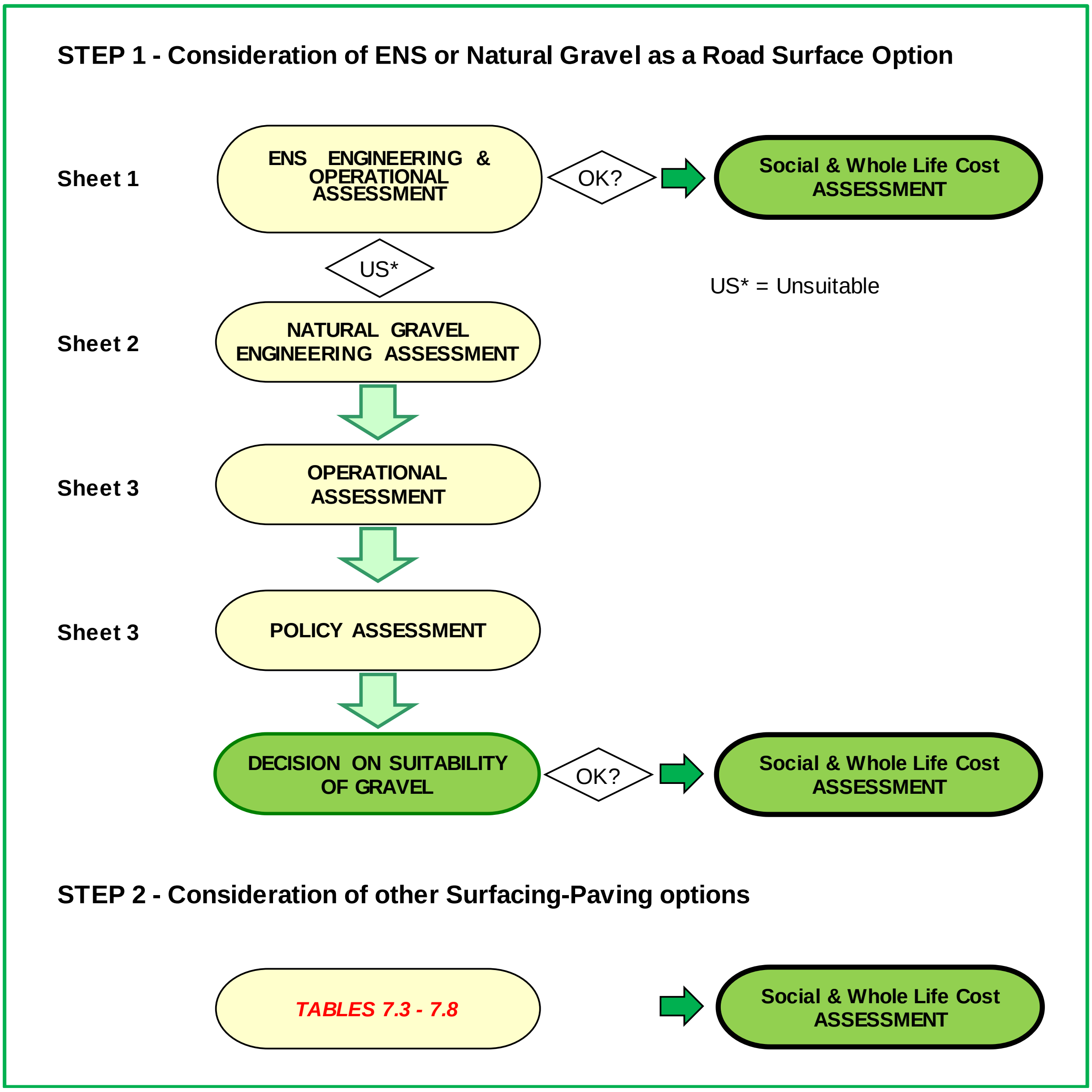


Figure 7.5: Overview of SDMS procedure

SHEET 1 - Assessment of Suitability and Engineered Natural Surface - ENS (Engineered Earth Road) as a feasible option

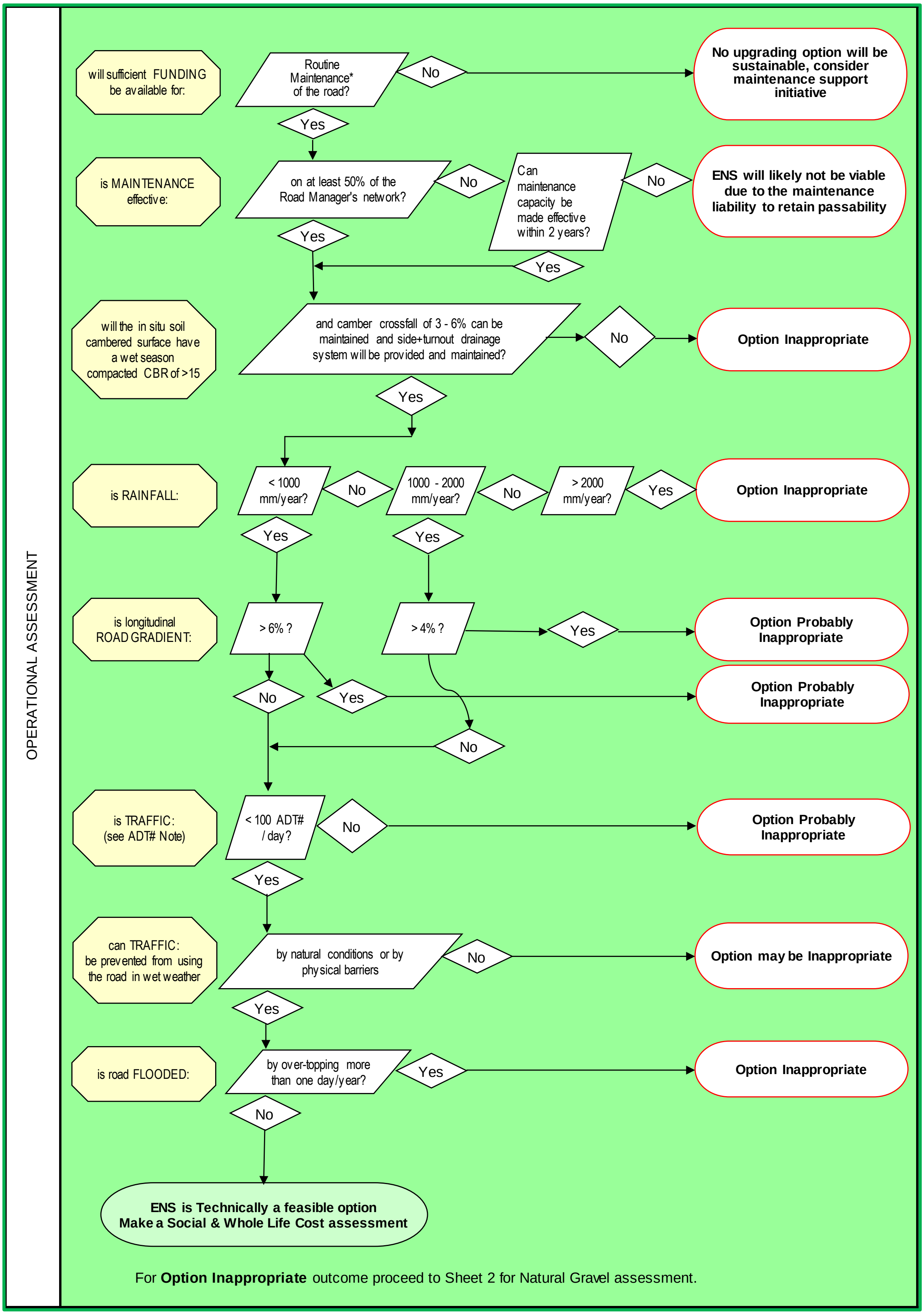


Figure 7.6: Decision flow chart for the preliminary consideration of LVR surface options for a road section – STEP 1

SHEET 2 - Engineering Assessment of Natural Gravel Surface Option

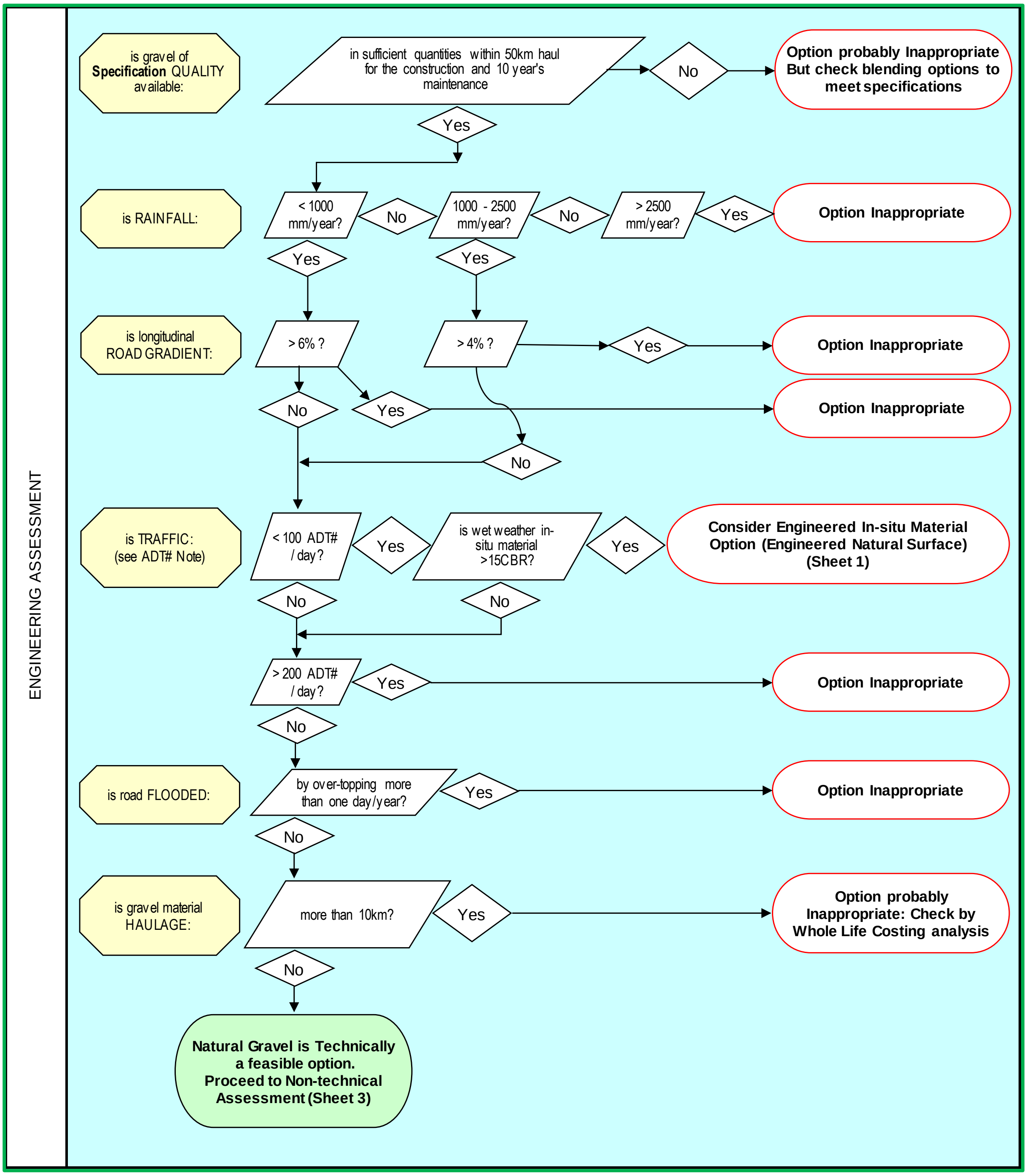


Figure 7.7: Decision flow chart for the preliminary consideration of LVR surface options for a road section – Step 1 continued

SHEET 3 - Operational, Socio-economic and Economic Assessment of Natural Gravel as a surface option.

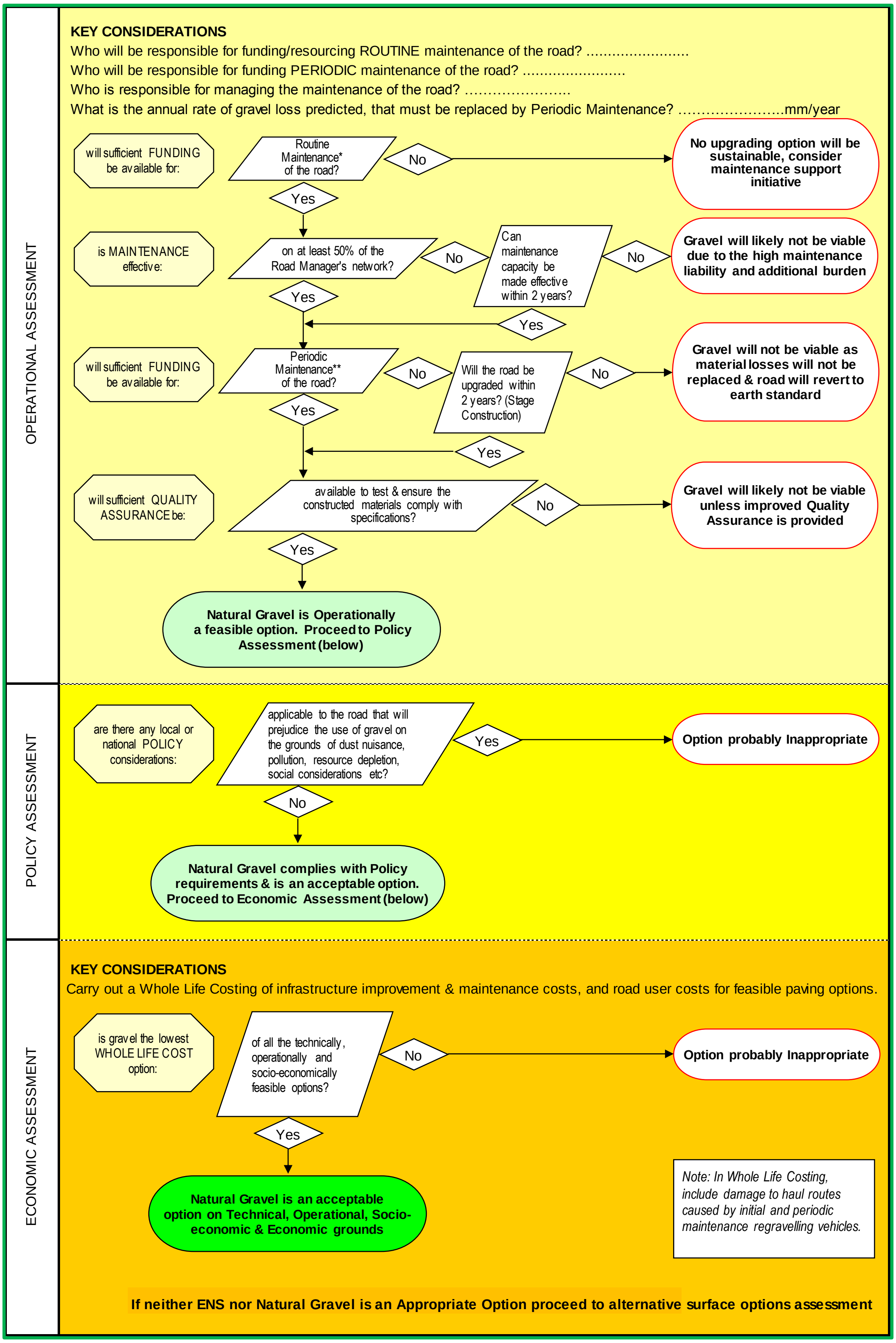


Figure 7.8: Decision flow Cchart for the preliminary consideration of LVR surface – Step 1 continued

Step 2 involves the consideration of surfacing/paving options (S-01 to S-14) as listed in Section 7.1.1.

If the Step 1 assessment indicates that neither ENS nor Natural Gravel are viable options for a particular road section, then the assessment should proceed to the 'screening' process (see Tables 7.5 to 7.8) to select a shortlist of appropriate and viable surface and/or paving options based on the evaluation criteria included in these tables.

In the screening process the Tables 7.3 and 7.4 set out the evaluation criteria in terms of indicative traffic regime and erosion potential.

Table 7.3: Definition of indicative traffic regime

Indicative Category	Traffic Description
Light	Mainly non-motorised, pedestrian and animal modes, motorbikes & less than 25 motor vehicles per day, with few medium/heavy vehicles. No access for overloaded vehicles. Typical of a Rural Road with individual axle loads up to 2.5 tonne.
Moderate	Up to about 100 motor vehicles per day including up to 20 medium (10t) goods vehicles, with no significant overloading. Typical of a Rural Road with individual axle loads up to 6 tonne.
High	Between 100 and 300 motor vehicles per day. Accessible by all vehicle types including heavy and multi-axle (3 axle +) trucks, Construction & timber materials haulage routes. Specific design methodology to be applied.

Table 7.4: Definition of erosion potential

Road alignment longitudinal gradient	Annual Rainfall (mm)			
	< 1000	1000 - 2500	2500 - 4000	>4000
Flat (< 1%)	A	A	B	C
Moderate (1-3%)	A	B	B	C
High (3-6%)	B	C	C	D
Very High (>6%)	C	C	D	D
A = Low; B = Moderate; C High; D = Very High				

Note:

1. Areas prone to regular flooding should be classed as "High Risk" irrespective of rainfall.

In the following Tables

✓	**Indicates suitable for evaluation**	●	Mortared

Note: Cost ratings are indicative only and will depend on local factors.

Table 7.5: Preliminary engineering filter - surfacing

PAVING CATEGORY	BASIC		STONE					BR	BITUMEN					CONC	
	Engineered Natural Surface	Gravel Surface	Waterbound/Drybound Macadam	Hand Packed Stone	Stone Setts or Pavé	Mortared Stone	Dressed Stone/Cobble Stone	Fired Clay Brick Pavement: Un-/mortared Joints	Bituminous Sand Seal	Bituminous Slurry Seal	Bituminous Chip Seal	Cape Seal	Ottaseal	Non-Reinforced Concrete	
Economically available Materials	S01	S02	S03	S04	S05	S06	S07	S08	S09	S10	S11	S12	S13	S14	
Crushed stone aggregate			✓	✓						✓	✓	✓		✓	
Stone pieces/blocks				✓	✓	✓	✓								
Natural gravel		✓											✓		
Colluvial/alluvial gravel		✓											✓		
Weathered rock		✓													
Fired clay bricks								✓							
Clay soil								✓							
Sand					✓	✓	✓	✓	✓	✓				✓	
Cement						✓		●						✓	
Lime										✓					
Bitumen									✓		✓	✓	✓		
Bitumen Emulsion									✓	✓	✓	✓			

Table 7.6: Preliminary engineering filter - pavement layers / shoulders

PAVING CATEGORY	BASES							SUB-BASES						SHOULDERS			
	Waterbound macadam	Drybound macadam	Natural gravel	Armoured gravel	Cement stabilised soil	Lime stabilisede soil	Emulsion s tabilised soil	Waterbound macadam	Drybound macadam	Natural gravel	Cement stabilised soil	Lime stabilisede soil	Emulsion stabilised soil	Stone macadam	Natural gravel	Cement stabilised soil	Lime stabilisede soil
Economically available Materials																	
Crushed stone aggregate	✓	✓		✓				✓	✓					✓			
Stone pieces/ blocks																	
Natural gravel			✓	✓						✓					✓		
Colluvial/alluvial gravel			✓	✓						✓					✓		
Weathered rock			✓	✓						✓					✓		
Fired clay bricks																	
Clay soil						✓						✓					✓
Sand					✓		✓				✓		✓			✓	
Cement					✓						✓					✓	
Lime						✓						✓					✓
Bitumen																	
Bitumen Emulsion							✓						✓				

Table 7.7: Secondary engineering filters – surfacing

PAVING CATEGORY	BASIC		STONE					BR			BITUMEN					CONC
	Engineered Natural Surface	Gravel Surface	Waterbround/Drybound Macadam	Hand Packed Stone	Stone Setts or Pavé	Mortared Stone	Dressed Stone/Cobble Stone	Fired Clay Brick Pavement: Un-/mortared Joints	Bituminous Sand Seal	Bituminous Slurry Seal	Bituminous Chip Seal (single)	Bituminous Chip Seal (double)	Cape Seal	Ottaseal (single)	Ottaseal (double)	Non-Reinforced Concrete
Traffic Regime: See Table 8.3	S01	S02	S03	S04	S05	S06	S07	S08	S09	S10	S11	S11	S12	S13	S13	S14
Light traffic	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Moderate traffic		✓	✓	✓	✓	✓	✓	✓				✓	✓	✓	✓	✓
Heavy traffic (overload risk)					✓		✓					✓			✓	✓
Construction Regime																
High labour content	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			✓
Intermediate machinery	✓	✓	✓	✓					✓	✓	✓	✓	✓			✓
Low cost	✓	✓		✓					✓	✓	✓					
Moderate cost			✓		✓	✓		✓				✓	✓	✓		
High cost							✓								✓	✓
Maintenance Requirement																
Low					✓	✓	✓	✓								✓
Moderate				✓					✓	✓	✓	✓	✓	✓	✓	
High	✓	✓	✓													
Erosion Regime (See Table 8.4)																
A: low erosion regime	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
B: Moderate erosion regime				✓	✓	✓	✓	✓				✓	✓	✓	✓	✓
C: High erosion regime					✓	✓	✓							✓	✓	
D: Very high erosion regime					✓	✓	✓							✓	✓	

Table 7.8: Secondary engineering filters - pavement layers / shoulders

	BASES							SUB-BASES						SHOULDERS				
	Waterbound macadam	Drybound macadam	Natural gravel	Armoured gravel	Cement stabilised soil	Lime stabilisede soil	Emulsion stabilised soil	Waterbound macadam	Drybound macadam	Natural gravel	Cement stabilised soil	Lime stabilisede soil	Emulsion stabilised soil	Stone macadam	Natural gravel	Cement stabilised soil	Lime stabilisede soil	Sealed
Traffic Regime: See Table 8.3																		
Light traffic	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓					✓
Moderate traffic	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓					
Heavy traffic (overload risk)	✓	✓						✓	✓	✓	✓							
Construction Regime																		
High labour content	✓	✓						✓	✓					✓				
Intermediate machinery	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Low cost			✓	✓						✓					✓			
Moderate cost	✓	✓			✓	✓		✓	✓		✓	✓		✓		✓	✓	✓
High cost							✓						✓					
Maintenance Requirement																		
Low	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓					✓
Moderate							✓							✓		✓	✓	
High															✓			
Erosion Regime (See Table 8.4)																		
A Low erosion regime														✓	✓	✓	✓	✓
B Moderate erosion regime														✓				✓
C High erosion regime																		✓
D Very high erosion regime																		✓

7.2.3 Design of bituminous surfacing

The design of a particular type of surface treatment is usually project specific and related to such factors as traffic volume, climatic conditions, available type and quality of materials. Various methods of design have been developed by various authorities for the design of surface treatments. The approach to the design of surface treatments given in this section is generic, with the objective of presenting typical binder and aggregate application rates for planning or tendering purposes only. Where applicable, reference has been made to the source document for the design of the particular surface treatment which should be consulted for detailed design purposes.

Prime coat

This is used to provide an effective bond between the surface treatment and the existing road surface or underlying pavement layer and is essential for good performance of a bituminous surfacing. This generally requires that the non-bituminous road surface or base layer must be primed with an appropriate grade of bitumen before the start of construction of the surface treatment.

Typical primes are:

1. **Bitumen primes:** Low viscosity, medium curing cutback bitumens such as MC-30, MC-70, or in rare circumstances, MC-250, can be used for prime coats.
2. **Emulsion primes:** Bitumen emulsion primes are not suitable for priming stabilised bases as they tend to form a skin on the road surface and to not penetrate this surface.
3. **Tar primes:** Low-viscosity tar primes such as 3/12 EVT are suitable for priming road surfaces but are no longer in common use because of their carcinogenic properties which are potentially harmful to humans and the environment.

The choice of prime depends principally on the texture and density of the surface being primed. Low viscosity primes are necessary for dense cement or lime stabilised surfaces while higher viscosity primes are used for untreated, coarse-textured surfaces. Emulsion primes are not recommended for saline base courses.

The grade of prime and the nominal rates of application to be used on the various types of pavements are given in Table 7.9.

Table 7.9: Typical prime application rates in relation to pavement surface type

Pavement surface	Prime	
	Grade	Rate of application (l/m^2)
Tightly bonded (light primer)	MC-70	0.6 – 0.7
Medium porosity (medium primer)	MC-30 / MC-70	0.7 – 0.8
Porous (heavy primer	MC-30	0.85 – 1.1

Sand seal (S-09)

Design: There are no formal methods for the design of sand seals with the binder and aggregate application rates being based on local experience.

Materials: Typical constituents for sand seals are:

- Binder: The following grades of binder are typically used:
  - MC-800 cut-back bitumen;
  - MC-3000 cut-back bitumen;
  - Spray-grade emulsion (65% or 70% of net bitumen);
  - 150/200 penetration grade bitumen.
- Aggregate: The grading of the sand may vary to a fair degree, but the conditions of Table 7.10 must be met.

Table 7.10: Grading of sand for use in sand seal

Sieve size (mm)	Percentage by mass Passing through sieve
6.7	100
0.300	0 – 15
0.150	0 - 2
Sand equivalent (%): 35 Min	

Application rates: For planning or tender purposes, typical binder and aggregate application rates for sand seals are given in Table 7.11.

Table 7.11: Binder and aggregate application rates for sand seals

Application	Hot spray rates of MC3000 cut-back Bitumen (l/m^2)	Aggregate application rate (m^3/m^2)
Double sand seal used as a permanent seal	1.2 – 1.4 per layer	0.010 – 0.012 per layer
Single sand seal used as a cover seal over an Otta Seal or Surface Dressing	0.8 – 1.0	0.010 – 0.012
Single seal used as a maintenance remedy on an existing surfaced road	1.0 – 1.2	0.010 – 0.012

Slurry seal (S-10)

Design: The design of a Slurry Seal surfacing is based on semi-empirical methods or experience with the exact proportions of the mix being determined by trial mixes for which the following guidelines may be used:

Materials: The typical composition of a slurry is as follows:

- Filler should be between 1% and 2% of the mass of fine aggregate;
- Undiluted Bitumen Emulsion should be approximately 20% by weight of fine aggregate.

Application rates: For planning or tender purposes, the typical composition of the slurry may be based on the mass proportions indicated in Table 7.12.

Table 7.12: Nominal slurry seal mix components

Material	Proportion (Parts)
Fine aggregate (dry)	100
Cement (or lime)	1.0 – 1.5
60% Stable grade emulsion	20
Water	+/- 15

Chip seal (S-11)

Design: The design methods for both single and double chip seals are presented in Overseas Road Note 31 (2nd edition): *A guide to surface dressing in tropical and sub-tropical countries*. In essence, the design is based the concept of partially filling the voids in the covering aggregate and that the volume of these voids is controlled by the Average Least Dimension (ALD) of the sealing chips. Corrections to the spray rate need to be subsequently carried out to take account of site conditions as described in the guide.

Materials: Typical constituents for chip seals are:

- Binder: The bituminous binder can consist of any of the following:
    - 80/100 or 150/200 penetration grade bitumen;
    - MC 3000 grade cutback bitumen;
    - spray grade anionic (60) or cationic (65 or 70);
    - Modified binders (polymer modified and bitumen rubber);
    - Foamed bitumen.
- Aggregate: The aggregate for a Chip Seal shall be durable and free from organic matter or any other contamination. Typical grading requirements for Chip Seals are given in Table 7.13.

Table 7.13: Aggregate requirements for bituminous chip seals

Sieve Size (mm)	Nominal Aggregate Size (mm)			
	19.0	**13.2**	**9.5**	**6.7**
	Grading (%passing)			
26.5	100			
19.0	85 - 100	100		
13.2	0 - 30	85 – 100	100	
9.5	0 - 5	0 – 30	85 - 100	100
6.7	-	-	0 - 5	0 - 40
4.75	-	-	0 - 5	0 - 40
2.36	-	-	-	0 - 5
0.425 (fines)	< 0.5	< 0.5	< 0.5	< 2.0
0.075 (dust)	< 0.5	< 0.5	< 0.5	< 1.0
Materials Properties				
Flakiness Index	Max 20	Max 25	Max 25	Max 30
10% FACT (dry)	AADT > 1000vpd: Min 160kN ; AADT < 1000vpd: 120kN			
10% (wet)	Min 75% of corresponding 10% FACT dry			

Application rates: For planning purposes, typical binder and aggregate application rates for single bituminous Chip Seals are given in Table 7.14.

Table 7.14: Binder and application rates for chip seals

Item	Double Chip Seal		Single Chip Seal (Reseal)	
	2nd 9.5 mm 1st 19.0 mm	2nd 6.7 mm 1st 13.2 mm	13.2 mm	9.5 mm
Aggregate spread rates (m^3/m^2)				
2nd layer	0.09	0.007		
1st layer	0.015	0.011	0.012	0.010
Hot spray rates of 80/100 pen grade bitumen (l/m^2)				
Traffic AADT < 200	3.0 (total)	2.3 (total)	1.6	1.3
Traffic AADT 200 - 1000	2.5 (total)	1.9 (total)	1.3	1.0

Note: *See also Table 7.15*

Conversions from hot spray rates in volume (litres) to tonnes for payment purposes must be made for the bitumen density at a spraying temperature of 180^{o}C. For planning purposes, a hot density of 0.90 kg/l should be used until reliable data for the particular bitumen is available.

Adhesion agents: The success of a bituminous seal depends not only upon the strength of the two main constituents – the binder and the aggregate – but also upon the attainment of adhesion between these materials - a condition that is sometimes not achieved in practice. In such a case a proprietary adhesion agent could be used to facilitate the attainment of a strong and continuing bond between the binder and the aggregate. The agent can be used in the aggregate pre-coating material (see below), in the binder or in both.

Precoating agents: Surfacing aggregates are often contaminated with dust on construction sites and, in that condition, the dust tends to prevent actual contact between the aggregate and the binder. This prevents or retards the setting action of the binder which results in poor adhesion between the constituents. This problem can be overcome by sprinkling the aggregate with water or, alternatively, by using an appropriate pre-coating material which increases the ability of the binder to wet the aggregate and improve adhesion between binder and aggregate.

A number of materials may be used for pre-coating aggregates including diesel fuel oil, cutback bitumen, bitumen pre-coating emulsion and proprietary products.

Cape seal (S-12)

Design: As a combination single seal + slurry seal, the design of a Cape Seal is similar to that for a Chip Seal and Slurry Seal as described above.

Materials: Typical constituents for Cape Seals are:

- Binder: As is the case with Chip Seals, a variety of binder types may be used for constructing a Cape Seal;
- Aggregate: The same requirements are required as for Chip Seals and Slurry Seals.

Application rates: For planning purposes, typical binder and aggregate application rates for single Chip seals are given in Table 7.15.

Table 7.15 Nominal bituminous chip seal application rates

Nominal size of aggregate (mm)	Nominal rates of application For planning / tender purposes	
	Binder (litres of net Bitumen cold per m^2)	Aggregate (m3/m2)
13.2	1.4	0.009
19.0	1.6	0.014

Otta seal (S-13)

General Design Principles: The design of the Otta Seal relies on an empirical approach in terms of the selection of both an appropriate type of binder and an aggregate application rate. Full details of the design methods are given in the *Botswana Guideline No. 1: The Design, Construction and maintenance of Otta Seals (1999).*

As a general guide, the choice of binder in relation to traffic and aggregate grading is given in Table 7.16.

Table 7.16: Choice of Otta Seal binder in relation to traffic and grading

AADT (vpd) at time of construction	Type of Bitumen		
	Open Grading	Medium Grading	Dense Grading
> 1000	N/A	150/200 pen. Grade	MC 3000 MC 800 in cold weather
100 - 1000	150/200 pen. grade	150/200 pen. Grade In cold weather	MC 3000 MC 800 in cold weather
< 100	150/200 pen. grade	MC 3000	MC 800

For design purposes, preferred grading in relation to traffic.

Application Rates: The following Application rates for binder and aggregates are recommended:

- Binder: As a general guide, Table 7.17 gives the hot spray rates for primed base courses.

Table 7.17: Nominal binder application rates for Otta seals (l/m^2)

Type of Otta seal	Grading			
	Open	Medium	Dense	
			AADT < 100	AADT > 100
Double 1st Layer 2nd Layer	 1.7 1.6	 1.8 1.4	 1.8 2.0	 1.7 1.9
Single with Sand Cover Seal 1st Layer Fine Sand Crusher Dust/Coarse River Sand	 1.7 0.8 0.9	 1.8 0.7 0.8	 2.0 - -	 1.9 0.9 0.7
Single	1.8	1.9	2.1	2.0
Maintenance Reseal (Single)	1.7	1.8	2.0	1.8

The following points should be noted with regard to the binder application rates:

- Hot spray rates lower than 1.6 l/m^2 should not be allowed.

- Binder for the sand seal cover seal shall be MC 3000 for crusher dust or coarse river sand and MC 800 for fine sand.
- Where the aggregate has a water absorbency of more than 2%, the hot spray rate should be increased by 0.3 l/m^2.

Aggregate: As a general guide, Table 7.18 gives the aggregate application rates for Otta Seals.

Table 7.18: Nominal Otta seal aggregate application rates

Type of Seal	Aggregate Application Rates (m^3/m^2)		
	Open Grading	**Medium Grading**	**Dense Grading**
Otta Seals	0.013 – 0.016	0.013 – 0.016	0.016 – 0.020
Sand Cover Seals	0.010 – 0.012		

The following points should be noted with regard to the aggregate application rates:

1. Sufficient amounts of aggregate should be applied to ensure that there is some surplus material during rolling (to prevent aggregate pick-up) and through the initial curing period of the seal.
2. Aggregate embedment will normally take about 3 – 6 weeks to be achieved where crushed rock is used, after which any excess aggregate can be swept off. Where natural gravel is used the initial curing period will be considerably longer (typically 6 – 10 weeks).

7.3 Paving Design Traffic Classes for LVR

Surfacing design is considered separately for Paved roads and Unpaved roads.

For the structural pavement design of paved roads, five traffic classes have been defined as shown in Table 7.19. If the estimate of cumulative traffic is close to the boundaries of a traffic class, then the basic traffic data and forecasts should be re-evaluated and sensitivity analyses carried out to ensure that the choice of traffic class is appropriate. If there is any doubt about the accuracy of the traffic estimates the next higher traffic class should be selected for the design.

Table 7.19 : Traffic classes for LVR pavement design

Traffic range (mesas)	**LV1**	**LV2**	**LV3**	**LV4**	**LV5/T2(1)**
	< 0.01	0.01 – 0.1	0.1 – 0.3	0.3 – 0.5	0.5 – 1.0

LV5/T2 is the transition traffic zone between low-volume and high-volume roads with the former traffic class (LV5) applying to the lower boundary of the traffic range and the latter traffic class (T2) applying to the upper boundary.

Roads expected to carry more than 1.0 mesa during their design life should be designed as HVR according to the 2006 Pavement Design Manual.

For Unpaved roads (earth and gravel surface), the design is based principally on traffic flow volumes DC1 to DC4 (See Chapter 1).

7.4 Subgrade

Subgrades are classified in engineering terms on the basis of the laboratory soaked CBR tests on samples. The structural catalogues given in this manual require that the subgrade strength for design be assigned to a strength class reflecting the sensitivity of thickness design to subgrade strength. The classes are defined in Table 7.20.

Table 7.20 Subgrade classes

Design CBR	S2	S3	S4	S5	S6
Range %	3 - 4	5 - 8	9 - 14	15 - 29	30+

It is critical that the nominal subgrade strength is available to a reasonable depth in order that the pavement structure performs satisfactorily. The concept of "material depth" is used to denote the depth below the finished level of the road to which soil characteristics have a significant effect on pavement behaviour. In addition, the moisture regime may need to be controlled by, for example, the provision of adequate subsurface drainage and/or surface drainage. Below this depth the strength and density of the soils are assumed to have a negligible effect on the pavement.

Figure 7.21 shows the material depth in relation to the main structural components of the road pavement, while Table 7.22 specifies typical material depths used for determining the design CBR of the subgrade for the various road categories.

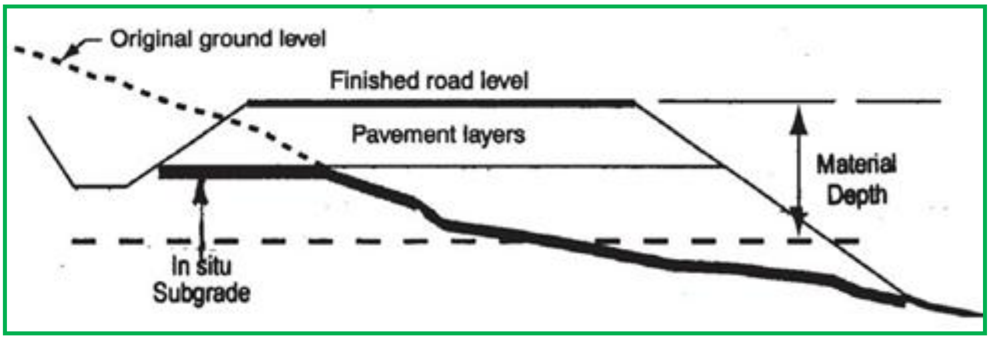


Figure 7.21 Material depth

Table 7.22 Typical material depth by road category

Road Category		Material depth (mm)
1	High Volume	1000 - 1200
2,3		800 - 1000
4	Low volume	800
5		700

It should be clearly understood that the minimum depths indicated in Table 7.22 are not depths to which re-compaction and reworking is necessarily required. Rather, they are the depths to which the Engineer should confirm that the nominal subgrade strength is available. In general, unnecessary working of the subgrade should be avoided and limited to rolling prior to constructing overlying layers.

7.5 Design of Engineered Natural Surfaces (ENS)

The following design standards are recommended for Engineered Natural Surfaces (ENS) in the DC1 design class carrying (AADT) < 25 vpd. Traffic flow volume is the determining design criteria for this type of road surface. In some circumstances ENS can satisfactorily accommodate higher traffic flows. The details of the cross-section are given in Chapter 6 but shown schematically in Figure 7.9 for convenience.

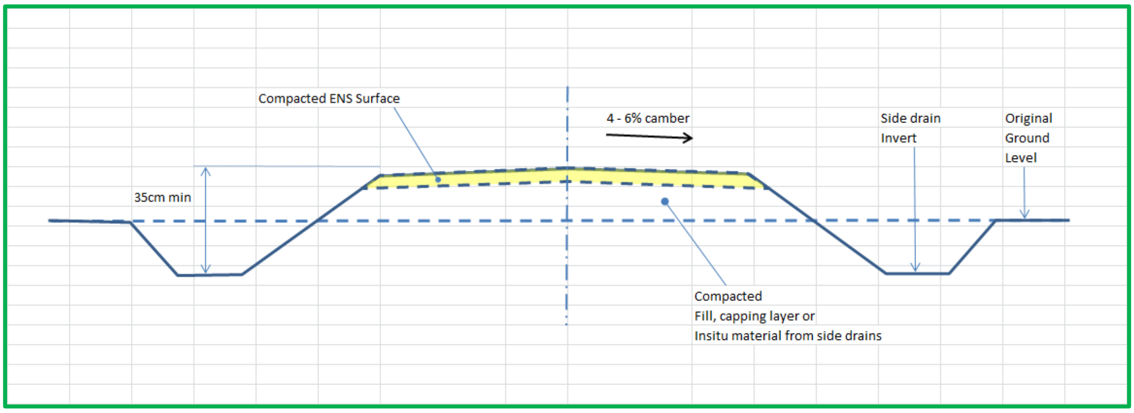


Figure 7.9: Typical Engineered Natural Surface road cross section in flat terrain

1. The side drain may be trapezoidal, V or rectangular (lined) in shape. The edge of road/shoulder should be at least 30cm above the bed or invert of the side drain, whatever the side drain cross section shape, or the surrounding ground level. These requirements do not apply in sandy free-draining soil or expansive soil subgrades.
2. The crown height of the earth road should be at least 35 cm above the bed or invert of the side drain, whatever the side drain cross section shape, or the ground level.
3. Where the topography allows, wide, shallow trapezoidal side drains for earth roads are preferred. They minimise erosion risk, and will not block as easily as narrow ditches. The ditches usually grass over in time, binding the soil surface and further slowing down the speed of water, both of which act to prevent or reduce erosion.
4. The surface of earth roads should be mechanically graded or manually shaped and compacted to provide a suitably robust and running surface for traffic and the road surface should have a ***minimum*** camber of 4% to ensure water runs off the surface and into the side drains.
5. Areas where there are specific problems (usually due to water or to the poor condition of the subgrade) may be treated in isolation by localised replacement of subgrade, gravelling or other surface upgrade, installation of culverts, raising the roadway or by installing other drainage measures. This is the basis of a “spot improvement” approach
6. Water should be drained away from the carriageway side drains by installing lead off (mitre or turn out) drains, to divert the flow into open space away from the road.
7. These requirements need to be **maintained** to keep the ENS in a satisfactory serviceable condition.

Expansive soil formations

For a considerable area of the country (particularly the north east) the in situ surface material consists of expansive clays. These are extremely problematic as a road formation or running surface. The soils generally lose most of their traffic bearing strength when wet or soaked.

Side drains should not be constructed unless they are absolutely essential to stop ponding. Where side drains are necessary, they should be as shallow as possible and located as far from the toe of the fill as possible. Vegetation cover should be encouraged in suitable growing environment to counter erosion tendencies.

Ideally, construction over expansive soil should be done when the in-situ moisture content is at its highest, i.e. at the end of rainy season.

It is essential to maintain the road surface camber to shed rainwater as quickly as possible and avoid ponding or standing water in potholes. This maintenance should be achieved regularly during the rainy season.

Consideration should be given to closing the road with managed barriers during periods of rain. A maintained camber will quickly dry out and allow vehicle passage within a reasonable period afterwards without undue damage to the ENS running surface. These are important political and economic decisions to be shared with the appropriate authorities and stakeholders.

7.6 Design of Natural Gravel Roads

7.6.1 Overview

Many of the design considerations for ENS apply for Natural Gravel-surfaced roads.

A Natural Gravel surface is often considered as the usual upgrade option for ENS roads where improvement is justified. However, particular care should be taken in considering this option.

The following design standards are recommended for Natural Gravel or crushed stone LVR surfaces carrying up to a maximum traffic flow (AADT) of 200 vpd in the DC1 to DC4 design classes. Traffic flow volume is the principal determining design criterion for this type of road surface.

Local environment factors may further restrict the satisfactory use of natural gravel surface for sections of route that are affected by:

- Longitudinal gradient >6%;
- Annual rainfall >2,000mm;
- Excessive haul distances for initial and maintenance (re-)gravelling;
- Available gravel material does not meet specifications;
- Dust emissions in settlements or adjacent to high value crops;
- Seasonal flooding.

As annual gravel loss rates or costs may be excessive in these cases, other surface options should be considered.

A gravel road can be considered to consist of a wearing course and a structural layer (base) which covers the in situ material and provides adequate structural protection for the road foundation. The wearing course will suffer material losses due to traffic and weather and should be regularly reshaped and replenished under the maintenance regime to ensure that the structural gravel layer retains at the minimum design thickness. In practical terms the wearing and structural layers will usually be of the same material and source and be laid in accordance with the requirements discussed hereafter.

Wearing course gravel material losses can be of the order of 25-50mm/100vpd on flat sections of route. Higher losses may occur due to factors of rainfall, gradient, poor quality material, or poor (or lack of) maintenance practices.

For the Gravel Road cross section, the side drain may be trapezoidal, V or rectangular (lined) in shape. The edge of road/shoulder should be at least 30cm above the bed or invert of the side drain whatever the side drain cross section shape or the surrounding ground level. These requirements do not apply in sandy free-draining soil or expansive clay subgrades.

To achieve adequate external drainage, the road must also be raised above the level of existing ground such that the crown of the road is always maintained at a minimum height (h_{min}) above the side drain inverts or adjacent ground level, allowing for the variation in wearing course thickness. Cross sections are shown in detail in Chapter 6 and shown here schematically for convenience (Figure 7.10).

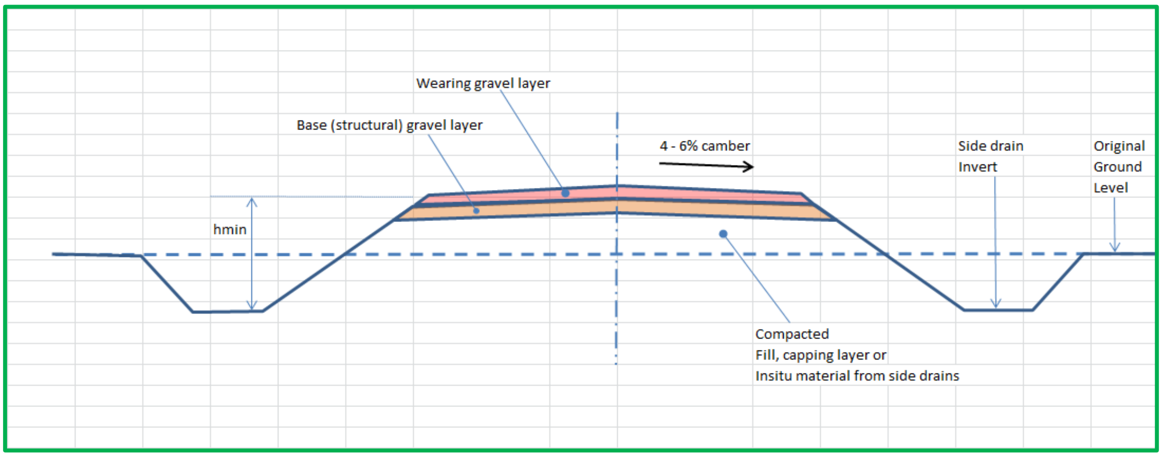


Figure 7.10: Typical gravel road cross section in flat terrain

The minimum height (h_{min}) is dependent on the climate and road design class as shown in Table 7.23.

Table 7.23: Required minimum height (h_{min}) between road crown of structural gravel layer and invert level of side drain or adjacent ground in relation to climate

Road Class	Climate	
	Wet (N < 4)	Dry (N > 4)
	H_{min} (mm)	H_{min} (mm)
DC1	350	250
DC2	400	300
DC3	450	350
DC4	500	400

Gravel roads passing through settlement areas or with adjacent high value crops in particular require materials that do not generate excessive dust in dry weather. Consideration should therefore be given to the type of gravel wearing course material to be used in particular locations such as towns or settlements, or adjacent to high value crops.

Much of the information presented in this Section of the LVR Manual is based on the "Pavement and Materials Design Manual" prepared by the United Republic of Tanzania

Ministry of Works 1999, and on relevant ERA and TRL publications. Available information has been modified to provide a simple procedure to design LVR gravel surfaces, which is appropriate to South Sudanese conditions.

7.6.2 Design principles for gravel roads

The design procedure consists of the following steps:

1. Assess likely Maintenance regime.
2. Traffic (Baseline flow and forecast).
3. Material and geotechnical information (Field survey and material properties).
4. Subgrade (Classification, foundation for expansive soils and material strength).
5. Thickness design (Gravel wearing coarse thickness).
6. Materials design.

It is an essential consideration in the design of gravel roads to ensure all-weather access. This requirement places particular emphasis on the need for sufficient bearing capacity of the base structural gravel layer and provision of drainage and sufficient earthworks in flood or problem soil areas (e.g. over black cotton soils).

Performance characteristics that will assist in identifying suitable material are shown in Figure.8.1 in Sub-section *8.3.7*.

7.6.3 Maintenance

The material requirements for the gravel wearing course include provision of a gravel surface that is effectively maintainable. Adherence to the limits on oversize particles in the material is of particular importance in this regard and will sometimes necessitate the use of crushing or screening equipment or activities during material production.

Regular and timely maintenance of a gravel surface is **vital**. If this is not arranged or achieved, then the gravel surfacing will quickly deteriorate and the road will rapidly revert to a poor standard earth track with an associated loss of considerable investment and access. It is important to assess the likely maintenance regime for the constructed gravel surface LVR. If the maintenance authority does not have the arrangements, resources or funds for regular maintenance, then it is likely that the benefits of the gravel surface investment will not be sustained and full access will be lost. An initial indicator of maintenance capacity would be to determine whether more than 50% of the existing gravel surface network under management is satisfactorily maintained. If it is not, then investment in improved maintenance capacity or other surface options may be appropriate.

7.6.4 Design method

The required gravel thickness shall be determined as follows:

1. Determine the minimum thickness necessary to avoid excessive compressive strain in the subgrade (Base Gravel layer thickness and any necessary subgrade improvement: D1).

2. Determine the extra thickness needed to compensate for the gravel loss under traffic during the period between re-gravelling maintenance operations (GW: Wearing Gravel layer thickness: D2).

3. Determine the total gravel thickness required by adding the above two thicknesses (D1+ D2).

	GW	**Thickness D2**
	Base	**Thickness D1**

7.6.5 Minimum thickness required

It is necessary to limit the compressive strain in the subgrade to prevent excessive permanent deformation at the surface of the road. Figure 7.11 gives the minimum gravel thickness required for each traffic category with the required thickness of Wearing Gravel Layer – GW (D2) and Base Gravel layer or improved subgrade materials depending on subgrade strength category.

Sub grade	AADT < 20		AADT 20 - 50		AADT 50 - 200	
S5/6 CBR >15	150 mm GW		175 mm GW		200 mm GW	
S4 CBR 8 - 14	200 mm GW		150 mm GW 150 mm G25		175 mm GW 150 mm G25	
S3 CBR 5 - 7	Dry Zones (mm) 150 GW 150 G15	Wet Zones (mm) 150 GW 300 G15	Dry Zones (mm) 150 GW 150 G25 150 G15	Wet Zones (mm) 150 GW 200 G25 200 G15	Dry Zones (mm) 200 GW 150 G25 200 G15	Wet Zones (mm) 200 GW 200 G25 250 G15

Figure 7.11: Minimum thickness for surfacing and improved subgrade for gravel Roads for ADDTs < 200

Notes
Subgrade classifications from Table 8.2
GW = G45 or better in Table 8.1
G15 and G25 defined in Table 8.1

7.6.6 Gravel loss

The GW gravel wearing course material losses will depend on a range of factors as previously discussed in *7.5.1*. It is important to assess the likely annual rate of loss to determine maintenance liabilities and ensure that adequate arrangements are in place for the relatively expensive occasional maintenance re-gravelling. The following provides guidance on likely surface gravel loss rates for gravel surface material that is within specification and adequately maintained.

According to TRL Laboratory Report LR 1111, an estimate of the annual average gravel loss for rolling terrain can be estimated from the following equation:

$$GL = f.(4.2 + 0.092\ T + 3.50\ R^2 + 1.88V).T^2 / (T^2 + 50)$$

Where

GL = the annual gravel loss measured in mm

T = the total traffic volume in the first year in both directions, measured in thousands of vehicles

R = the average annual rainfall measured in m

V = the total (rise + fall) as a percentage of the length of the road

f = 0.94 to 1.29 for lateritic gravels

= 1.1 to 1.51 for quartizitic gravels

= 0.7 to 0.96 for volcanic gravels (weathered lava or tuff)

= 1.5 for coral gravels

= 1.38 for sandstone gravels

These gravel loss estimates are only indicative, and there is no substitute for analysis of local gravel road performance/maintenance records to develop realistic estimates of actual gravel losses in the local environment. Loss rates will be significantly higher on steep grades.

7.6.7 Total thickness required

The wearing course of a new gravel road shall have a total thickness D calculated from:

D = D1 + N.GL

Where D1 is the minimum thickness **base** thickness from Figure 7.11

N is the period between regravelling operations in years

GL is the annual gravel loss calculated above,

and N.GL is at least the minimum **GW** thickness from Figure 7.11

Maintenance re-gravelling operations should be programmed to ensure that the actual gravel thickness never falls below the minimum thickness D1.

7.6.8 Pavement and materials

Experience with local materials

Knowledge of past performance of locally occurring materials for gravel roads is essential. Material standards may be altered to take advantage of available gravel sources provided they have proved to give satisfactory performance under similar conditions. See chapter 8 and Appendix C.

Improved subgrade layer

Depending on the characteristics of the subgrade, improved subgrade layers shall be constructed if required according to Subsection *7.3.2*, on which the gravel base and wearing course are placed according to Figure 7.11.

The use of Subgrade Improvement can save on the use of more expensive, high quality gravel on weaker subgrades. In general the use of improved subgrade layers has the following advantages:

- Provision of extra protection under heavy axle loads;
- Protection of underlying earthworks;
- Provides running surface for construction traffic;
- Assists compaction of upper pavement layers;
- Can act as a drainage filter layer;
- More economical use of available materials.

Subgrade CBR

All subgrade materials shall normally be brought to a strength of at least a minimum CBR of 7% for minor gravel roads (AADT <50) through Subgrade Improvement, and at least a minimum CBR 25 % for major gravel roads (AADT >50).

Treatment of expansive soil formations

The treatment operations to be considered on Expansive Formations are outlined in Appendix D.

7.6.9 Determination of CBR_{design}

The CBR_{design} is the CBR value of a homogenous section for which the subgrade strength is classified into S3, S4 or S5 for the purpose of gravel surfacing design. The procedure to determine CBR_{design} is shown in the flow chart in Figure 7.12.

Homogenous sections

Identification of sections deemed to have homogenous subgrade conditions is carried out by desk studies of appropriate documents such as geological maps, followed by site reconnaissance that might include excavation of inspection pits and initial indicator testing for confirmation of the site observations. The identification of localised areas that require individual treatment is an essential part of the site reconnaissance. Demarcation of homogenous sections shall be reviewed and changed as required when the CBR test results of the centre line soil survey are available.

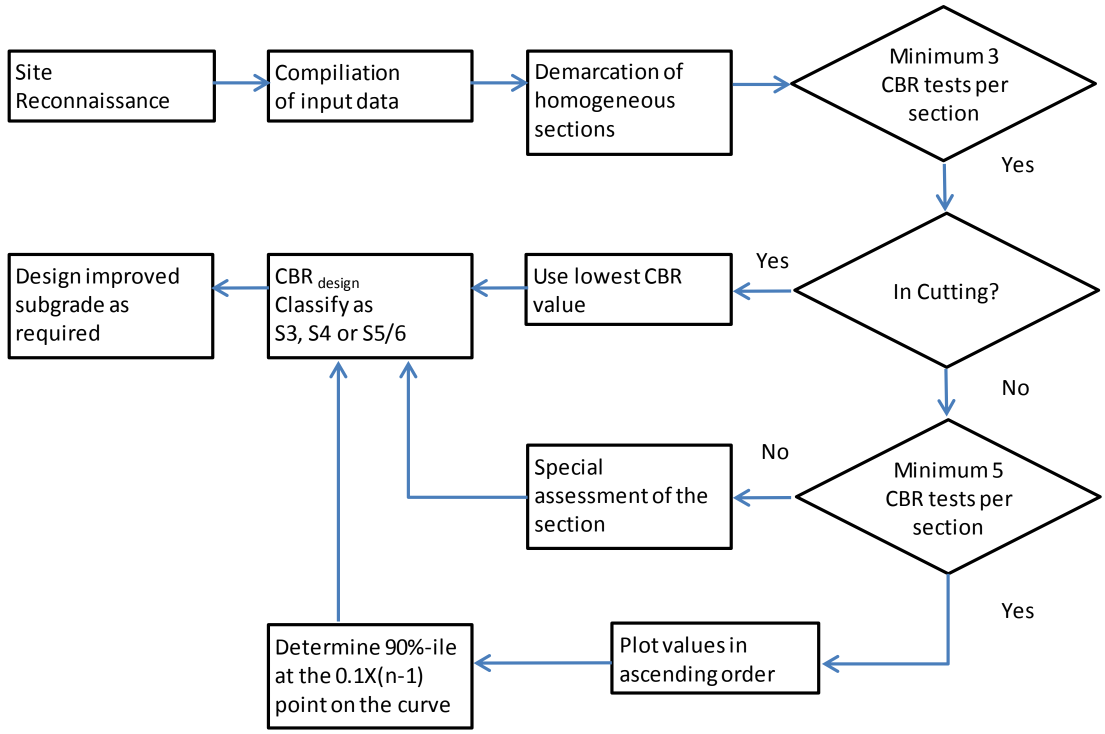


Figure 7.12: Flow chart for gravel surface subgrade design

Statistical analysis

The CBR_{design} for cuttings is the lowest CBR value encountered for the homogenous section. The CBR_{design} for sections that do not require special assessment or are not within cuttings are determined by the 90%-ile value of the CBR test results. The 90%-ile value for a section of this type is the CBR value which 10% of the test results fall below. The following example shows how this is calculated.

1. CBR values are plotted in ascending order (number of tests on the "x axis" and the CBR test result values on the "y axis");
2. Calculate d = 0.1 x (n-1), where n = number of tests;
3. d is measured along the "x axis" and the CBR_{design} is determined from the "y axis".

Laboratory testing

Each CBR value shall be determined by laboratory measurement carried out for a minimum of three density values to give a CBR - Density relationship for the material. The CBR value is determined at the normal field density specified for the respective operation (i.e. a minimum in-situ density of 95% of the maximum dry density determined in accordance with the requirements of AASHTO T180). See Appendix B for further guidance on testing.

7.6.10 Crossfall and drainage

The crossfall of carriageway and shoulders for gravel roads shall be a minimum of 4% as stipulated in Chapter 6. This is to ensure that potholes do not develop by avoiding standing water and rapidly removing surface water. To ensure that excessive crossfall does not cause erosion of the surface, the crossfall should not be greater than 6%. Provision and maintenance of adequate drainage is extremely important for the performance of gravel roads. The road surface crossfall should be maintained at between 4 and 6% under the maintenance regime. The drainage system must be maintained to ensure that surface water is conducted away from the roadway with minimum erosion and siltation risk to the road infrastructure and adjoining land.

7.7 Structural Design of Paved Roads

The structure of a paved road consists typically of one or more layers of material with different strength characteristics (Figure 7.13), each layer serving the purpose of distributing the load it receives at the top over a wider area at the bottom. The layers in the upper part of the structure are subjected to higher stress levels than those lower down and therefore need to be constructed from stronger material. The surfacing may be either structural or non-structural in terms of its contribution to the overall strength of the road pavement.

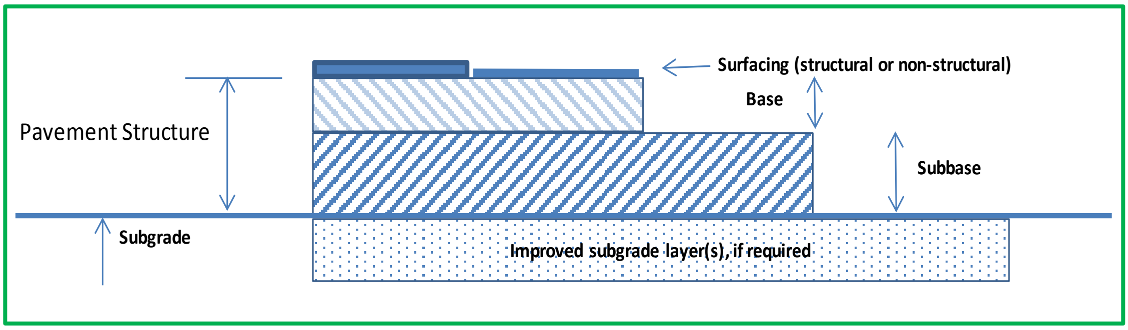


Figure 7.13: Paved road - typical pavement layers

7.7.1 Design methods

There are a number of methods that have been developed for the design of flexible paved roads ranging from the simple to the complex and based on both mechanistic/analytical and empirical methods. The purely empirical design methods are limited in their application to conditions similar to those for which they were developed whilst the mechanistic/analytical methods require not only a calibration against empirical data but also a considerable amount of material testing and computational effort and their application to highly variable, naturally occurring materials which make up the bulk of LVR pavements is questionable. The pavement design method used in this manual is an empirically-based design method.

The DCP method of materials assessment and pavement design is useful where a basic or more developed pavement structure is already in place and needs to be enhanced or upgraded.

7.7.2 Design method for bituminous surfaced roads

Design charts or catalogue methods are the easiest to use because all the practical and theoretical works have been carried out and different structures are presented in chart form for various combinations of traffic, environmental effects, pavement materials and design options.

The design method presented in this manual is based on research undertaken in a number of countries in southern Africa (SADC, 2003). It differs from the traditionally accepted design criteria applied to the design of heavily trafficked roads in that it recognises the controlling influence of the road environment on the deterioration of lighter pavement structures. By incorporating a recognised climatic variable, the N-value (Chapter 4), the geographical transferability of the research findings can be undertaken with confidence in South Sudan.

The LVR design process for bituminous surfaced roads is outlined in the flow chart presented in Figure 7.14. This process indicates the sequence of steps that are required to produce a pavement design that is appropriate and adequate for an individual road.

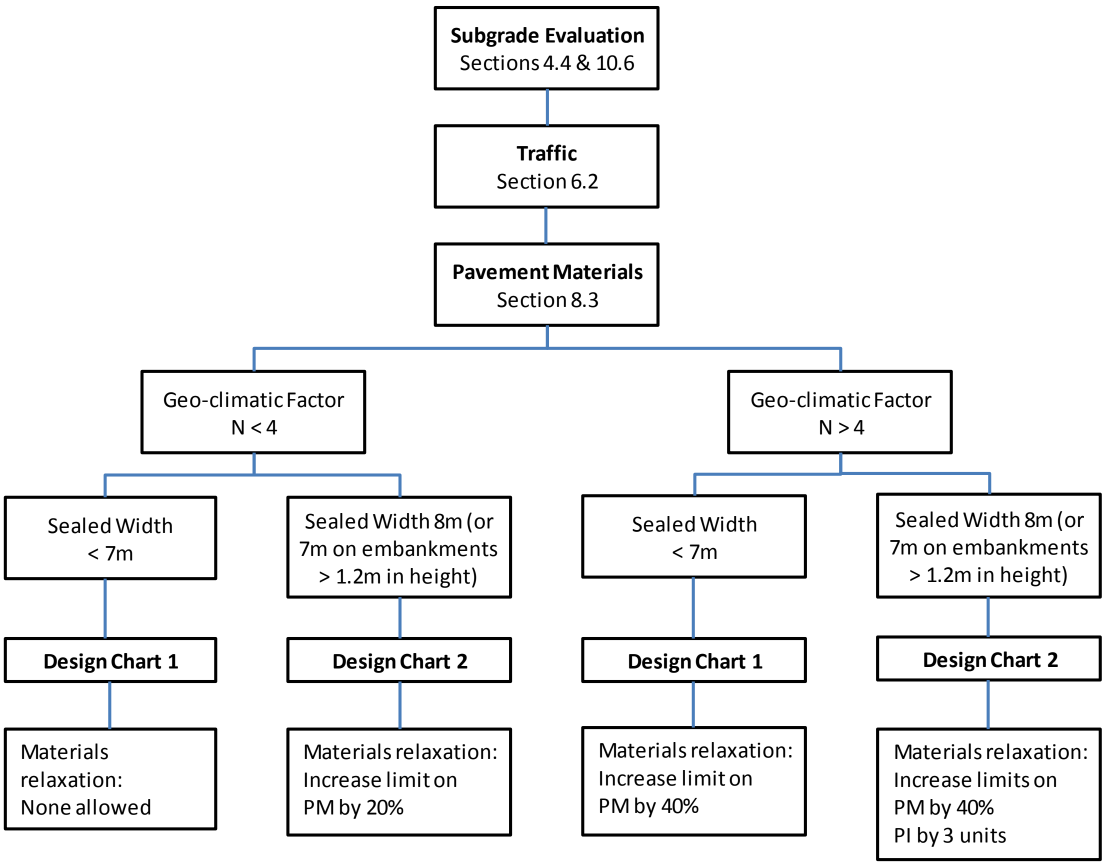


Figure 7.14: Flow chart for bituminous surfaced road pavement design process

Climate:

The design method utilises two design charts each applicable to a different climatic zone characterised by the Weinert N-values (Chapter 4) and the shoulder and drainage design adopted.

Approximate N-values for South Sudan are shown in Chapter 4, Table 4.2 and provides the means of placing the road in the appropriate climatic zone for design purposes. The two design charts are presented in Section 7.6: Design Standards, and offer a total of sixty different pavement structures depending on traffic and subgrade class.

Traffic and environmental effects:

For a correctly constructed pavement carrying low levels of traffic, there is a low risk of a pavement failure being induced by traffic, and deterioration is controlled mainly by environmental factors. However, as the traffic levels increase, the specification for roadbases should approach those of traffic design charts for high volume roads presented in ORN 31 (TRL, 1997). Experience suggests that the transition from low-volume to high-volume roads is typically in the 1.0 Mesa range.

Sealed width:

When the total sealed width is 7 metres or less, the outer wheel-track of normal motor traffic is within one metre of the edge of the seal. This affects pavement performance adversely because of seasonal moisture ingress. Therefore, relatively stronger pavements are necessary in these situations. If the road width is sufficient for the outer wheel to be more than 1.5 metres from the pavement edge, and good drainage is ensured by maintaining the crown height at least 750mm above the ditch invert, an improvement in pavement performance occurs.

This is reflected in the catalogues where different sealed surface widths are treated separately. Thus a wider sealed cross-section in climatic zones where N<4 (a relatively wet environment) allows a shift from Catalogue 1 (N<4) to Catalogue 2 (N>4). This allows the use of thinner pavement layers and a relaxation of the quality requirements for the base.

When a road is on an embankment of more than 1.2 m in height, the material in the roadbase and sub-base stays relatively dry, even in the wet season. In this case, the design category can be relaxed, and a pavement with a 7 m total sealed width can be designed to the same criteria as for an 8 m seal.

7.7.3 Use of the design charts

For guidance, the following design options are used in the catalogues related to the design traffic class shown in Table 7.19:

Climatic zones N < 4

1. Where the total sealed surface is 8 m or less, use Pavement Design Chart 1 (Table 7.24. No roadbase materials adjustments are allowed.
2. Where the total sealed surface is 8 m or more, use Pavement Design Chart 2 (Table 7.25). The limit on the plasticity modulus of the roadbase may be increased by 20 per cent.
3. Where the total sealed surface is less than 8m but the pavement is on an embankment in excess of 1.2 m in height, use Pavement Design Chart 2 (Table 7.25). The limit on the plasticity modulus of the roadbase may be increased by 20 per cent.
4. If the Engineer deems that other risk factors (e.g. poor maintenance and/or construction quality) are too high, then Pavement Design Chart 1 should be used.

Climatic zones N > 4

Use Pavement Design Chart 2 (Table 7.25).

1. Where the total sealed surface is less than 8 metres, the limit on the plasticity modulus of the roadbase may be increased by 40%.

2. Where the total sealed surface is over 8 metres and when the pavement is on an embankment in excess of 1.2 metres in height, the plasticity modulus of the road base may be increased by up to 40% and the plasticity index by 3 units.

The design flow chart in Figure 7.14 should be used iteratively depending on conditions on the individual project as in the following example:

Once the quality of the available materials and haul distances are known, the flow chart and the design charts can be used to review the most economical cross-section and pavement; this involves assessment of design traffic class, design period, cross-section and other environmental and design considerations. It may be more economical to use a wider cross-section in the seasonal tropical and wet climate zone, and then shift to Design Chart 2 than to design a narrow cross-section and a pavement using Design Chart 1, however the minimum width of carriageway and shoulders is controlled by the geometric standards adopted and this depends on traffic volume and composition.

The design charts do not cater for weak subgrades (CBR < 3%) and other problems soils. Design guidance for these conditions is given in Section 7.4.

Reducing risks in special cases:

When the project is located close to the border between the two climatic zones, the lower N-value should be used to reduce risks. When close to the borderline between two traffic design classes, and in the absence of more reliable data, the next highest design class should be used.

Table 7.24: Bituminous pavement design chart 1 (mm)

Traffic range (mesas)	**LV1**	**LV2**	**LV3**	**LV4**	**LV5**
Subgrade class (CBR)	**< 0.01**	**0.01 – 0.1**	**0.1 – 0.3**	**0.3 – 0.5**	**0.5 – 1.0**
S2 (3-4%)	150 G65	150 G65	150 G65	175 G80	200 G80
	150 G15	125 G30	150 G30	175 G30	175 G30
		130 G15	175 G15	175 G15	200 G15
S3 (5-7%)	125 G65	150 G65	150 G65	175 G65	200 G80
	150 G15	100 G30	150 G30	150 G30	150 G30
		100 G15	150 G15	150 G15	150 G15
S4 (8-14%)	175 G45	150 G65	150 G65	175 G65	200 G80
		120 G30	200 G30	200 G30	200 G30
S5 (15-29%)	175 G45	125 G65	175 G65	175 G65	175 G80
		125 G30	150 G30	150 G30	150 G30
S6 (>30%)	150 G45	150 G65	175 G65	175 G65	200 G80

Table 7.25: Bituminous pavement design chart 2 (mm)

Traffic range (mesas)	**LV1**	**LV2**	**LV3**	**LV4**	**LV5**
Subgrade class (CBR)	**< 0.01**	**0.01 – 0.1**	**0.1 – 0.3**	**0.3 – 0.5**	**0.5 – 1.0**
S2 (3-4%)	150 G45	150 G65	150 G80	175 G80	200 G80
	150 G15	120 G30	150 G30	150 G30	175 G30
		120 G15	150 G15	150 G15	175 G15
S3 (5-7%)	125 G45	150 G55	175 G65	200 G65	200 G65
	125 G15	150 G30	175 G30	200 G30	250 G30
S4 (8-14%)	150 G45	150 G45	150 G55	175 G55	175 G65
		100 G30	150 G30	175 G30	200 G30
S5 (15-29%)	150 G45	175 G55	175 G55	175 G55	175 G65
S6 (>30%)	150 G45	150 G45	150 G55	150 G55	175 G65

7.7.4 Non bituminous surfaced roads

Table 7.26 lists the non-bituminous pavement (NBP) options with their respective design charts.

Table 7.26: Non-bituminous pavement surfacing options

NBP Option	**Code Ref.**	**Table**
Water-bound and Dry-bound Macadams	WBM and DBM	7.28
Hand-Packed Stone	HPS	7.29
Stone Setts or Pavé	SSP and MSSP	7.30
Cobblestone / Dressed Stone	CS, DS & MCS, MDS	7.30
Fired Clay Brick	CB, MCB	7.30
Non-reinforced Concrete	NRC	7.31

In Tables 7.28 to 7.31, unbound gravel material is assumed to be used for layers. In many cases the specifications for the strength of these materials is flexible and, depending on the materials available, substitutions can be made. It is indicated in the Tables where substitutions are allowed and where they are restricted. Table 7.27 defines the allowable substitutions. Table 7.27 is used by simply taking the ratio of thicknesses of the material to be used and the material designated in the thickness designs in Tables 7.28 to 7.31 and scaling the thickness given in the Tables appropriately. For example, if the thickness of a G45 material is given as 150mm in the Tables and a G80 material was more readily available the thickness required becomes:

$$150 \times 65/80 = 122\text{mm}$$

Table 7.27: Substitution of pavement layer material

Material Designation	Material CBR (%)	Required thickness (mm)
G15	15	100
G30	30	90
G45	45	80
G65	65	70
G80	80	65

Water-bound and Dry-bound Macadam (WBM and DBM)

For the introduction to Water and Dry Bound Macadam, refer to Sub section 7.1.3. The WBM or DBM may be constructed as a low cost, initial surface to be later sealed and upgraded in a 'stage construction' strategy.

WBM or DBM is suitable for labour based construction and should provide a relatively high quality surface layer similar to a good quality natural gravel surface. However, like gravel, it is worn away by traffic and rainfall and therefore requires similar levels of maintenance.

The structural designs for WBM and DBM are as shown in Table 7.28 with the WBM or DBM itself acting as the wearing course. A capping layers and a sub-base are required as indicated but thicknesses can be reduced if stronger material is available.

Table 7.28: Thickness designs for WBM and DBM pavements (mm)

Traffic range (mesas)	**LV1**	**LV2**	**LV3**	**LV4**	**LV5**
Subgrade class (CBR)	**< 0.01**	**0.01 – 0.1**	**0.1 – 0.3**	**0.3 – 0.5**	**0.5 – 1.0**
S2 (3-4%)	150 WBM	150 WBM	150 WBM	NA	NA
	150 G30	150 G30	175 G20		
		150 G15	200 G15		
S3 (5-7%)	150 WBM	150 WBM	150 WBM	NA	NA
	125 G30	125 G30	150 G30		
		100 G15	150 G15		
S4 (8-14%)	150 WBM	150 WBM	150 WBM	NA	NA
	100 G30	150 G30	200 G30		
S5 (15-29%)	150 WBM	150 WBM	150 WBM	NA	NA
	NOTE	NOTE	NOTE		
S6 (>30%)	150 WBM	150 WBM	150 WBM	NA	NA
	NOTE	NOTE	NOTE		

Notes:

1. The capping layer of G15 material and the sub-base layer of G30 material can be reduced in thickness if stronger material is available (Table 7.27)
2. On subgrade > 15%, the material should be scarified and re-compacted to ensure the depth of material of in situ CBR >15% is in agreement with the recommendations in Table 7.22

Hand-packed stone (HPS)

For the introduction to Hand Packed Stone, refer to Sub section 7.1.3.

Hand Packed Stone is a proven labour based technique. The Hand Packed Stone is normally bedded on a thin layer of sand or gravel.

For use by heavy traffic, the layer should be compacted with a vibrating or heavy non-vibrating roller. An edge restraint or kerb constructed of large or mortar jointed stones improves durability and lateral stability.

A degree of interlock is achieved and has been assumed in the designs shown in Table 7.29. The structures also require a capping layer when the subgrade is weak and a conventional sub-base of G30 material or stronger.

Table 7.29: Thicknesses designs for Hand Packed Stone (HPS) pavement (mm)

Traffic range (mesas)	**LV1**	**LV2**	**LV3**	**LV4**	**LV5**
Subgrade class (CBR)	**< 0.01**	**0.01 – 0.1**	**0.1 – 0.3**	**0.3 – 0.5**	**0.5 – 1.0**
S2 (3-4%)	150 HPS	200 HPS	200 HPS	250 HPS	NA
	50 SBL	50 SBL	50 SBL	50 SBL	
	175 G30	125 G30	150 G30	150 G30	
		150 G15	200 G15	200 G15	
S3 (5-7%)	150 HPS	200 HPS	200HPS	250 HPS	NA
	50 SBL	50 SBL	50 SBL	50 SBL	
	125 G30	200 G30	150 G30	150 G30	
			150 G15	150 G15	
S4 (8-14%)	150 HPS	200 HPS	200 HPS	250 HPS	NA
	50 SBL	50 SBL	50 SBL	30 SBL	
	100 G30	150 G30	200 G30	200 G30	
S5 (15-29%)	150 HPS	200 HPS	200 HPS	250 HPS	NA
	50 SBL	50 SBL	50 SBL	50 SBL	
	NOTE	NOTE	NOTE	NOTE	
S6 (>30%)	150 HPS	200 HPS	200 HPS	250 HPS	NA
	50 SBL	50 SBL	50 SBL	50 SBL	
	NOTE	NOTE	NOTE	NOTE	

Notes:

1. The capping layer of G15 material and the sub-base layer of G30 material can be reduced in thickness if stronger material is available (Table 7.27)
2. On subgrade > 15%, the material should be scarified and re-compacted to ensure the depth of material of in situ CBR >15% is in agreement with the recommendations in Table 7.22.

Stone sett or pavé pavements (SSP or MSSP).

Stone sett surfacing or Pavé consists of a layer of roughly cubic (100mm) stone setts laid on a bed of sand or fine aggregate within mortared stone or concrete edge restraints. The individual stones should have at least one face that is fairly smooth to be the upper or surface face when placed. Each stone sett is adjusted with a small (mason's) hammer and then tapped into position to the level of the surrounding stones. Sand or fine aggregate is brushed into the spaces between the stones and the layer is then compacted with a roller or plate compactor. Suitable structural designs are shown in Table 7.30.

Table 7.30 Thicknesses designs for various discrete element surfacings (mm)

Traffic range (mesas)	**LV1**	**LV2**	**LV3**	**LV4**	**LV5**
Subgrade class (CBR)	**< 0.01**	**0.01 – 0.1**	**0.1 – 0.3**	**0.3 – 0.5**	**0.5 – 1.0**
S2 (3-4%)	100 SSP	100 SSP	100 SSP	100 SSP	100 SSP
	25 SBL	25 SBL	25 SBL	25 SBL	25 SBL
	100 G65	150 G80	150 G80	150 G80	150 G80
	100 G30	150 G30	150 G30	175 G30	200 G30
	100 G15	175 G15	175 G15	200 G15	200 G15
S3 (5-7%)	100 SSP	100 SSP	100 SSP	100 SSP	100 SSP
	25 SBL	25 SBL	25 SBL	25 SBL	25 SBL
	125 G65	125 G80	125 G80	150 G80	150 G80
	100 G30	125 G30	125 G30	150 G30	175 G30
		150 G15	150 G15	150 G15	175 G15
S4 (8-14%)	100 SSP	100 SSP	100 SSP	100 SSP	100 SSP
	25 SBL	25 SBL	25 SBL	25 SBL	25 SBL
	150 G65	150 G80	150 G80	150 G80	175 G80
		150 G30	200 G30	200 G30	225 G30
S5 (15-29%)	100 SSP	100 SSP	100 SSP	100 SSP	100 SSP
	25 SBL	25 SBL	25 SBL	25 SBL	25 SBL
	125 G65	125 G80	150 G80	150 G80	150 G80
		125 G30	125 G30	125 G30	150 G30
S6 (>30%)	100 SSP	100 SSP	100 SSP	100 SSP	100 SSP
	25 SBL	25 SBL	25 SBL	25 SBL	25 SBL
	125 G65	150 G80	150 G80	150 G80	175 G80
	NOTE	NOTE	NOTE	NOTE	NOTE

Notes:
1. The capping layer of G15 material and the sub-base layer of G30 material can be reduced in thickness if stronger material is available
2. The capping layer can be G10 provided it is laid 7% thicker
3. The roadbase layers (G65 and G80) must not be weaker
4. The sub-base layers can be material stronger than G30 and laid to reduced thickness; Table 7.27
5. On subgrades > 15%, the material should be scarified and re-compacted to ensure the depth of material of in situ CBR >15% is in agreement with the recommendations in Table 7.22.

Cobblestone or dressed stone pavement (CS, DS, MCS or MDS)

Cobble or Dressed Stone surfacing consists of a layer of roughly rectangular dressed stone laid on a bed of sand or fine aggregate within mortared stone or concrete edge restraints. The individual stones should have at least one face that is fairly smooth, to be the upper or surface face when placed. Each stone is adjusted with a small (mason's) hammer and then tapped into position to the level of the surrounding stones. Sand or fine aggregates is brushed into the spaces between the stones and the layer then compacted with a roller or plate compacter. Cobble stones are generally 150 mm thick and dressed stones generally 150-200mm thick. These options are suited to homogeneous rock types that have inherent orthogonal stress patterns (such as granite) that allow for easy break of the fresh rock into the required shapes by labour based means. The thickness designs are given in Table 7.30 except that the thickness of the cobblestone is generally 150mm instead of 100mm shown in the Table.

Fired clay brick pavement

Fired Clay Bricks are the product of firing moulded blocks of clay. The surfacing consists of a layer of edge-on engineering quality bricks within mortar bedded and jointed edge restraints, or kerbs, on each side of the pavement. The thickness designs are as shown in Table 7.30 for LV1 and LV2. Fired clay brick surfacings are not suitable for traffic classes above LV2.

Mortared options

In some circumstances (e.g. on slopes in high rainfall areas and volume susceptible subgrade) it may be advantageous to use mortared options. This can be done with Hand-packed Stone, Stone Setts (or Pavé), Cobblestone (or Dressed Stone), and Fired Clay Brick pavements. The construction procedure is largely the same as for the un-mortared options except that cement mortar is used instead of sand for bedding and joint filling. The behaviour of mortared pavements is different to that of sand-bedded pavements and is more analogous to a rigid pavement than a flexible one. There is, however, little formal guidance on mortared option, although empirical evidence indicates that inter-block cracking may occur. For this reason the option is currently only recommended for the lightest traffic divisions up to LV2 (Table 7.30) until further locally relevant evidence is available.

Non reinforced concrete (NRC)

The non-reinforced cement concrete option for LVRs involves casting slabs of 4.0 to 5.0 metres in length between formwork with load transfer dowels between them. In some cases, where continuity of traffic demands it, these slabs may be half carriageway width. The thickness designs are given in Table 7.31 The end slab panels of a section of NRC paving should be increased in thickness by 50mm or lightly reinforced with a steel grid to counteract the wheel impact loading as traffic moves onto the end slab from adjacent surfacing.

Table 7.31 Thicknesses designs (mm) - Non-Reinforced Concrete Pavement (NRC)

Traffic range (mesas)	**LV1**	**LV2**	**LV3**	**LV4**	**LV5**
Subgrade class (CBR)	**< 0.01**	**0.01 – 0.1**	**0.1 – 0.3**	**0.3 – 0.5**	**0.5 – 1.0**
S2 (3-4%)	160 NRC	170 NRC	175 NRC	180 NRC	190 NRC
	150 G30	150 G30	150 G30	150 G30	150 G30
S3 (5-7%)	150 NRC	160 NRC	165 NRC	170 NRC	180 NRC
	125 G30	125 G30	125 G30	125 G30	125 G30
S4 (8-14%)	150 NRC	150 NRC	160 NRC	170 NRC	180 NRC
	100 G30	100 G30	100 G30	100 G30	100 G30
S5 (15-29%)	150 NRC	150 NRC	160 NRC	170 NRC	180 NRC
	100 G30	100 G30	100 G30	100 G30	100 G30
S6 (>30%)	150 NRC	150 NRC	160 NRC	170 NRC	180 NRC

Notes:

1. Cube strength = 30 MPa at 28 days.
2. On subgrades > 30%, the material should be scarified and re-compacted to ensure the depth of material of in situ CBR >30% is in agreement with the recommendations in Table 7.22.

Other options

Reinforced Concrete Paving (RCP) is unlikely to be economic for LVR application in South Sudan. There are other surfacing and paving options that may be appropriate for application in South Sudan. These could be considered after the necessary investigation and trialling in local conditions.

7.8 Pavement Drainage and Shoulders

Moisture is the single most important factor affecting pavement performance and long-term maintenance costs. Thus one of the significant challenges faced by the designer is to provide a pavement structure in which the detrimental effects of moisture are contained to acceptable limits in relation to the traffic loading, nature of the materials being used, construction and maintenance provisions and degree of acceptable risk. This challenge is accentuated by the fact that most low volume roads will be constructed from natural, often unprocessed, materials which tend to be moisture sensitive. This places extra emphasis on drainage and moisture control for achieving satisfactory pavement life. Two inter-related aspects of drainage need to be considered during road design, namely *internal and external* drainage. This section focuses on internal drainage only which is concerned with water that enters the road structure directly from above the road pavement or directly from below and the measures that can be adopted to avoid trapping water within the pavement structure. External drainage which seeks to control water before it enters the pavement structure is discussed in Chapter 9: Drainage.

7.8.1 Sources of moisture entry into a pavement

The various causes of water ingress to, and egress from, a pavement are listed in Table 8.30 and discussed in this Section.

Table 7.32: Typical causes of water ingress to, and egress from a road pavement

Means of Water Ingress	**Causes**
Through the pavement surface	through cracks due to pavement failure
	penetration through intact layers
From the subgrade	artesian head in the subgrade
	pumping action at formation level
	capillary action in the sub-base
From the road margins	seepage from higher ground, particularly in cuttings
	reverse falls at formation level
	lateral/median drain surcharging
	capillary action in the sub-base
	through an unsealed shoulder collecting pavement and ground run-off
Through hydrogenesis (aerial well effect)	condensation and collection of water from vapour phase onto underside of an impermeable surface
Means of Water Egress	**Causes**
Through the pavement surface	through cracks under pumping action through the intact surfacing
Into the subgrade	soakaway action
	subgrade suction
To the road margins	into lateral/median drains under gravitational flow in the sub-base
	into positive drains through cross-drains acting as collectors

7.8.2 Permeability

Permeability is a measure of the ease with which water passes through a material and is one of the key material parameters affecting drainage. Moisture ingress to, or egress from, a pavement will be influenced by the permeability of the pavement, subgrade and surrounding materials. The relative permeability of adjacent materials may also govern moisture conditions. A significant decrease in permeability with depth or across boundaries between materials (i.e. permeability inversion) can lead to saturation of the materials in the vicinity of the inversion. Typical permeability values for saturated soils are presented in Table 7.31.

Table 7.33: Typical material permeabilities (Lay, 1998)

Material	Permeability	Description
Gap-graded crushed rock	> 30 mm/s	Free draining
Gravel	> 10 mm/s	
Coarse sand	> 1 mm/s	
Medium sand	1 mm/s	Permeable
Fine sand	10 µm/s	
Sandy loam	1 µm/s	Practically impermeable
Silt	100 nm/s	
Clay	10 nm/s	Impermeable
Bituminous surfacing (1)	1 nm/s	

Note:

(1) Applies to well-maintained double chip seal. Thicker asphalt layers can exhibit significant permeability as a result of a linking of air voids. Permeability increases as the void content of the mix increases, with typical values ranging from 300 µm/s at 2% air voids to 30 µm/s at 12% air voids. Typically, a 1% increase in air voids content will result in a three-fold increase in permeability (Waters, 1982).

7.8.3 Achieving effective internal drainage

The following guidance is provided for achieving effective internal drainage of the road structure.

Side drainage and crown height above drain invert:

Side drainage is one of the most significant factors affecting pavement performance. The “drainage factor” is the product of the height of the crown of the road above the bottom of the ditch (h) and the horizontal distance from the centreline of the road to the bottom of the ditch (d) and can be used to classify the type of drainage prevailing at the road site. This classification of road drainage is shown in Table 7.34.

Implied in the Table is the critical nature of the crown height which correlates well with the actual service life of pavements constructed from natural gravels. A minimum value, h, of 0.75m is recommended.

Table 7.34: Classification of road drainage

Drainage Factor DF = d x h	Classification
< 2.5	Very poor
2.6 – 5.0	Poor
5.1 – 7.5	Moderate
> 7.5 or free draining	Good

Note

1. Classification can move up one class if longitudinal gradient > 1%

Irrespective of climatic region, if the site has effective side drains and adequate crown height, then the in-situ subgrade strength stays above the design value. If the drainage is poor, the in-situ strengths will fall to below the design value.

Drainage within pavement layers: Drainage within the pavement layers themselves is an essential element of structural design because the strength of the subgrade in service depends critically on the moisture content during the most likely adverse conditions. Since it is impossible to guarantee that road surfaces will remain waterproof throughout their lives, it is critical to ensure that water is able to drain away quickly from within the pavement. This can be achieved by a number of measures as discussed below.

Avoiding permeability inversion: A permeability inversion exists when the permeability of the pavement and subgrade layers decreases with depth. Under infiltration of rainwater, there is potential for moisture accumulation at the interface of the layers. The creation of a perched water table could lead to shoulder saturation and rapid lateral wetting under the seal may occur. This may lead to base or sub-base saturation in the outer wheel track and result in catastrophic failure of the base layer when trafficked. A permeability inversion often occurs at the interface between sub-base and subgrade since many subgrades are cohesive fine-grained materials. Under these circumstances, a more conservative design approach is required that specifically caters for these conditions.

In view of the foregoing, it is desirable for good internal drainage that permeability inversion does not occur. This is achieved by ensuring that the permeability of the pavement and subgrade layers are at least equal or are increasing with depth. For example, the permeability of the base must be less than or equal to the permeability of the sub-base in a three layered system.

Where permeability inversion is unavoidable, the road shoulder should be sealed to an appropriate width to ensure that a lateral wetting front does not extend under the outer wheel track of the pavement.

Ensuring proper shoulder design: When permeable roadbase materials are used, particular attention must be given to the drainage of this layer. Ideally, the roadbase and sub-base should extend right across the shoulders to the drainage ditches. In addition, proper crossfall is needed to assist the shedding of water into the side drains. A suitable value for paved roads is about 2.5 to 3% for the carriageway, with a slope of about 4-6% for the shoulders.

Increased crossfalls of 4-6%, are required for unpaved roads (earth and gravel).

Lateral drainage can also be encouraged by constructing the pavement layers with an exaggerated crossfall, especially where a permeability inversion occurs. This can be achieved by constructing the top of the sub-base with a crossfall of 3-4% and the top of the subgrade with a crossfall of 4-5%. Although this is not an efficient way to drain the pavement it is relatively inexpensive and therefore worthwhile of consideration, particularly as full under pavement drainage is rarely likely to be economically justified for LVRs. Figure 7.15 illustrates the recommended drainage arrangements for a paved LVR.

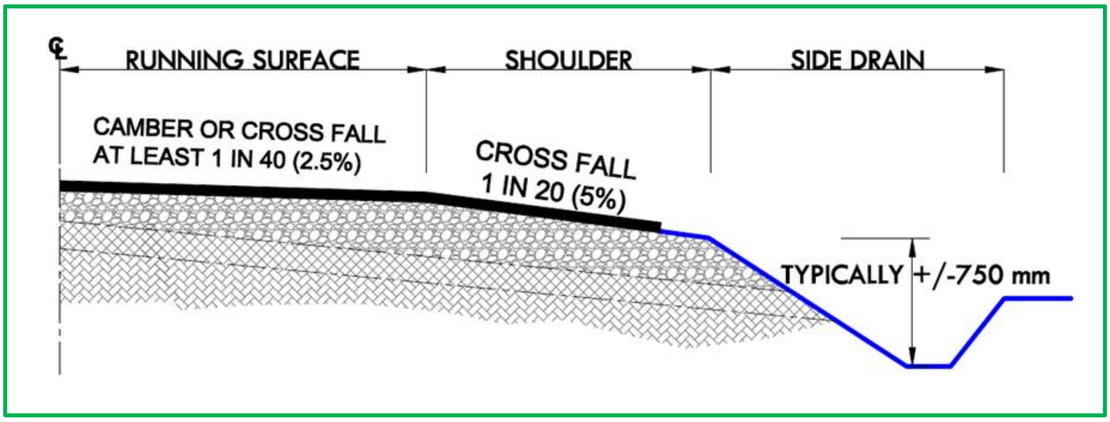


Figure 7.15: Recommended pavement drainage arrangements

If it is too costly to extend the roadbase and sub-base material across the shoulder, drainage channels or ‘grips’ at 3m to 5m intervals should be cut through the shoulder to a depth of 50mm below sub-base level. These channels should be back-filled with material of roadbase quality but which is more permeable than the roadbase itself, and should be given a fall of 1 in 10 to the side ditch. Alternatively, a preferable option would be to provide a continuous layer of pervious material of 75mm to 100mm thickness laid under the shoulder such that the bottom of the drainage layer is at the level of the top of the sub-base. The purpose of such measures should be clearly stated on construction drawings.

Sealing of shoulders: It is generally recommended that, wherever possible for South Sudan, shoulders of paved roads should be sealed, for the following reasons:

- They provide better support and moisture protection for the pavement layers and also reduces erosion of the shoulders (especially on steep gradients);
- They improve pavement performance by ensuring that the zone of seasonal moisture variation does not penetrate to under the outer wheel track (see Figure 7.16);
- They reduce maintenance costs by avoiding the need for reshaping and re-gravelling at regular intervals;
- They reduce the risk of road accidents, especially where the edge drop between the shoulder and the pavement is significant or the shoulders are relatively soft.

For the above reasons, it is generally the case that if it is economically justifiable to pave a road then it is very likely that it will also be economically justifiable to provide paved rather than unpaved shoulders. This should be undertaken as part of the design consideration of the pavement cross-section.

Unsealed shoulders: A common problem associated with the use of unsealed shoulders is water infiltration into the roadbase and sub-base for a number of reasons, which are illustrated in Figure 7.17 and include:

- Rutting adjacent to the sealed surface;
- Build-up of deposits of grass and debris;

- Poor joint between the base and shoulder (common when a paved shoulder has been added after initial construction).

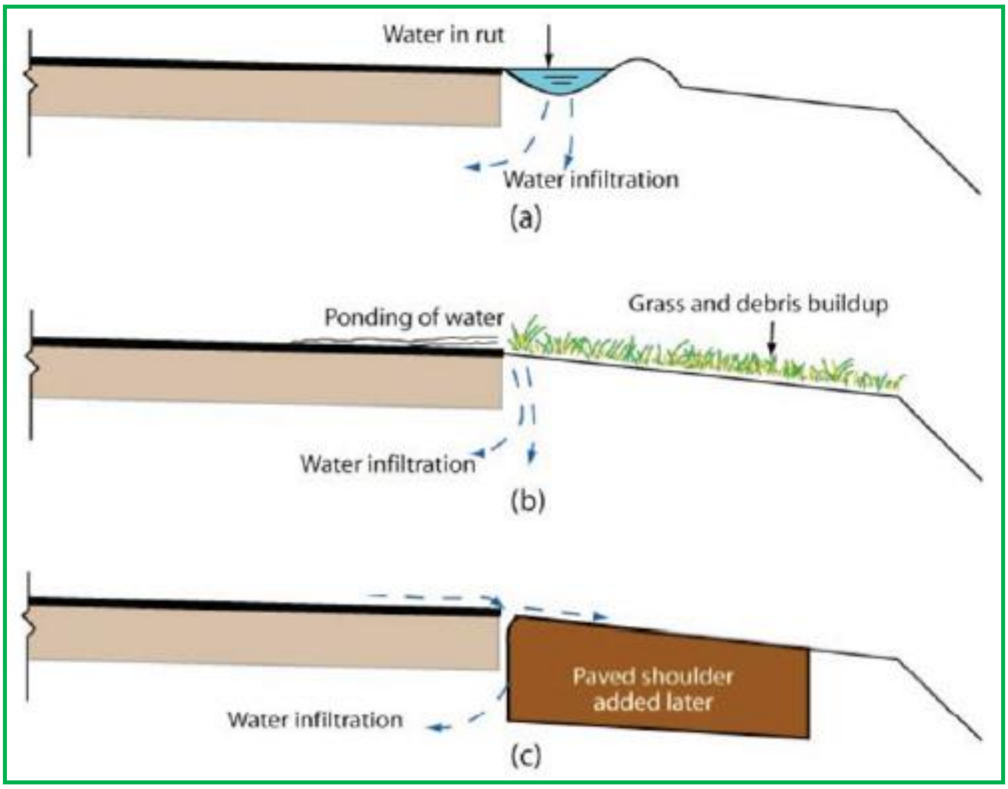


Figure 7.16 Typical drainage deficiencies associated with pavement shoulder construction (adapted from Birgisson and Ruth, 2003)

Avoiding 'trench' construction: Under no circumstances should the trench (or boxed in) type of cross section be used in which the pavement layers are confined between continuous impervious shoulders. This type of construction has the undesirable feature of trapping water at the pavement/shoulder interface and inhibiting flow into drainage ditches which, in turn, facilitates damage to the pavement and shoulders under even light trafficking. This ancient type of road construction is totally unsuited to modern traffic loading. "Boxed" construction is a common cause of road failure due to the reduction in strength and stiffness of the pavement material and the subgrade below that required to sustain the traffic loading.

Adopting an appropriate pavement cross-section: In terms of pavement cross-section, the two moisture zones in the pavement which are of critical significance are the equilibrium zone and the zone of seasonal moisture variation (see Figure 7.17: Right with a sealed shoulder; left with an unsealed shoulder).

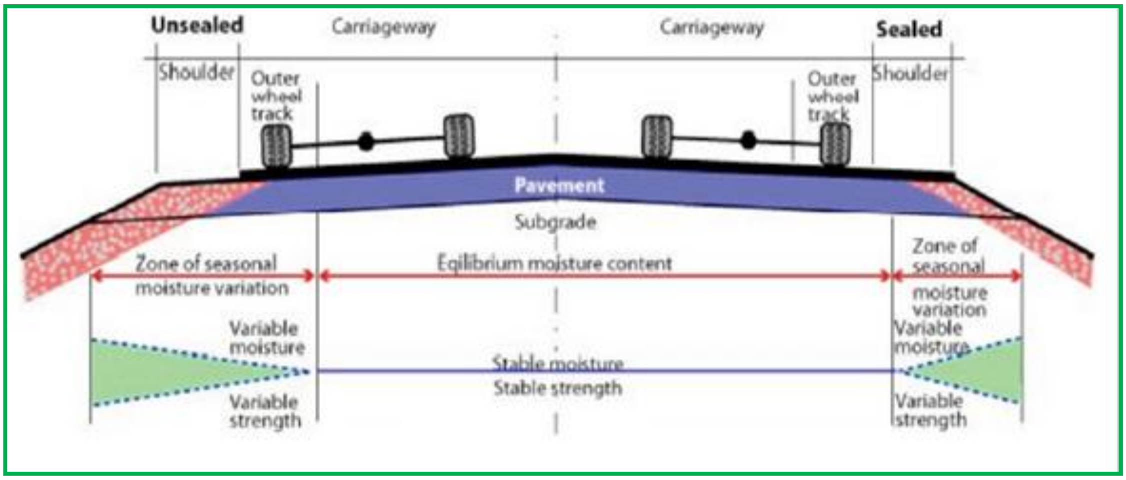


Figure 7.17: Moisture zones in a typical paved LVR

From extensive research work carried out in a number of tropical regions of the world (e.g. Morris and Gray, 1976; Gourley and Greening, 1999), it has been found that:

1. In sealed pavements over a deep water table, moisture contents in the equilibrium zone normally reach an equilibrium value after about two years from construction and remain sensibly constant thereafter.
2. In the zone of seasonal variation, the pavement moisture does not reach an equilibrium and fluctuates with variation in rainfall. Generally, this zone is wetter than the equilibrium zone in the rainy season and it is drier in the dry season. Thus, the edge of the pavement is of extreme importance to ultimate pavement performance, with or without paved shoulders, and is the most failure-prone region of a pavement when moisture conditions are relatively severe.

In order to ensure that the moisture and strength conditions under the outer wheel track will remain fairly stable and largely independent of seasonal variations, the shoulders should be sealed to a width of between about 1.0 and 1.2 m from the edge of the carriageway.

Adopting a holistic and integrated approach: The foregoing highlighted pavement drainage measures are all aimed at:

- Preventing water from entering the pavement in the first place;
- Facilitating its outflow as quickly as is reasonable, given the cost implications;
- Ensuring that the presence of water in the road for an extended period of time does not cause failures.

It should be appreciated, however, that the adoption of any single measure on its own is unlikely to be as effective as the adoption of a judicious mixture of a number of complementary measures applied simultaneously. Such an approach forms part of the philosophy of minimising the risks associated with using locally occurring natural materials in the pavements of LVRs.

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8 Construction Materials

8.1 Introduction

As indicated in Chapter 4 construction materials are a key element of the LVR road environment and their identification and characterisation are vital factors in the development of appropriate road LVR designs.

Sources of appropriate road-building materials have to be identified within an economic haulage distance and they must be available in sufficient quantity and of sufficient quality for the purposes intended. Previous experience in the area may assist with this but additional survey is usually essential.

Two of the most common reasons for construction costs to escalate, once construction has started and material sources fully explored, are that the materials are found to be deficient in quality or quantity. This leads to expensive delays whilst new sources are investigated or the road is redesigned to take account of the actual materials available.

8.2 The Use of Locally Available Materials

The maximum use of naturally occurring unprocessed materials is a central pillar of the LVR design philosophy. Current specifications tend to exclude the use of many naturally occurring, unprocessed materials (natural soils, gravel-soil mixtures and gravels) in pavement layers in favour of more expensive crushed rock, because they often do not comply with traditional requirements. However, recent research work has shown quite clearly that so-called “non-standard” materials can often be used successfully and cost-effectively in LVR pavements provided appropriate precautions are observed.

The adoption of this approach provides the scope to consider a reduction in specification standard when considering particular material types within defined environments. Recognising the material’s “fitness for purpose” is central to assessing the appropriate use of non-standard materials. However, the use of such materials requires a sound knowledge of their properties and behaviour in the prevailing environment.

A key objective in sustainable rural road construction is to best match the available construction material to the road task and the local environment. The benefits of utilising locally available materials arise from: a reduction in haulage costs; less damage to existing pavements from extended haul; stimulation of the local economy and local enterprise; road designs compatible with local maintenance capabilities and, generally, reduced whole life costs.

When reserves are limited or of marginal quality, their relevant usage is a priority and it is important to use materials to ensure that they are neither sub-standard nor wastefully above the standards demanded by their engineering task. Hence the necessity of deriving locally relevant specifications and either adapting designs or modifying materials to suit. Further guidance on the use of marginal materials is contained in Appendix C to this document.

If the project is in an area where good quality construction materials are scarce or unavailable, consideration should be given to:

- Modifying the design requirements;
- Modifying the material (eg mechanical or chemical stabilisation);
- Material processing (eg crushing, screening, blending);
- Innovative use of non-standard materials (particularly important for low traffic roads.

8.3 Construction Material Requirements

8.3.1 General material types

The material code and outline characteristics of the material types for both paved and unpaved LVRs that are used in the Catalogues of Designs adopted in the manual are described in Chapter 7.

Table 8.1 Pavement material types and abbreviated nominal specifications

Code	Material	Abbreviated Specifications
G80	Natural gravel	Min. CBR: 80% @ 98/100% AASHTO T180 and 4 days soaking Max. Swell: 0.2% Max. Size and grading: Max size 37.5mm, grading as specified. PI: < 6 or as otherwise specified (material specific).
G65	Natural gravel	Min. CBR: 65% @ 98/100% AASHTO T180 and 4 days soaking Max. Swell: 0.2% Max. Size and grading: Max size 37.5mm, grading as specified PI: < 6 or as otherwise specified (material specific)
G55	Natural gravel	Min. CBR: 55% @ 98/100% AASHTO T180 and 4 days soaking Max. Swell: 0.2% Max. Size and grading: Max size 37.5mm, grading as specified PI: < 6 or as otherwise specified (material specific)
G45	Natural gravel	Min. CBR: 45% @ 98/100% AASHTO T180 and 4 days soaking Max. Swell: 0.2% Max. Size and grading: Max size 37.5mm, grading as specified PI: < 6 or as otherwise specified (material specific)
G30	Natural gravel	Min. CBR: 30% @ 95/97% AASHTO T180 & highest anticipated moisture content Max. Swell: 1.0% 1.5% @ 100% AASHTO T180 Max. Size and grading: Max size 63mm or 2/3 layer thickness PI: < 12 or as otherwise specified (material specific)
G25	Natural gravel	Min. CBR: 30% @ 95/97% AASHTO T180 & highest anticipated moisture content Max. Swell: 1.0% @ 100% AASHTO T180 Max. Size and grading: Max sixe 63mm or 2/3 layer thickness. PI: <12 or as otherwise specified (material
G15	Gravel/soil	Min. CBR: 15% @ 93/95% AASHTO T180 & highest anticipated moisture content Max. Swell: 1.5% @ 100% AASHTO T180 Max. Size: 2/3 of layer thickness PI: < 12 or 3GM + 10 or as otherwise specified (material specific)
G7	Gravel/soil	Min. CBR: 7% @ 93/95% AASHTO T180 & highest anticipated moisture content Max. Swell: 1.5% @ 100% AASHTO T180 Max. Size: 2/3 layer thickness PI: < 12 or 3GM + 10 or as otherwise specified (material specific)
G3	Gravel/soil	Min. CBR: 3% @ 93/95% AASHTO T180 & highest anticipated moisture content Max. Swell: N/A Max. Size: 2/3 layer thickness

Road construction materials required may be summarised as:

- Common embankment fill;
- Capping layer / imported subgrade;
- Sub-base and road-base aggregate;

- Road surfacing aggregate;
- Paving stone (eg for cobblestone pavements);
- Aggregates for structural concrete;
- Filter/drainage material;
- Special requirements (eg rock-fill for gabion baskets).

8.3.2 Common embankment fill

In general, location and selection of fill material for low volume roads poses few problems. Exceptions include organic soils and clays with high liquid limit and plasticity. Problems may also exist in lacustrine and flood plain deposits where very fine materials are abundant.

Where possible, fill should be taken from within the road alignment (balanced cut-fill operations) or by excavation of the side drains (exception in areas of expansive soils). Borrow pits producing fills should be avoided as far as possible and special consideration should be given to the impacts of winning fill in agriculturally productive areas where land expropriation costs can be high.

8.3.3 Subgrade and improved subgrade

The subgrade can be made of the same material as any fill. Where in-situ and alignment soils are weak or problematic, import of improved subgrade may be necessary. As far as possible the requirement to import material from borrow areas should be avoided due to the additional haulage costs. However, import of strong (CBR>9) subgrade materials can provide economies with regard to the pavement thickness design. Where improvement is necessary or unavoidable, mechanical and chemical stabilisation methods can be considered.

Subgrades are classified on the basis of the laboratory soaked CBR tests on samples compacted to 97% AASHTO T180 compaction. Samples are soaked for four days or until zero swell is recorded. The subgrade strength for design is assigned to one of six strength classes reflecting the sensitivity of thickness design to subgrade strength. The classes are defined in Table.8.1.

Table 8.2: Subgrade classes

Design CBR class	**S2**	**S3**	**S4**	**S5**	**S6**
CBR range (%)	3 - 4	5 - 7	8 - 14	15 - 29	30+

No allowance for CBRs below 3% has been made because, from both a technical and economic perspective, it would normally be inappropriate to lay a pavement on soils of such poor bearing capacity. For such materials, special treatment is required.

The use of Class S2 soils as direct support for the pavement should be avoided as much as possible. Wherever practicable, such relatively poor soils should be excavated and replaced, or covered with an improved subgrade.

There are many advantages to improving the CBR strength of the in situ subgrade to a minimum of 15% (Subgrade Class S5) by constructing one or more improved layers where necessary. In principle, where a sufficient thickness of improved subgrade is placed, the overall subgrade bearing strength is increased to that of a higher class and the sub-base thickness may be reduced accordingly. This is often an economic advantage as sub-base quality materials are generally more expensive than fill materials, hence the decision whether or not to consider the use of an improved subgrade layer(s) will generally depend on the respective costs of sub-base and improved subgrade materials.

8.3.4 Roadbase and sub-base

Where possible, naturally occurring unprocessed materials should be selected for sub-base and roadbase in paved low volume roads. A wide range of materials including lateritic, calcareous and quartzitic gravels, river gravels and other transported and residual gravels, or granular materials resulting from weathering of rocks can be used successfully as roadbase material. Sub-base and roadbase materials are expected to meet requirements related to maximum particle size, grading, plasticity, and CBR. However, under certain circumstances, mechanical treatments may be required to improve the quality to the required standard. This often requires the use of special equipment and processing plants that are relatively immobile or static. For this reason, the borrow pits for roadbase and sub-base materials are usually spaced widely. In current practices, distances between these pits of about 50km are not unusual. Main sources of sub-base and base materials are rocky hillsides and cliffs, high steep hills, and river banks.

The minimum thickness of a deposit normally considered workable for excavation for materials for subgrade, sub-base and roadbase is of the order of one metre. However, thinner horizons could also be exploited if there are no alternatives. The absolute minimum depends on material availability and the thickness of the overburden. If there is no overburden, as may be the case in arid areas, horizons as thin as 300mm may be excavated.

The grading envelopes to be used for roadbase are shown in Table 8.3. Envelope A varies depending whether the nominal maximum particle size is 37.5mm, 20mm or 10mm. A requirement of five to ten per cent retained on successive sieves may be specified at higher traffic (>0.3Mesa) to prevent excessive loss in stability. Envelope C extends the upper limit of envelope B to allow the use of sandy materials, but its use is not permitted in wet climates.

Envelope D is similar to a gravel wearing course specification and is used for very low traffic volumes. The grading is specified only in terms of the grading modulus (GM) and can be used in both wet and dry climates.

Table 8.3 Particle Size Distribution for Natural Gravel Base

Test Sieve size	Per cent by mass of total aggregate passing test sieve				
	Envelope A Nominal maximum particle size			Envelope B	Envelope C
	37.5mm	20mm	10mm		
50mm	100			1	
37.5mm	80-100	100		80-100	
20mm	55-95	80-100	100	55-100	
10mm	40-80	55-85	60-100	40-100	
5mm	30-65	30-65	45-80	30-80	
2.36mm	20-50	20-50	35-75	20-70	20-100
1.18mm	-	-	-	-	-
425µm	8-30	12-30	12-45	8-45	8-80
300µm	-	-	-	-	-
75µm	5-20	5-20	5-20	5	5-30
Envelope D **1.65 < GM < 2.65**					

The strength requirement varies depending on the traffic level and climate, as outlined in the Catalogue of Structures. The soaked CBR test is used to specify the minimum strength of roadbase material. The plasticity requirement also varies depending on the traffic level and climate as shown in Tables 8.4 and 8.5. A maximum plasticity index of 6 has been retained for higher traffic levels, where the design chart merges to standard design documents, and also on weaker subgrades. For designs in dry environments the plasticity modulus for each traffic and subgrade class can be increased depending on the crown height and whether unsealed or sealed shoulders are used.

Table 8.4 Plasticity requirements for natural gravel roadbase materials

Subgrade class[4]	Property of base	Traffic class (mesas)				
		<0.01	0.01-0.1	0.1-0.3	0.3-0.5	0.5-1.0
S2	Ip PM Grading	<12 <400 B	<9 <150 B	<6 <120 A[5]	<6 <90 A[5]	<6 <90 A[5]
S3	Ip PM Grading	<15 <550 C[1]	<12 <250 B	<9 <180 B	<6 <90 A[5]	<6 <90 A[5]
S4	Ip PM Grading	Note[2] <800 D[3]	<12 <320 B	<12 <300 B	<9 <200 B	<9 <90 A[5]
S5	Ip PM Grading	Note[2] D[3]	<15 <400 B	<12 <350 B	<12 <250 B	<9 <150 A[5]
S6	Ip PM Grading	Note[2] D[3]	<15 <550 C[1]	<15 <500 B	<12 <300 B	<9 <180 A[5]

Notes:

1. Grading ‘C’ is not permitted in wet environments or climates (N<4); grading ‘B’ is the minimum requirement
2. Maximum Ip = 8 x GM
3. Grading ‘D’ is based on the grading modulus 1.65 < GM < 2.65
4. All base materials are natural gravels; Subgrades are non-expansive
5. Envelope A varies depending on whether the nominal maximum particle size is 37.5, 20 or 10mm

8.3.5 Lateritic roadbase gravels

A large number of factors control how a particular type of laterite is developed and the material tends to exhibit both vertical and lateral variability within a deep and irregular weathering profile.

The behaviour of lateritic materials in pavement structures depends mainly on their particle size characteristics, the nature and strength of the gravel sized particles, the degree of compaction as well as traffic and environmental conditions. The most important requirements for a laterite to show good field performance are that the material is well graded with a high content of hard, or quartz particles with adequate fines content. However, when judging the gradation of a lateritic gravel, it is important to assess its composition to decide if separate specific gravity determinations of the fines and coarse fractions should be made. For example, for nodular laterites, the coarse fraction is iron-rich whilst the fine fraction is kaolinite. Thus, if there is a significant difference in the specific gravities of the coarse and fine fractions, the grading should be calculated by use of both volume and mass proportions.

The requirements for selection and use of lateritic gravels for bases are slightly different to those given for other natural gravels. The maximum plasticity index of the lateritic roadbase is also relaxed. A maximum plasticity index of 9 has been specified for higher traffic levels and weak subgrades. For design traffic levels greater than 0.3 Mesa, a requirement is set that the liquid limit should be less than 30. Below this traffic level, this requirement is relaxed to a liquid limit of less than 35. Where sealed shoulders over one metre wide are specified in the design, the maximum plasticity modulus may be increased by 40 per cent. A minimum field compacted dry density of 2.0 mg/m^3 is required for these materials.

Table 8.5: Guidelines for the selection of lateritic gravel roadbase materials

Subgrade class	Property	Traffic class (mesas)				
		<0.01	0.01-0.1	0.1-0.3	0.3-0.5	0.5-1.0
S2	Ip PM Grading	<15 <400 B	<12 <150 B	<9 <150 A	<9 <120 A	<6 <90 A
S3	Ip PM Grading	<18 <550 C(1)	<15 <250 B	<12 <180 B	<9 <120 A	<6 <90 A
S4	Ip PM Grading	<20(1) <800 GM 1.6-2.6	<15 <320 B	<15 <300 B	<9 <200 B	<9 <90 A
S5	Ip PM Grading	<25(1) - GM 1.6-2.6	<18 <400 B	<15 <350 B	<12 <250 B	<9 <150 B
S6	Ip PM Grading	<25(1) - GM 1.6-2.6	<20 <550 B	<18 <400 B	<15 <300 B	<12 <180 A

Notes:

1. Maximum Ip = 8 x GM
2. Unsealed shoulders are assumed. Further modification to the limits can be made if the shoulders are sealed.
3. The compaction requirement for the soaked CBR test to define the subgrade classes is 100% Mod. AASHTO with a minimum soaking time of 4 days or until zero swell is recorded. This is a relaxation of the soaked CBR requirement for natural gravel base materials given in the catalogues.

8.3.6 Material requirements for sub-base

Strength requirements: A minimum CBR of 30% is required at the highest anticipated moisture content when compacted to the specified field density, usually a minimum of 95% (preferably 97% where practicable) AASHTO T180 compaction.

Under conditions of good drainage and when the water table is not near the ground surface, the field moisture content under a sealed pavement will be equal to or less than the optimum moisture content in the AASHTO T180 compaction test. In such conditions, the sub-base material should be tested in the laboratory in an unsaturated state.

If the roadbase allows water to drain into the lower layers, as may occur with unsealed shoulders and under conditions of poor surface maintenance where the roadbase is pervious, saturation of the sub-base is likely. In these circumstances the bearing capacity should be determined on samples soaked in water for a period of four days. The test should be conducted on samples prepared at the density and moisture content likely to be achieved in the field.

Particle size distribution and plasticity requirements: In order to achieve the required bearing capacity, and for uniform support to be provided to the upper pavement, limits on soil plasticity and particle size distribution may be required. Materials which meet the recommendations of Tables 8.6 and 8.7 will usually be found to have adequate bearing capacity.

Table 8.6: Typical particle size distribution for sub-bases

Sieve Size (mm)	Per cent by mass of total aggregate passing test sieve
50	100
37.5	80 – 100
20	60 – 100
5	30 – 100
1.18	17 – 75
0.3	9 – 50
0.075	5 - 25

Table 8.7 Plasticity characteristics for granular sub-bases

Climate	Liquid Limit	Plasticity Index	Linear Shrinkage
Moist tropical and wet tropical (N<4)	< 35	< 6	< 3
Seasonally wet tropical (N<4)	< 45	< 12	<6
Arid and semi-arid (N>4)	<55	< 20	<10

8.3.7 Material requirements for gravel wearing course

Ideally, the wearing course material should be durable and of consistent quality to ensure it wears evenly. The desirable characteristics of such a material are:

- Good skid resistance;
- Smooth riding characteristics;
- Cohesive properties;
- Resistance to ravelling and scouring;
- Wet and dry stability;
- Low permeability;
- Load spreading ability.

For ease of construction and maintenance, a wearing course material should also be easy to grade and compact. The material properties having the greatest influence on these characteristics are the particle size distribution and the properties of the coarse particles.

Performance-related specifications: Performance related specifications for wearing course materials have been developed for southern Africa based on extensive sampling, testing and monitoring of a large number of test sections. These specifications have been successfully implemented in a number of African countries and are considered to be generally applicable to the South Sudan environment. The specifications identify the most suitable materials in terms of two basic soil parameters; Shrinkage Product and Grading Coefficient, which are determined from particle size distribution and linear shrinkage tests. Their use as criteria for selecting appropriate GWC materials is illustrated in Figure 8.1 and defined in Table 8.8.

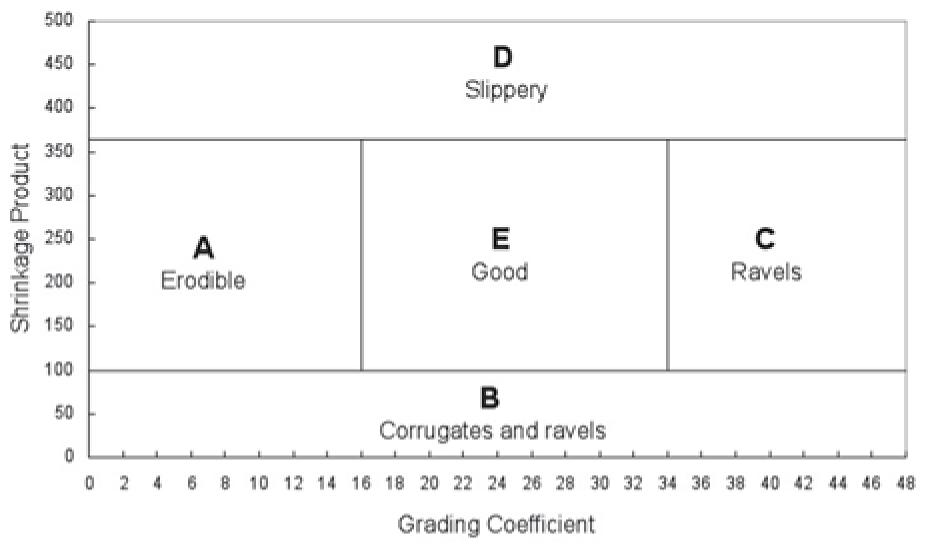


Figure 8.1: Material quality zones

The material quality zones define material quality in relation to their anticipated in-service performance. The combination of grading coefficient and shrinkage product of each material determines which material quality zone it falls into. The characteristics of materials in each zone are as follows:

A: Materials in this area generally perform satisfactorily but are finely graded and particularly prone to erosion. They should be avoided if possible, especially on steep grades and sections with steep cross-falls and super-elevations. Roads constructed from these materials require frequent periodic labour intensive maintenance over short lengths and have high gravel losses due to erosion.

B: These materials generally lack cohesion and are highly susceptible to the formation of loose material (ravelling) and corrugations. Regular maintenance is necessary if these materials are used and the road roughness is to be restricted to reasonable levels.

C: Materials in this zone generally comprise fine, gap-graded gravels lacking adequate cohesion, resulting in ravelling and the production of loose material.

D: Materials with a shrinkage product in excess of 365 tend to be slippery when wet.

E: Materials in this zone perform well in general, provided the oversize material is restricted to the recommended limits.

Table 8.8 Material specifications[1,3] for unsealed rural roads

Maximum size (mm)	37.5
Oversize index (I_o)	≤5%
Shrinkage product (S_p)	100 to 365 (max.240 preferable)
Grading coefficient (G_c)	16 to 34
Soaked CBR (at 95% Mod. AASHTO)	≥15%
Treton impact value (%)	20 to 65
a I_o = % retained on 37.5mm sieve)	
b S_p = Linear shrinkage x passing 0.425 sieve	
c G_c = (% passing 26.5mm – % passing 2.00mm) x (% passing4.75mm)/100	

Notes:

1. Specifications should be applicable after placement and compaction
2. The Grading Coefficient and Shrinkage Product must be based on a conventional particle size distribution determination which must be normalised for 100% passing the 37.5 mm screen.
3. Only representative material samples are to be tested.
4. The Treton Impact Value (TIV) limits exclude those materials that are too hard to be broken with a grid roller (TIV < 20%) or too soft to resist excessive crushing under traffic (TIV > 65%).

8.3.8 Road surfacing aggregate

The general requirements for aggregate to be used in a bituminous surfacing layer are that must be durable, strong and should also show good adhesion with bituminous binders. It should also be resistant both to the to the polishing and abrasion action of traffic. The main qualities for surfacing aggregate are summarised in Table 8.9.

Table 8.9 Basic requirements for surfacing aggregate

Key Engineering Factor	Material Requirement
Strength	Aggregate particles need to be load resistant to any loads and abrasion imposed during construction and the design life of the pavement.
Durability	Aggregate particles need to be resistant mineralogical change and to physical breakdown due to any wetting and drying cycles and abrasion imposed during construction or pavement design life.
Skid Resistance (Surface aggregate only)	Aggregate particles must be resistant to polishing.
Adhesiveness	Aggregate must be capable of adhesion to bitumen and sustaining that adhesion for its design life.

Adhesion failure implies a breakdown of the bonding forces between a stone aggregate and its coating of bituminous binder, leading to physical separation. Mechanical failure by fretting and subsequent ravelling of the surface is one possible, but invariable, consequence of adhesion failure.

Basic rocks are considered to have better adhesion properties than acidic rocks. The comparatively poor performance of acid rocks may not only be related to the high silica content but to the formation of sodium, potassium and aluminium hydroxides. This is considered more likely in felspathic minerals. Experience has indicated, for example, that coarse granite with large feldspar inclusions is likely to experience bitumen adhesion difficulties.

Apart from the petrological nature of the material, its cleanliness or freedom from dust is also a factor. Limits of less that 1% dust (<75 microns) are difficult to obtain by screening alone and washing of the aggregate may be required.

The resistance to abrasion is related to the petrological properties of the material: the proportion of hard minerals; the proportion and orientation of cleaved minerals; grain size; the nature of the interparticle bonding or cementation and the proportion of stable minerals resistant to weathering.

Resistance to polishing is considered a function of material fabric, texture and mineralogy. Rocks which contain minerals of differing hardness and which show a degree of friability tend to give high polishing resistance. Rocks that exhibit a moderate degree of decomposition give higher PSV results then fresh unweathered rocks. There is, therefore, an inverse relationship between polishing resistance and abrasion resistance.

Table 8.10: Aggregate requirements for chip seals

Sieve Size (mm)	**Nominal Aggregate Size (mm)**			
	19.0	**13.2**	**9.5**	**6.7**
	Grading (% passing)			
26.5	100			
19.0	85-100	100		
13.2	0-30	85-100	100	
9.5	0-5	0-30	85-100	100
6.7		-	0-5	0-40
4.75	-	-	0-5	0-40
2.36	-	-	-	0-5
0.425 (fines)	<0.5	<0.5	<0.5	<2.0
0.075 (dust)	<0.5	<0.5	<0.5	<1.0
Flakiness Index	Max 20	Max 25	Max 25	Max 30
10% FACT (dry)	AADT > 1000 vpd: Min 160 kN; AADT < 1000 vpd: 120 kN			
10% (wet)	Min 75% of corresponding 10% FACT dry			

8.3.9 *Block or paving stone*

The block stones should be a strong, homogenous, isotropic rock, free from significant discontinuities such as cavities, joints, faults and bedding planes. Rocks such as fresh granite, basalt and crystalline limestone have proven to be suitable materials. Quartzite rock is not suitable, nor is any rock that polishes or develops a slippery surface, or erodes under traffic. Rock for cobble stone should be tested to ensure it meets the specified requirements;

- Uniaxial compressive strength >75MPa;
- Los Angeles Abrasion value: <25%;
- Sodium Sulphate Soundness <10% loss.

The material infilling the spaces between the cobble stones should be a loose, dry natural or crushed stone material with a particle size distribution equivalent to a well-graded coarse sand to fine gravel. It must be clean and free from clay coating, organic debris and other deleterious materials.

8.3.10 Aggregates for structural concrete

The aggregate is divided into two parts: coarse aggregate and fine aggregate. The fine aggregate is normally naturally occurring sand, with particles up to about 2mm in size. The coarse aggregate is normally stone with a range of sizes from about 5mm to 20mm (or sometimes larger); it may be naturally occurring gravel, or more commonly crushed or hand-broken quarry stone. In areas without hard stone resources and with an established fired clay brick industry, burnt bricks can be machine or hand crushed to be used in concrete.

Aggregates must be entirely free from soil or organic materials such as grass and leaves, as well as fine particles such as silt and clay, otherwise the resulting concrete will be of poor quality. Some aggregates, particularly those from salty environments, may need to be washed to make them suitable for use.

Both the coarse and fine aggregates need to contain a range of particle sizes, and are mixed together in such a way that the fine aggregates fill the space between the coarse aggregate particles. A ratio by volume of one part fine aggregate to two parts coarse aggregate is generally used. Aggregates can be crushed and screened by hand or by machine.

8.3.11 Filter/drainage material

Filter materials have crucial roles in assisting in the prevention or in controlling the ingress of water and in the reduction of pore water pressures within both the earthworks and the pavement. Filter materials can account for a significant proportion of the construction material costs, particularly in wetter regions where road designs need to cater for the dispersion of large volumes of water, both as external drains and as internal layers within wet-fill embankments. The general requirements for filter material are a highly permeable mix comprising a durable aggregate that is resistant to chemical alteration, Table 8.11.

Table 8.11. Basic Requirements for filter/drainage materials

Key Engineering Factor	Material Requirement
Permeability	The fundamental filter property is primarily a function of material grading. It is generally desirable for filter aggregates to be equi-dimensional as this aids flow distribution and facilitates packing. It is also considered better to use material with rounded to sub-rounded rather than angular particles.
Strength	Aggregate particles need to be load resistant to abrasion and any loads imposed by the road design.
Resistance to Degradation	Aggregate particles need to be resistant to breakdown due to wetting and drying and weathering during construction and for the life of the project.
Resistance to Erosion	The as-placed material must be resistant to internal and external erosion.
Chemical Stability	Aggregate should generally be inert and resistant to alteration by groundwater. Weak surface coatings such as clay, iron oxide, calcium carbonate, gypsum etc. are undesirable.

8.4 Material Improvement

Obtaining materials that comply with the necessary grading (particle size distribution-PSD) and plasticity specifications for a gravel wearing course in South Sudan can be difficult. Many of the natural gravels tend to be coarsely graded and relatively non plastic and the use of such materials results in very high roughness levels and high rates of gravel loss in service and, in the final analysis, very high life-cycle costs.

In order to achieve suitable wearing course properties a suitable PSD can be obtained by breaking down oversized material to a maximum size of 50 mm or smaller. Atterberg limits may be modified by granular/mechanical stabilisation (blending) with other materials. These material improvement measures are discussed briefly below and further options are presented in Appendix C: Marginal Materials.

Reducing oversize: Various measures are available for reducing oversize including the use of labour, mobile crushers, grid rollers or rock crushers. The choice of method will depend on the type of project and material to be broken down:

1. **Hand labour**: This is quite feasible, especially on relatively small, labour-based projects where material can either be hand screened and/or broken down to various sizes and stockpiled in advance of construction.
2. **Mobile crushers**: The crushing of borrow pit materials may be achieved with a single stage crushing unit or, in the other extreme, stage crushing and screening plant.
3. **Grid rollers**: These are manufactured as a heavy mesh drum designed to produce a high contact pressure and then to allow the smaller particles resulting from the breakdown to fall clear of the contact zone.
4. **Rock crusher**: The “Rockbuster” is a patented plant item which is basically a tractor-towed hammermill. The hammermill action of the Rockbuster will act on the material that it passes over, breaking down both large and small sizes. There is the potential to “over-crush” a material and create too many fines in the product. It may be necessary to rill out only the larger particles in a material and process these with the Rockbuster, with the crushed material then blended back into the original product.

Where materials with a suitable grading and/or plasticity are unavailable locally, granular mechanical stabilisation may be possible by undertaking the following:

- Mixing of materials from various parts of a deposit at the source of supply;
- Mixing of selected, imported material with in-situ materials;
- Mixing two or more selected imported natural gravels, soils and/or quarry products on-site or in a mixing plant.

Such stabilisation can achieve the following:

- Correction of grading generally associated with gap graded or high fines content gravels;
- Correction of grading and increasing plasticity of dune or river-deposited sands which are often single sized;
- Correction of grading and/or plasticity in crushed quarry products.

The following methodology, using a ternary diagram (Figure 8.2), has been developed for determining the optimal mix ratio for blending two or more materials to meet the required specification.

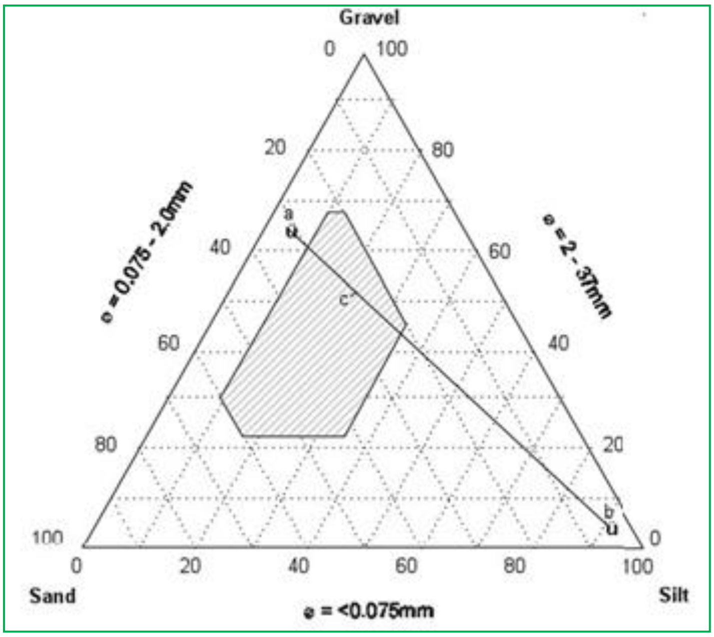


Figure 8.2: Ternary Diagram for Blending Unsealed Road Materials

1. Identify potential material sources that can be used to improve the available material.
2. Determine the particle size distribution of the available material and that considered for addition or blending (wet sieve analysis recalculated with 100 per cent passing the 37.5 mm sieve).
3. Determine the percentages of silt and clay (<0.075 mm), sand (0.075 - 2.0 mm) and gravel (2.0 -37.5 mm) for each source.
4. Plot the material properties on the ternary diagram as points a and b respectively (see example in Figure 8.2);
5. Connect the points. When the two points are connected, any point on the portion of the line in the shaded area indicates a feasible mixture of the two materials. The optimum mixture should be at point c in the centre of the shaded area.
6. The mix proportions are then the ratio of the line ac:bc. This can be equated to truck loads and dump spacing.
7. Once the mix proportions have been established, the Atterberg Limits of the mixture should be determined to check that the shrinkage product is within the desirable range (100 – 365 (or 240 if necessary). The quantity of binder added should be adjusted until the required shrinkage product is obtained, but ensuring that the mix quantities remain within the acceptable zone.

If the line does not intersect the shaded area at any point, the two materials cannot be successfully blended and alternative sources will have to be located, or a third source used for blending.

References

Smith

9 Road Drainage

9.1 Introduction

Road drainage design is the general term that is applied to two separate topics namely:

Internal road drainage. The process of minimising the quantity of water that remains within a road pavement by maximising the ability of the road to lose water to an external drainage system. Sometimes this definition also includes minimising the quantity of water that gets into a road pavement in the first place.

External drainage. This consists of three components:

1. The process of determining the quantity of water that falls upon the road itself and its associated works that needs to be channelled away from the road by the drainage system. This is water that falls upon the road as rain.
2. The process of determining the quantity of water that flows in the streams, rivers and natural drains that the road has to cross. This is water that falls as rainfall at locations away from the road.
3. Design of the individual engineering features of the drainage system to accommodate the flow of water.

This Chapter is concerned with the external drainage system and the drainage standards for roads carrying less than 300 two-axled (and larger) motorised vehicles per day. The Chapter is essentially a guide containing appropriate technical explanations of all the steps in designing the surface water drainage system for LVRs.

Internal pavement drainage is considered in Chapter 7. This Chapter does not deal with route surveying, site investigations, route selection or the actual structural design of bridges and major water crossings. The planning and structural design of river crossings of less than 10m span and drainage structures for roads being considered in this Manual is given in Volume 2. Larger structures are dealt with in the current MRB Road and Bridge Design Manuals.

Neither rainfall nor rivers distinguish between roads carrying low and high volumes of traffic. Therefore, the basic costs of protecting a road from the effects of water are essentially the same and largely independent of traffic. Hence, for LVRs the cost of the drainage system can comprise a larger proportion of the costs of the road.

There are, of course, different levels of protection associated with the risk of serious damage to the road. For principal trunk roads little risk can be tolerated and so expensive drainage measures must be employed. For LVRs the consequences of failure in the drainage system are correspondingly lower but, within the range covered by LVRs, there are some significant differences depending on the length of the road and the availability of an alternative route.

The challenge for the engineer is to choose a level of protection that is suitable for the class of road and the consequences of drainage failure. Thus a certain amount of engineering judgement is required.

Unfortunately, although it is possible to define the probability of specific storm events from extensive rainfall records, if such records are available, it is practically impossible to define the overall level of risk inherent in a drainage system design itself. This is because there are so many other factors that influence its performance. First of all, simply calculating the water volumes flowing in the drainage system following a specific storm involves several important assumptions.

Secondly, the drainage system is not a fixed, unchanging system despite every effort by the designer to protect it and to make it so. Changes are always occurring as a result of aspects such as sedimentation, erosion, the transport of debris, growth of vegetation and landslides. For example, sedimentation will always occur in some places within the drainage system. This affects water flow and drainage capacities in complex ways. Partial blockage by debris or landslides, a particularly important problem in mountainous areas, can quickly lead to full blockage and catastrophic failures unless cleared by maintenance activities.

Erosion is also a formidable enemy of the drainage designer. Very erodible soils can be found extensively in many parts of South Sudan and catastrophic levels of erosion can arise from small disruptions in the smooth flow of water leading to failure of the drainage system.

Naturally the designer attempts to minimise these affects but the effectiveness in doing so is directly related to the cost and to the effectiveness of maintenance (also a function of cost). Hence different levels of risk, and therefore cost, are applied to roads of different standard.

9.2 Summary of Standards and Departures from Standards

9.2.1 Design standards and storm return period

Once the drainage design has been completed, and provided maintenance is carried out to remove potential blockages and repair minor damage, a road drainage system should operate successfully for many years. However, drainage systems cannot be designed for the very worst conditions that might occur on extremely rare occasions because it is too expensive to do so. The various standards for the design of drainage are based on different levels of risk that are attached to the likely occurrence of the different storm intensities for which they are designed, assuming that appropriate routine maintenance is carried out.

Storm events are defined by the intensity and duration of rainfall and are extremely variable in nature over periods of many years. Thus a statistical distribution of storm severities shows that very severe storms are quite rare and that less severe storms are more common. The risk of a severe storm occurring is defined by the statistical concept of its likely *return* period which is directly related to the probability of such a storm occurring in any one year. Thus a very severe storm may be expected, say, once every 50 years but a less severe storm may be expected every 10 years.

This does not mean that such storms will occur on such a regular basis. A severe storm expected once every 50 years has, on average, a probability of occurring in any year of 1 in 50 (or 0.02 or 2%). Similarly a storm of lower intensity that is expected to occur, on average, once every 10 years has a probability of occurring in any one year of 1 in 10 (or 0.1 or 10%). The operative words here are “on average” and it is useful to realise that there is always a finite probability that the worst storm for 200 years may occur tomorrow.

Most drainage structures are likely to be severely damaged if their capacity is exceeded for any length of time hence their capacity is the most important aspect of their design. In general, the more severe the storm for which the structure is designed, the more expensive it is to build; and the cost of designing for the highest possible storm severity (i.e. zero risk) is prohibitive. Drainage standards are therefore defined by the level of risk. This is done using the concept of return period of the maximum storm for which they are designed.

There are three factors that determine the level of risk that is appropriate for each structure namely:

- The standard of the road (i.e. the traffic level);
- The cost of the drainage structure itself;
- The severity of the consequences should the road become impassable because of a failure of the drainage system.

If a drainage structure on a road carrying high levels of traffic is damaged or fails completely, the disruption and associated costs to the traffic can be very high and therefore the structures on such a road are designed for low risk (i.e. for storms of long return periods). They are therefore relatively expensive. On the other hand, if a drainage structure should fail on a road carrying low levels of traffic, the likely disruption to traffic and the associated costs are less and hence the higher cost of designing the drainage for low risk cannot be justified. The drainage is therefore designed for shorter storm return periods.

Similarly, the cost of replacement or repair of large and expensive drainage structures is high and therefore they are designed to minimise this risk by designing for very severe storms (i.e. storms with long return periods). This increases their cost but reduces the risk of damage. Higher risks can be tolerated for smaller and less expensive structures that are usually easier to repair; hence these are designed for less severe storms (i.e. shorter return periods).

An overriding principle for the designer is to consider the consequences of a drainage failure. In situations where the road is relatively short and an alternative route, albeit a longer one is available, the social and economic consequences of a drainage failure that makes the road impassable for any length of time are not high. In contrast, there are also many situations in South Sudan where there is no alternative route at all or, if there is one, it is very long. Under these circumstances additional expenditure to reduce the risk of such an occurrence is justified. This is done by designing for a larger storm (i.e. a longer storm return period).

It is difficult to calculate the exact trade-off between the cost of designing for low risk and the costs and consequences of failure of a drainage structure. Furthermore, the precision with which design storms can be calculated depends on the availability of detailed rainfall data that are required to have been collected over a period of many years. Even with good rainfall data, there are other uncertain assumptions that need to be made in carrying out the calculations. Thus, in most situations the accuracy of the calculations of the required water flow capacity is not very high despite the apparent sophistication that is apparent in some methods of drainage design and it is therefore important to include a factor of safety.

Because of these issues the drainage standards can only be based on a review of practices throughout the world combined with local engineering judgement and consensus. Table 9.1 indicates the design standards for LVRs in South Sudan. For strategic routes, routes of very high economic or social importance or if the alternative route in the event of a drainage failure is more than an additional 75km or if there is no alternative route suitable for vehicles, Table 9.2 should be used instead.

Table 9.1: Design storm return period (years)

Structure type	**Geometric design standard**	
	DC3-4	DC1-2
Gutters and inlets	2	2
Side ditches	5	5
Ford	5	5
Drift	5	5
Culvert diameter <2m	10	10
Large culvert diameter >2m	15	10
Gabion abutment bridge	20	15
Short span bridge (<10m)	25	15
Masonry arch bridge	25	25
Medium span bridge (15 – 50m)	50	25
Long span bridge >50m	100	50

Table 9.2: Design storm return period (years) for severe risk situations

Structure type	Geometric design standard	
	DC3-4	DC1-2
Gutters and inlets	5	5
Side ditches	10	10
Ford	10	10
Drift	10	10
Culvert diameter <2m	20	20
Large culvert diameter >2m	25	20
Gabion abutment bridge	25	20
Short span bridge (<10m)	50	25
Masonry arch bridge	50	25
Medium span bridge (15 – 50m)	100	50
Long span bridge >50m	100	100

9.2.2 Methods of design

The simplest method of all is essentially a stage construction process whereby simple rules of thumb are used for the initial design with little or no calculation. The road is built and then, in the following year or two, problems that arise where there is inadequate capacity in the drainage system are rectified as quickly as possible. Such an approach is normally used only for very low volume roads and may be applicable if the engineering resources are readily available during the required period following initial construction. It should be noted that in South Sudan mobilization costs due to long haul distances to site and general high construction costs are unlikely to result in repairs being carried out at a later date, with the exception of the lowest level of road, which could possibly be maintained through community engagement and labour based methods. Therefore it may be more cost effective to design conservatively where haul distances and distance to site are noted to be high.

Very few national standards specifically address the problem of designing drainage for LVRs. The implication is that the methods used for all roads should be applied to LVRs but this is impracticable. The methods described in this manual range from the simplest approach appropriate to the lowest standards up to more comprehensive methods that could be used whenever sufficient data are available. The manual does not include the full range of methods suitable for the higher road classes.

9.2.3 Departures from standards

It is fundamental to the concept of setting standards that they should be applied at all times. However, the basic standards for drainage structures and drainage design cannot be precisely defined because sufficient data may not be available to carry out the designs in the ideal way. As a result, the designer must use simpler methods. Furthermore, even if data are available to allow more sophisticated methods to be used, there are worrying large differences in the results that the various methods give. Thus whether sophisticated numerical methods or simple methods are used, different answers will arise from the various methods. All that can be done is for the designer to use the methods available and to exercise a degree of engineering judgement in selecting the result for the design.

The same arguments do not apply to the detailed engineering design of the components of the drainage system once the maximum water flow has been estimated. If the designer wishes to depart from these, then written approval will be required from Ministry of Roads and

Bridges. The designer should submit all proposals for departures from standards to the appropriate client officer for evaluation.

9.3 Hydrology: Estimating Maximum Flow for Drainage Design

Before a drainage structure can be designed, it is necessary to determine the maximum likely flow of water to be accommodated by the structure. Estimation of maximum peak flow for design of cross drainage structures is detailed in Chapter 6 of Volume 2, and is not detailed further here. Information may be needed on:

- Water catchment area;
- Rainfall characteristics;
- Topography;
- Vegetation and soils;
- Catchment shape;
- Stream and river flows if available;
- Available storage in lakes and swamps;
- Rural and urban development plans;
- Water management plans (e.g. river basin master plans).

The remainder of this Chapter deals primarily with external drainage and erosion control.

9.4 Components of External Drainage

An effective external drainage system must fulfil several functions:

- Prevent or minimise the entry of surface water into the pavement;
- Prevent or minimise the adverse effects of sub-surface water;
- Remove water from the vicinity of the pavement as quickly as possible;
- Allow water to flow from one side of the road to the other.

This must be achieved without endangering the road or adjacent areas through increased erosion or risk of instability. Thus an external drainage system consists of several complementary components:

- Surface drainage to remove water from the road surface quickly (i.e. camber);
- Side drainage to take water from the road and to prevent water from reaching the road;
- Turnouts to take the water in the side drain away from the road;
- Cross drainage to allow the water in the side drains, and from any other sources, to cross the road line by channelling it under or across the road;
- Interceptor drains to collect surface water before it reaches the road;
- Sub-surface drains to cut off sub-surface water and to lower the water table when required;
- Erosion control (often simple scour checks) to slow down the water in the side drains and prevent erosion in the drains themselves and downstream of drainage outlets or crossings.

All these types of drains have to work together in order to protect the road from being damaged by water. Cross-drainage includes structures to allow permanent or seasonal watercourses to cross the road line and therefore includes bridges. The appropriate cross drainage structures for low volume roads are dealt with in Volume 2.

9.4.1 General principles

Conservation of the natural drainage system around the road alignment is one of the most important concerns during design and construction. By effectively creating a barrier to natural surface drainage that is only crossed at intervals by constructed drainage crossings, road construction can lead to significant local increases in catchment areas and increased water flows. Furthermore, in the case of paved roads especially, road drainage reduces the time taken to reach maximum flow by shedding water from impermeable surfaces relatively quickly. Therefore, in addition to constructing a drainage system to convey the design run-off without surcharge, blockage by sediments, or scour, attention must be paid to strengthening those parts of the natural slope drainage system that experience increased run-off, and hence erosion potential, as a result of road construction. The main ways of doing this are to:

- Control road surface drainage;
- Design culverts or drifts that convey water and debris load efficiently;
- Ensure there are enough drainage crossings to prevent excessive concentration of flow;
- Protect drainage structures and stream channels for as far downstream as is necessary to ensure their safety and prevent erosion of land adjacent to the water course;
- Plant vegetation on all new slopes and poorly-vegetated areas, around the edges of drainage structures and appropriately along stream courses, without impairing their hydraulic efficiency or capacity.

9.4.2 Sources of water

This chapter is concerned with dealing with the water that flows outside the road prism. Minimising the amount of water that gets into the structure of the road itself and minimising the damage that it can cause are dealt with in Chapter 7.

9.4.3 Road surface drainage

Camber is a critical part of the road drainage system, removing water from the road surface and transferring it to the side drains or verge. Camber and cross-fall are part of the geometric design of the road. Their values are discussed in the geometric design chapter (Chapter 6) and surfacing and pavement design chapter (Chapter 7) of this Manual. Chapter 6 details the camber to be applied for each road classification.

9.4.4 Side drains

Side drains serve two main functions namely to collect and remove surface water from the immediate vicinity of the road and, where needed, to prevent any sub-surface water from adversely affecting the road pavement structure.

Seepage may occur where the road is in cut and may result in groundwater entering the sub-base or subgrade layers as illustrated in Figures 9.1 and 9.2. Inadequate surface or subsurface drainage can therefore adversely affect the pavement by weakening the soil support, and initiating creep or failure of the downhill fill or slope. Localised seepage can be corrected in various ways but seepage along more impervious layers, such as shale or clay, combined with changes in road elevation grades, may require subsurface drains as well as ditches as shown in Figure 9.3.

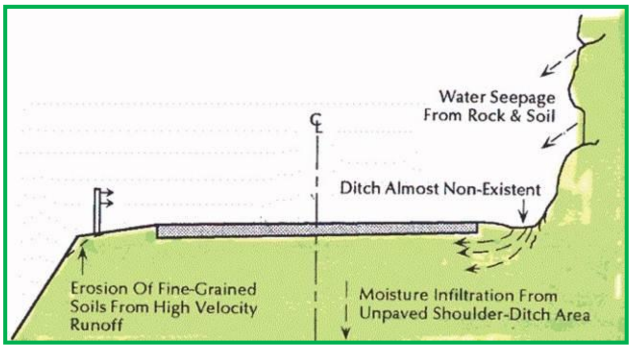


Figure 9.1: Inadequate side drains

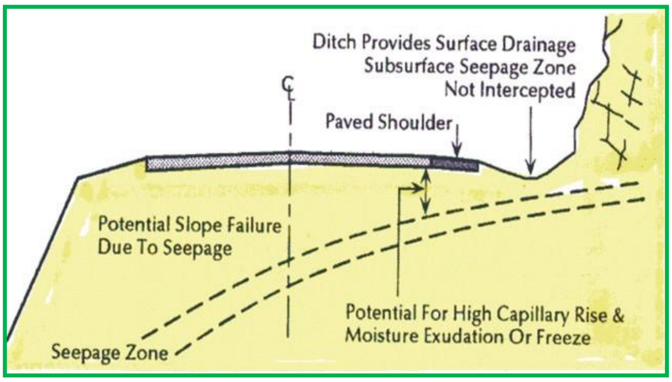


Figure 9.2: Inadequate side drains and subsurface drainage

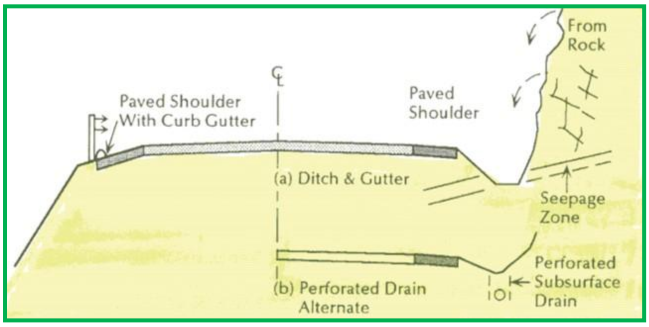


Figure 9.3: Proper interception of surface runoff and subsurface seepage

If the road has effective side drains and adequate crown height, then the in situ subgrade strength is more likely to stay above the design value. If the drainage is poor, the in situ strengths will fall to below the design value. Crown height is discussed in Chapter 7 of this Manual.

Side drains can be constructed in three forms (Figure 9.4): V-shaped, rectangular or trapezoidal.

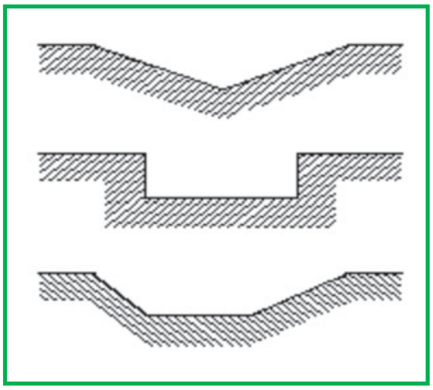


Figure 9.4: Side drains

The choice of side drain cross-section depends on the required hydraulic capacity, arrangements for maintenance, space restrictions, traffic safety and any requirements relating to the height between the crown of the pavement and the drain invert (as discussed in Chapter 6). Construction method will also influence the design selection. It may be preferable to opt for larger V-shaped drains rather than trapezoidal drains if an equipment based construction method (i.e. including use of graders) or intermediate based technology (i.e. including use of towed graders) are being applied. This should be considered at the design stage.

Design volumes of run-off are usually estimated using the Rational Method (See Volume 2). Flow velocities are calculated from the Manning equation (See Volume 2,) using roughness values shown in Table 6.5 of Volume 2.

Where labour is available for the application of labour based methods, the adoption of a trapezoidal cross-section will facilitate maintenance and will be acceptable from the point of view of traffic safety. It is much easier and appropriate to dig and clean a trapezoidal drain with hand tools and the risk of erosion is lower. The minimum recommended width of the side drain is 500mm. This shape carries a high flow capacity and, by carefully selecting the gradients of its side slopes, it will resist erosion.

The V-shape is the standard shape for a drainage ditch constructed by a motor-grader or towed grader. It can be easily maintained by heavy or intermediate equipment but it has relatively low capacity necessitating more frequent structures for emptying it. Furthermore the shape concentrates flow at the invert and encourages erosion.

The rectangular shaped drain requires little space but needs to be lined with rock, brick or stone masonry, or concrete to maintain its shape. Rectangular shaped side drains are usually used in an urban or mountain road environment where space in the road corridor is limited.

In very flat terrain and reasonable soils it is often best to use wide unlined “meadow drains”. These are formed shallow and continuous depressions in the surface that avoid abrupt changes in surface profile. When properly designed, their capacity is high and the flow velocity is low so that erosion should be controlled.

When the subgrade is an expansive soil, changes in moisture content near to the road itself must be minimised.

As far as traffic safety is concerned, a wide and shallow drain for a given flow capacity is preferable to a deeper one but, particularly on steep sidelong ground, the extra width required to achieve this may be impracticable or too expensive.

Side drains (as well as the road itself) should have a minimum longitudinal gradient of 0.5%, except on crest and sag curves. Slackening of the side drain gradient in the lower reaches of significant lengths of drain should be avoided in order to prevent siltation.

For the construction of LVRs the spoil material from the construction of the side drain is usually used to provide the formation of the road and its camber. When roads are built using labour-based methods this is usually the only source of material (unless the road is to be built on an embankment) hence it is important that the size of the drain is wide and deep enough to provide sufficient material. Failure to do so is often the reason for the resulting low camber and early deterioration of gravel and earth roads. In most circumstances a wide trapezoidal drain is the ideal solution.

Access across side drains for pedestrians, animals and vehicles needs to be considered. Community representatives should be consulted with regard to locations, especially for established routes. The methods that could be used are:

- Widening the drain and taking its alignment slightly away from the road;
- Hardening the invert and sides of the drain;
- Beam/slab covers or small culverts.

The arrangement must be maintainable and not risk blockage of the side drain. Failure to accommodate these needs will usually result in later ad hoc arrangements which may partially or fully block the side drain and, if not remedied, will lead to a local failure of the drainage system and even the road itself.

Groundwater in the subgrade can be released either by using a drainage layer at sub-base level or by incorporating gravel cross drains (grips) in the shoulder that exit via a weephole in the side drain backed with a piece of filter fabric. The weepholes must be set at the correct level to take the water from the appropriate pavement layer and the drain must be sufficiently deep so that there is little possibility of the water in the drain being of sufficient depth for it to flow back into the road.

Deeper drains, comprising a filter-wrapped perforated pipe within a graded gravel backfill, can be constructed under very wet slope conditions to a depth of 1 to 1.5m below the level of the side drain invert, and led to the nearest culvert inlet.

9.4.5 Erosion control in the side drain

When the water flows too fast, it will erode the bottom of the drain. The faster that water flows, the more soil it can erode and carry away. There are various methods of reducing erosion, the two most common being to build simple scour checks or to line the drains.

Scour checks (sometimes called check dams) reduce the speed of water and help prevent it from eroding the road structure. Typical designs are shown in Figure 9.5. The scour check acts as a small dam and, when naturally silted up on the upstream side, effectively reduces the gradient of the drain on that side, and therefore the velocity of the water. The energy of the water flowing over the dam is dissipated by allowing it to fall onto an apron of stones. Scour checks are usually constructed with natural stone, masonry, concrete or with wooden or bamboo stakes. By using natural building materials available along the road side, they can be constructed at low cost and be easily maintained after the road has been completed.

There must be sufficient cross-sectional area above the scour check (i.e. where the water has been slowed down) to accommodate the maximum design flow. Wide drains are also preferred to reduce the velocity of the water and minimise erosion but space is at a premium in the type of terrain where scour checks are required so wide drains may not always be practicable.

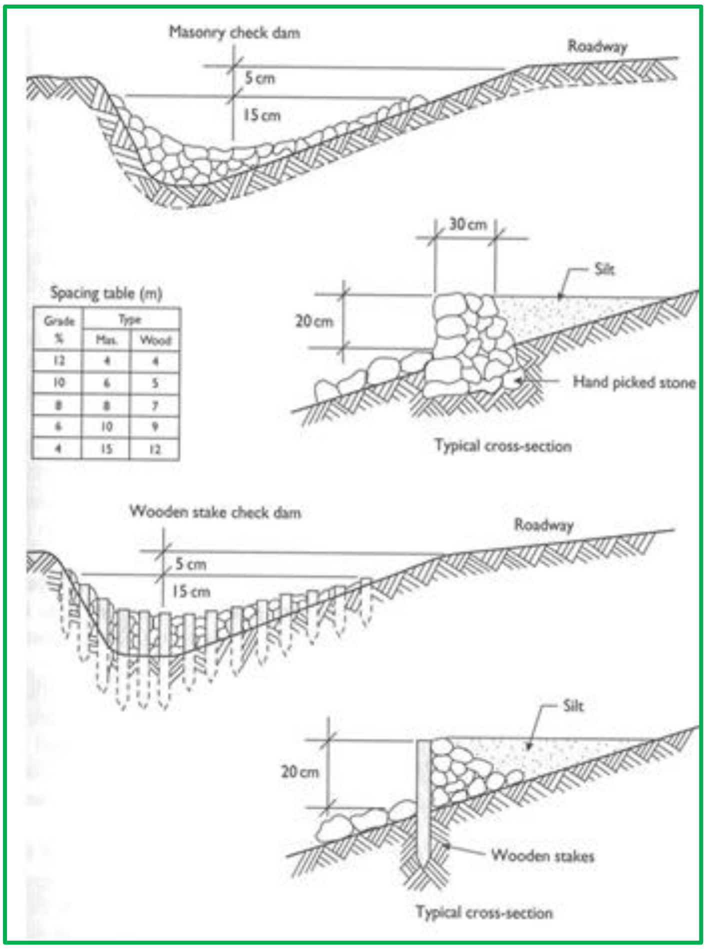


Figure 9.5: Typical design of scour checks

The distance between scour checks depends on the road gradient and the erosion potential of the soils. Table 9.6 shows recommended values but these may need to be modified for more erodible soils.

Table 9.6: Spacing between scour checks

Road gradient (%)	Scour check interval (m)
3	Not required
4	17
5	13
6	10
7	8
8	7
9	6
10	5
11	4
12	4

After the basic scour check has been constructed, an apron should be built immediately downstream using stones. The apron will help resist the forces of the waterfall created by the scour check. Sods of grass should be placed against the upstream face of the scour check wall to prevent water seeping through it and to encourage silting to commence on the upstream side. The long-term goal is to establish a complete grass covering over the silted scour checks to stabilise them.

Sections of side drain with scour checks cannot be maintained by motor grader or towed grader and will need to be maintained by hand.

Depending on the strength of the material in which the drains are excavated and the velocity of run-off they are expected to carry, side drains may also need to be lined. The controlling factor is the ease of erosion of the soil. Table 9.7 indicates the critical velocities for different materials. With velocities greater than those shown, erosion protection measures will be required.

The drains may be lined with heavy-duty polythene, or some other impermeable material, before masonry pitching is applied. This will prevent water penetration if the masonry becomes cracked by movement. The lining can also be extended up the banks to prevent lateral erosion. When the cross-sectional area is less than about $0.1m^2$ and the gradient is gentle, drains can be lined with unbound masonry. Larger and steeper drains are lined with mortared masonry, although they are considerably more expensive. Any gap between the drain and the hillside must be filled with compacted impermeable material (e.g. clay) sloping towards the drain to minimise infiltration behind it.

Table 9.7: Permissible flow velocities (m/sec) in excavated ditch drains

Soil type	Clear water	Water carrying fine silt	Water carrying sand and fine gravel
Fine sand	0.45	0.75	0.45
Sandy loam	0.55	0.75	0.6
Silty loam	0.6	0.9	0.6
'Good' loam	0.75	1.05	0.7
Lined with established grass on good soil	1.7	1.7	1.7
Lined with bunched grasses (exposed soil between plants)	1.1	1.1	1.1
Volcanic ash	0.75	1.05	0.6
Fine gravel	0.75	1.5	1.15
Stiff clay	1.15	1.5	0.9
Graded loam to cobbles	1.15	1.5	1.5
Graded silt to cobbles	1.2	1.7	1.5
Alluvial silts (non colloidal)	0.6	1.05	0.6
Alluvial silts (colloidal)	1.15	1.50	0.9
Coarse gravel	1.2	1.85	2.0
Cobbles and shingles	1.5	1.7	2.0
Shales	1.85	1.85	1.5
Rock	Negligible scour at all velocities		

Channels can also be lined with gabion, dry stone pitching, rip-rap or vegetation.

When constructing a channel lining it is important to reproduce, as a minimum, the dimensions of the original channel. A curved rather than rectangular shaped cross-section to the bed lining is preferable. The main disadvantage with channel linings is that a lower channel roughness leads to an increase in flow velocity and hence an increase in scour potential further downstream. In the case of masonry aprons, or gabion mattresses with masonry screeds, some reduction in velocity can be achieved by grouting protruding stones into the surface.

Masonry linings can be constructed to fit the streambed much more closely than gabion. They are also less easily abraded, but they cannot tolerate significant settlements, loss of support by seepage erosion or high groundwater pressure.

Dry stone pitching is usually only suitable where discharges are lower than 1 m/sec per metre width, and where sediment load is relatively fine-grained.

Grass can provide some resistance to channel erosion and may be used where flow velocities are not expected to be too high. The introduction of grass will also tend to reduce flow velocities, although channel vegetation should not be so widespread as to inhibit or divert flow, which could lead to bank scour. Where immediate effective protection is required, a structural solution is preferable to a vegetative one.

The winning of boulders and cobbles from gully beds for road construction materials can reduce the armouring effect provided by coarse material. If the bed material appears to be weathered and static for much of the time, then its removal could expose more erodible sediments beneath. In such cases, extraction from the channel bed should be discouraged or prohibited. Conversely, where the entire bed deposit is fresh and evidently mobile, the removal of material may not have a significant effect on channel stability, especially if the quantities concerned are small compared to the volume of bed load.

Cascades or steps in the drain long-section can also be a useful means of reducing flow velocity, although both scour checks and cascades can impede the transport of debris, increasing the risk of blockage.

9.4.6 Mitre drains or turnouts

It is normally best practice to discharge the water from the side drains as frequently as possible. If it can be discharged on the same side of the road as the drain, a turnout or mitre drain is used to lead the water away. Mitre drains simply lead the water onto adjacent land therefore care is required to design them to ensure that problems associated with the road are not passed on to the farmer or landowner. It is advisable to consult adjacent land users regarding the discharge of water onto their land to gain their support and agreement and to avoid possible problems in the future.

The principle is to aim for low volumes and low velocities at each discharge point to minimise local erosion and potential downstream problems. The maximum spacing of turnouts depends on the volume of water flowing in the drain and therefore hydrological principles may need to be used to estimate this. However, in many cases it is only water shed from the road itself that flows in the side drain and this is relatively easy to estimate using the Rational Method (Chapter 6, Volume 2).

Where soils are very erodible, it may be preferable to increase side drain capacity to convey runoff to the next available safe discharge point rather than to construct side drain turnouts or relief culverts on erodible slopes. With the extra volumes of water that this entails, the design of these less frequent safe discharge points will usually be more expensive.

In mountainous terrain the discharge of water is considerably more difficult and consequently more expensive. This is discussed in more detail in Section 9.6.

Table 9.8 gives the maximum spacing. However, spacings of mitre drains should normally be more frequent than this and values as low as one every 20 m may be required to satisfy landowners.

Table 9.8: Maximum spacing of mitre drains

Road gradient (%)	Maximum mitre drain interval (metres)
12	40
10	80
8	120(1)
6	150(1)
4	200(1)
2	80(2)
<2	50(2)

Notes:

1. A maximum of 100m is preferred but not essential
2. At low gradients silting becomes a problem

In order to ensure that water flows out of the side drain into the mitre drain, a block-off is required as shown in Figure 9.6. It is essential that the mitre drain is able to discharge all the water from the side drain. If the slope of the mitre drain is insufficient, the mitre drain needs to be made wide enough to ensure this.

The desirable slope of the mitre drains is 2%. The gradient should not exceed 5% otherwise there may be erosion in the drain or on the land where the water is discharged. The drain should lead gradually across the land, getting shallower and shallower. Stones may need to be laid at the end of the drain to help prevent erosion.

In mountainous terrain, it may be necessary to accept steeper gradients. In such cases, appropriate soil erosion measures should be considered.

In flat terrain, a small gradient of 1% or even 0.5% may be necessary to discharge water, or to avoid very long drains. These low gradients should only be used when absolutely necessary. The slope should be continuous with no high or low spots. For flat sections of road, mitre drains are required at frequent intervals of 50m to minimise silting.

Angle of mitre drains

The angle between the mitre drain and the side drain should not be greater than 45 degrees. An angle of 30 degrees is ideal (Figure 9.6).

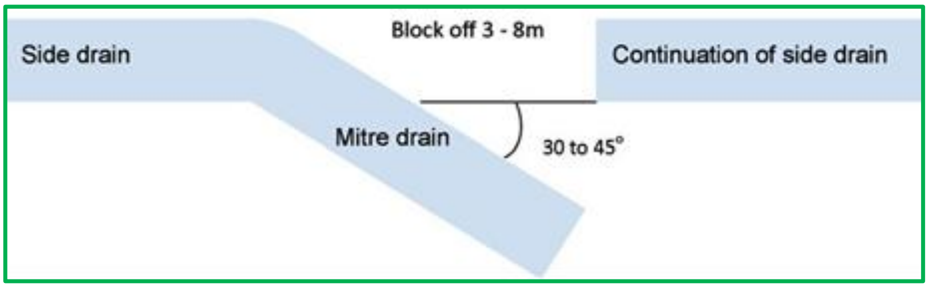


Figure 9.6: Angle of mitre drain

If it is necessary to take water off at an angle greater than 45 degrees, it should be done in two or more bends so that each bend is not greater than 45 degrees (Figure 9.7).

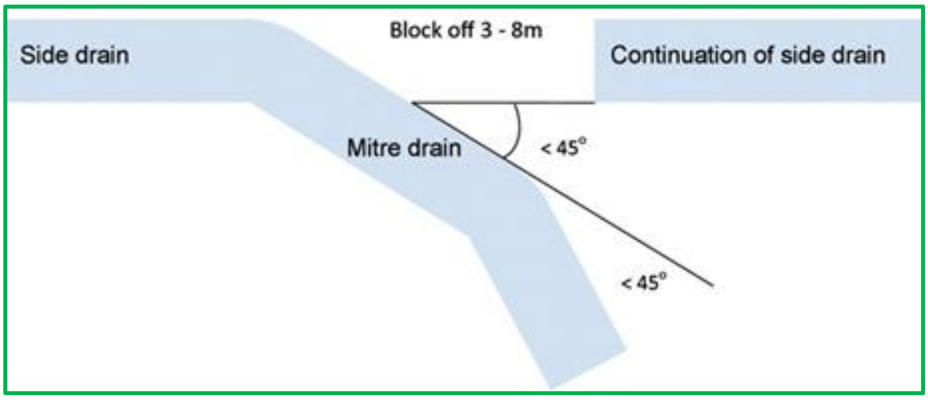


Figure 9.7: Mitre drain angle greater than 45 degrees

9.4.7 Wet lands

Road crossings in wet areas, including damp meadows, swamps, high groundwater areas, and spring sources, are problematic and undesirable. Wet areas are ecologically valuable and difficult for road building. Soils in these areas are often weak and require considerable subgrade reinforcement. Drainage measures are expensive and may have limited effectiveness. Therefore, if at all possible, such areas should be avoided.

If wet areas must be crossed, special drainage or construction methods should be used to reduce impacts from the crossing, which will usually require an embankment. They include multiple drainage pipes or coarse permeable rock fill to keep the flow dispersed, subgrade reinforcement with coarse permeable rock, grade control, and the use of filter layers and geotextiles. The objective is to maintain the natural groundwater level and flow patterns dispersed across the meadow and, at the same time, provide for a stable, dry roadway surface.

Local wet areas can be temporarily crossed, or 'bridged' over, using logs, landing mats, tyres, aggregate, and so on. Ideally, the temporary structure will be separated from the wet area with a layer of geotextile. This helps to facilitate removal of the temporary material and minimizes damage to the site. Also, a layer of geotextile can provide some reinforcement strength as well as provide separation to keep aggregate or other materials from punching into the weak subgrade.

Subsurface drainage, through use of under-drains or aggregate filter blankets, is commonly used along a road in localised wet or spring areas, such as a wet cut bank with seepage, to specifically remove the groundwater and keep the roadway subgrade dry. A typical under-drain design uses an interceptor trench1-2 metres deep and backfilled with drain rock, as shown in Figure 9.8.

Subsurface drainage is typically needed in local wet areas and is much more cost-effective than adding a thick structural section to the road or making frequent road repairs. In extensive swamp or wet areas, subsurface drainage will often not be effective. Here, either the roadway platform needs to be raised well above the water table, or the surfacing thickness design may be based upon wet, weak subgrade conditions that will require a relatively thick structural section. A thick aggregate layer is commonly used, with the thickness based upon the strength of the soil and anticipated traffic loads.

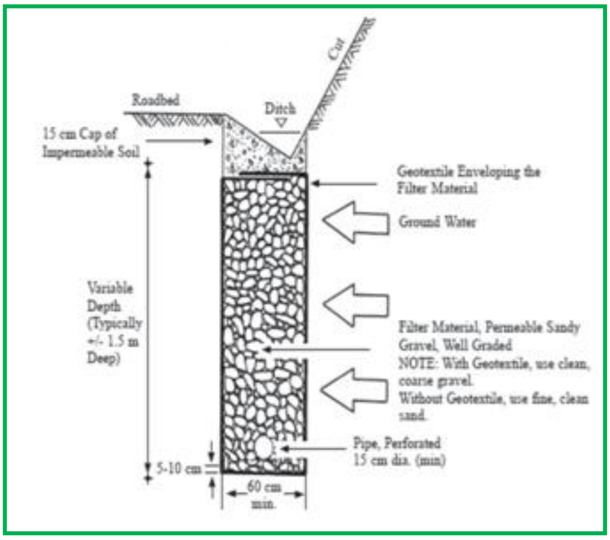


Figure 9.8: Typical sub-surface drain

9.4.8 Interceptor, cut-off or catch-water drains

As its names imply, such drains are constructed to prevent water flowing into vulnerable locations by 'intercepting', 'cutting off' or 'catching' the water flow and diverting it to a safe place.

For example, where the road is situated in sidelong ground on a hillside, a significant amount of rainwater may flow down the hill towards the road. This may cause damage to the face of cuttings and even cause landslips. Where this danger exists an interceptor drain should be installed to intercept this surface water and carry it to a safe point of discharge; usually a natural watercourse (Figure 9.9).

The interceptor drain should be located so that:

- It drains at a satisfactory gradient throughout its length (2%);
- It is not too close to the cut face. It should be at least 3-5m away so that it does not increase the danger of a landslip.

If steep gradients in the drain are unavoidable then scour checks (Section 9.4.5) should be installed.

The material excavated to form the drain is usually placed on the downhill side to form a bund. Vegetation cover should be established as soon as possible in the invert and sloping sides of the interceptor drain and bund to resist erosion. However, where no seepage is tolerable, consideration should be given to lining the drain so that it is truly impermeable thereby minimising the risk that water will weaken the cut slope.

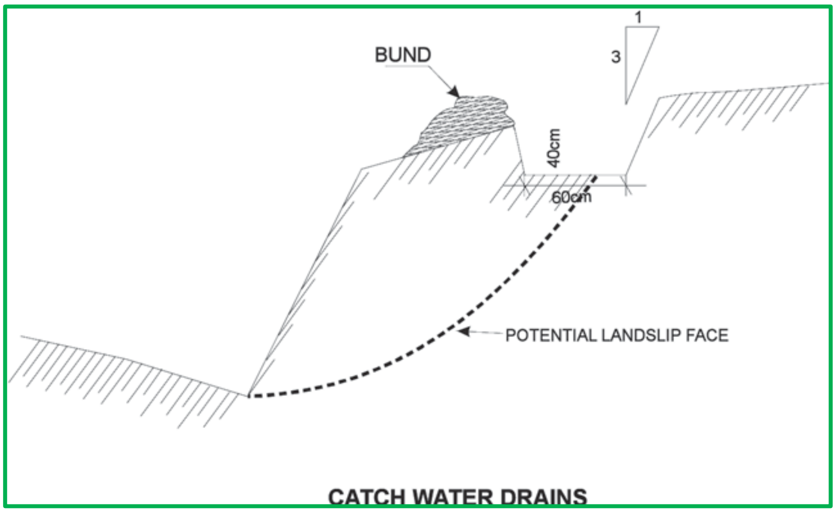


Figure 9.9: An interceptor, cut-off or catch-water drain

The interceptor drain should normally be 600mm wide, 400mm (minimum) deep with sides back-sloped at 3:1 (vertical: horizontal).

Similar interceptor drains can be used whenever water is flowing towards the road; they are not restricted to protecting cut slopes, but such drains are only useful when surface runoff rates are significant.

Surface runoff can be expected only during high intensity rainfall on moderate to steeply inclined slopes, on slopes of low permeability where vegetation is patchy, or where runoff from agricultural land becomes concentrated onto un-vegetated soil slopes. If surface runoff is substantial, and there is a clear threat of erosion or slope failure further downslope, the use of such drains is justifiable. However, they are not without problems. They are easily damaged or blocked by debris and are often not seen and therefore not cleaned on a regular basis. In addition, differential settlement or ground movement will dislocate masonry drains, leading to concentrated seepage if they are constructed without polythene lining. If there is any doubt about their effectiveness, or whether they can be maintained in the long term, it is better not to build them than have them become forgotten and allowed to fall into disrepair, making drainage and instability problems worse.

Factors to be considered in the design of surface drains are:

- Water collected by the drain must be discharged safely in a manner that will not initiate erosion elsewhere;
- Construction of masonry-lined drains should be limited to undisturbed slope materials; differential settlement, which frequently occurs in made ground and particularly at the interface between natural ground and fill, will lead to rupture;
- Drain gradients should not exceed 15 %;
- For ease of maintenance and to minimise erosion they should be wide and have sloped sides;
- Where people have to cross the drain, easy side slopes should be provided so that the people will not fill the drain to cross it.
- Stepped drain outlets should be provided with a cascade down to the collection point;
- Drains should discharge into a stream channel wherever possible, and preferably into channels that already convey a sizeable flow in comparison to the drain discharge;

- Low points in the drain system should be designed against overtopping by widening or raising the side walls;
- Lengths of drain should be kept short by the construction of frequent outlets in order to reduce erosion potential should drain failure occur.

Where it is not practicable to discharge cut-off drainage into an adjacent stream channel, cascades can be constructed down the cut slope to convey water into the side drain. However, these structures are often vulnerable to the effects of side splash, undermining by seepage erosion and concentrated runoff along their margins. They must be designed to contain the water, and their margins must be protected with vegetation or stone pitching.

In very sensitive locations a simple earth bund can be constructed instead of a cut-off drain. The disadvantage is that material may have to be excavated a little way from the bund and cast or transported. However, the distinct advantage is that the soil surface is not disturbed at the bund and existing vegetation can be encouraged to grow onto the bund to stabilise it. A range of bio-engineering measures can also be used in sensitive areas and specialist advice should be sought on this.

9.4.9 Chutes

Chutes are structures intended to convey a concentration of water down a slope that, without such protection, would be subject to scour. Since flow velocities are very high, stilling basins are required to prevent downstream erosion. The entrance of the chute needs to be designed to ensure that water is deflected from the side drain into the chute, particularly where the road is on the steep grade.

9.5 General Erosion Control

Erosion forces are one of the most destructive forces an engineer has to contend with in designing and constructing roads but the problem of erosion can be minimised by providing suitable precautions at all stages in the design.

The construction of a road often requires land clearing and levelling in the preparation stage. It involves removal of shrubs and trees that are normally acting as wind-breaks, rainfall ‘sponges’ and soil stabilisers and therefore, on removal, the soil erosion process is accelerated, especially in sloping areas.

After construction, erosion often appears in road embankments as gullies in the shoulders and embankment slopes; as gouges in the side drains, which endangers the traffic; and the actual road foundation. It undermines fills and backslopes, initiating landslides, undermines bridge foundations and other road structures, clogging drainage ditches, culverts and other waterways in the watershed.

It is often impossible to make reliable predictions concerning the full extent of erosion protection likely to be required until the road drainage system is fully functioning and the slopes and drainage channels have responded to the new drainage regime. Constructed roads interrupt the natural drainage of an area, and concentrated water discharge through culverts and drains leads to soil erosion if the drainage is not properly designed.

The general design philosophy of stream course protection is to dissipate as much water energy as possible in the vicinity of the road itself, where erosion is likely to be worst, and protect outfall channels down to a point where they are large enough or sufficiently resistant to withstand the increased flow.

Outfall channel protection usually consists of check dams, cascades and channel linings. It is not uncommon to build protection works for 20-60m downstream of culverts, and there are instances where they have been constructed for distances of 500m or more. If investment to this level of protection is considered necessary, it is clearly important to be sure that the measures will be effective.

Protection of erodible channels upstream of culverts is usually accomplished by check dams and cascades constructed over much shorter lengths, and usually within 20m of the inlet.

Good erosion control should preferably start at the top of the rainfall catchment with the objective being the reduction of water run-off towards the road. The road should be designed with sufficient numbers of culverts and mitre drains to avoid large concentrations of water discharging through the structures. Below the road, water should be channelled safely to a disposal point (e.g. a stream) or dispersed without causing damage to the land.

Often the problem of erosion extends beyond the road environment itself and affects dams, slopes, rivers and streams well away from the road. The steepness of the cut slopes and constructed embankments together with a deficiency in drainage means that landslides may result.

The storage of spoil during road construction may kill local indigenous vegetation, which can cause erosion and slope stability problems. In mountainous regions large quantities of spoil can be generated and the balance between cut and fill is difficult to maintain. Storage of spoil or disposal through haulage may be difficult; therefore the process will involve more effective environmental management to avoid erosion problems.

The channelling of run-off through new routes will result in changes within the natural equilibrium. Excessive water flows may be generated when drainage ditches and other water control structures have become blocked or damaged. The excessive flows will find new routes, which will result in an enlargement of the erosion problems.

Chain impacts, including soil contamination and damage will affect the road environment. Soil contamination will possibly result in vegetation loss and therefore resistance to erosion. Construction of the road may result in deforestation which, in turn, will lead to erosion of bare slopes, the re-channelling of rivers and streams, possibly minor landslides and changes in the microclimatic conditions. The roadworks themselves will temporarily increase waterborne material because rainfall erodes the surface of temporary or new surfaces before they are stabilised.

9.5.1 Identifying and assessing potential erosion problems

The initial project survey will possibly indicate the range of problems that may be encountered, and the design should include measures to mitigate the problems. The following should be considered:

1. Previous or similar construction projects. These can be useful indicators, and evidence of erosion problems can be obtained from the local population.
2. Desk study as part of the pre-feasibility study. More detailed information can often be obtained from a desk study, from maps (geological hydrological, and topographic) and aerial photographs if available.
3. Historic evidence. Signs of erosion or soil instability and evidence of major floods and local agricultural practices should be sought.
4. Drainage design. Consider how water flows will be concentrated by the construction of the road.
5. Cleared areas. Review the areas that will no longer be vegetated after the construction.
6. Cut or fill slopes. Review the slopes that will be at greater angles than previous natural slopes.

9.5.2 Mitigation measures to control erosion and scour

There are a wide range of methods and techniques that may be employed to prevent erosion and allow for the construction of a road in an environment with little or no erosion impact. The simple technique of replanting cleared areas will be effective generally, while the more difficult cases may be addressed with measures such as retaining walls.

The simplest ways of controlling erosion of soil in road projects is by avoidance. This can be achieved by:

- Reducing the area of ground that is to be cleared;
- Quickly replanting cleared areas, maintaining the planted areas and specific bio-engineering measures;
- Avoiding erosion sensitive alignments;
- Controlling the rate and volume of water flows in the area.

Replanting

An important method for reducing erosion and stability problems is by replanting cleared areas. It is suggested that this procedure should be carried out as early as possible during the construction process, and before the erosion becomes too advanced. It is important to select the correct vegetation that will address the specific engineering function required for stabilisation.

The engineering functions of vegetation in erosion protection measures are:

- Retaining material from moving over the soil surface;
- Armour plating the surface against erosion and abrasion;
- Supporting the slope by stabilising it from the base;
- Reinforcing the soil by increasing its effective shear strength;
- Drain the soil profile by taking water into the roots.

Slope protection

Avoiding erosion by stabilising slopes requires good engineering design of the slope form and drainage. This topic is dealt with in more detail in the Chapter 10 on Roadside Slope Stability.

Riprap

The size of riprap needed to protect the stream bank and not move is related to the speed of flow as shown in Figure 9.12. The flow along a long tangent section of stream, or the flow parallel (VP) to the stream, is assumed to be about 2/3, or 67%, of the average velocity (VAVE). The flow in a curved section of stream, with an impinging flow, has an assumed impinging velocity (VI) equal to about 4/3, or 133%, of the average velocity, VAVE. Thus, riprap in an area with relatively fast flow, such as a bend in the channel, will have higher stresses and require larger rock than the size needed in a straight part of the channel.

Note that most of the rock should be as large as, or larger than, the size indicated in Figure 9.10. The Isbash Curve indicates the maximum size rock that might be considered in a critical application. If suitably large rock is not available then the use of cement grouted rock, masonry, or gabions should be considered. Riprap installation details are shown in the Note in Figure 9.10.

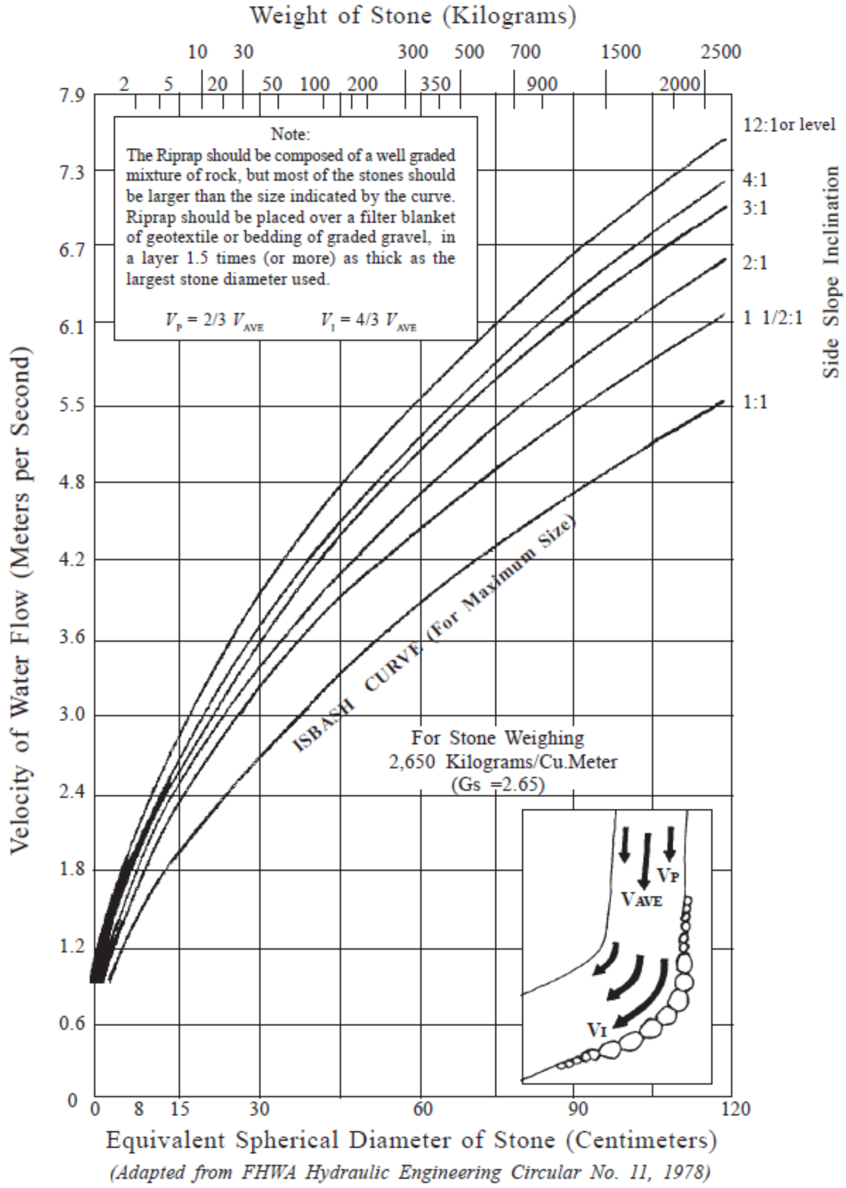


Figure 9.10: Size of stone that will resist displacement for various velocities of water flow and side slopes

Figures 9.11 and 9.12 illustrate the use of riprap. Ideally riprap should be placed upon a stable foundation and upon a filter layer made either of coarse sand, gravel, or a geotextile. The riprap itself should be graded to have a range of sizes that will minimise the voids and form a dense layer. The riprap should be placed in a layer with a thickness that is at least 1.5 times the size (diameter) of the largest specified stone, with the thickest zone at the base of the rock. In a stream channel, the riprap layer should cover the entire wetted channel sides, with some freeboard, and it should be placed to a depth equal or greater than the depth of expected scour.

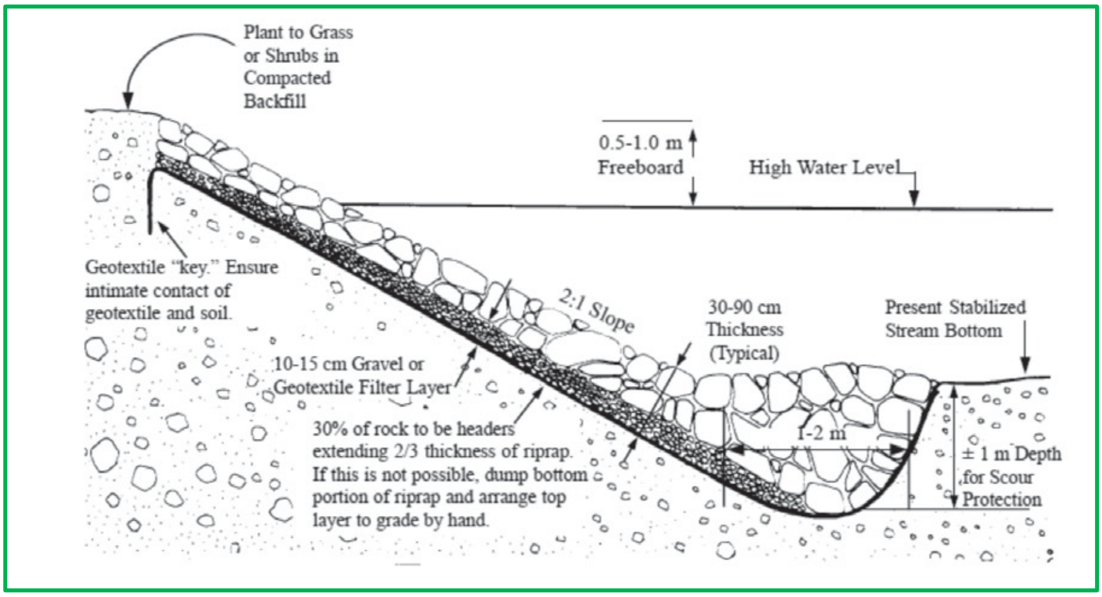


Figure 9.11: Use of riprap 1

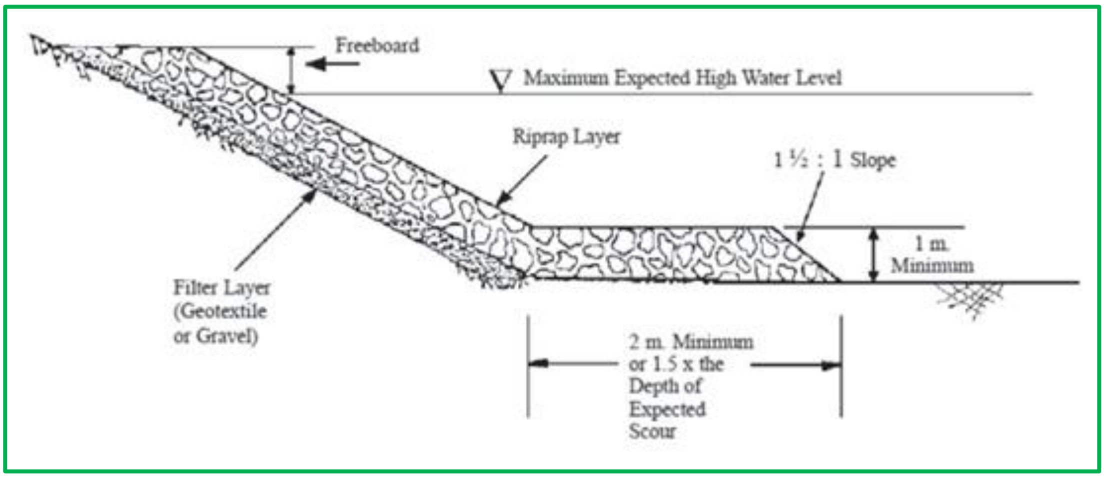


Figure 9.12: Use of riprap 2

Filters

A filter serves as a transitional layer of small gravel or geotextile placed between a structure, such as riprap, and the underlying soil. Its purpose is to prevent the movement of soil behind riprap, gabions or into under-drains, and allow groundwater to drain from the soil without building up pressure.

Traditionally, coarse sand or well-graded, free draining gravel have been used for filter materials. A sand or gravel filter layer is typically about 150 to 300mm thick. In some applications, two filter layers may be needed between fine soil and very large rock. Filter criteria have been developed to determine the particle size and gradation relationships needed between the fine soil, a filter material, and coarse rock such as riprap and are well documented elsewhere.

Today, geotextiles are commonly used to provide filter zones between materials of different size and gradation because they are economical if manufactured locally, easy to install, and perform well with a wide range of soils. When using geotextiles the fabric should be pulled tight across the soil area to be protected before the rock is placed. The geotextile can be a woven monofilament or a needle punched non-woven geotextile, but it must be permeable. The geotextile needs to have an apparent opening size of 0.25 to 0.5 mm. In the absence of other information, a 200 g/m^2 needle-punched non- woven geotextile is commonly used for many soil filtration and separation applications. Other common geotextile or geosynthetic material applications on roads include subgrade reinforcement to reduce the thickness of needed aggregate over very weak soils; separation of aggregate from soft subgrade soils; reinforcement of soils in structures such as retaining walls and reinforced fills; and entrapment of sediment with silt fences.

If knowledgeable engineers are not available, then geotextile distributors or manufacturers should be consulted regarding the function and appropriate types of geotextile to use in various engineering applications. Alternatively, information is available on the requirements of different geotextiles for filter applications in the references.

Erosion and scour protection of the road itself

Water produces harmful effects on road shoulders, slopes, drainage ditches and all the other road structures featured in the design. Spectacular failures can occur when cuttings collapse or embankments and bridges are carried away by flood-water. High water velocities can result in erosion that, if severe, can lead to the road being destroyed. For each type of structure used in the road, specific erosion problems can occur. Section 9.4.5 describes methods of minimising and controlling erosion in road side drains and other forms of drainage ditch. The specific problems associated with fords, drifts and bridge foundations are discussed in Volume 2.

It should also be noted that low flow velocities can result in silt being deposited which will, in turn, block the various drainage structures. The blockage could result in the drainage structure being overtopped at the next flood event. The diverted water then forges a new un-planned route, which results in erosion and possible washout in a new area. It is for this reason that the initial step in road drainage design is that of a hydrological assessment. This will provide design discharges from all major drainage structures and for rivers and streams adjacent to the road alignment.

9.6 Particular Drainage Problems in Severe Terrain

Much of what has been said already in previous sections is directly applicable in mountainous areas. However, the situations in such terrain are usually much more severe. Drainage structures have to resist scour and transmit debris every year and failure to do so will damage or destroy them more effectively than a hydraulic surcharge. It is apparent from experience in mountainous terrain that culverts and bridges are rarely subjected to surcharge or overtopping before the foundations are undermined by scour or the waterway is blocked by debris, both of which can occur during the course of a single flood.

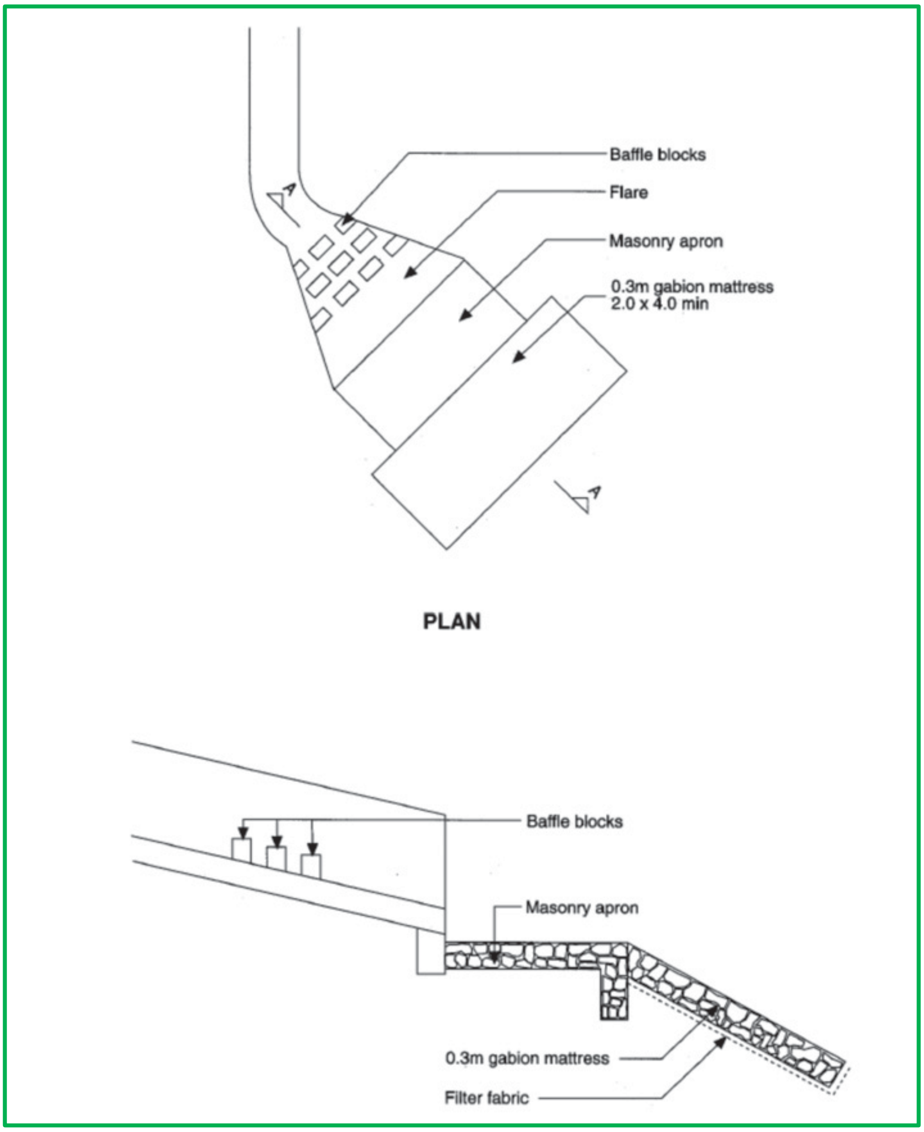


Figure 9.13: Suggested apron details for side drain turnout

9.6.1 Road Construction along valley floors

Valley floor and lower valley side alignments can encounter some or all of the following landforms and hazards:

- Broad rivers that may rise and fall rapidly by several metres on a regular basis;
- Rivers which are actively meandering and changing their plan-form, which could subsequently encroach on the alignment;
- Active river flood plains that are likely to flow full at least once a year - the erosive power against the banks of a river in flood is very great;
- Vigorous tributary streams that are usually highly erosive and capable of transporting large volumes of sediment;
- Fans from tributary valleys that are either eroding rapidly or building up by accumulating debris;

- Flood plain terraces that may be susceptible to river scour on numerous occasions during the wet season, and inundation once every 2-3 years;
- Higher level terraces that may be subject to scour on a regular basis where they protrude onto the active flood plain;
- Rock spurs or promontories that project into the flood plain, forming obstacles to river flow and road alignment;
- Steep, and often eroded, rock slopes on the outside of valley meander bends;
- Slope instability on the lower valley sides in general.

These conditions are most common on youthful valley floors, and especially those with gradients steeper than 1 in 20. The rivers that occupy these valley floors drain steep and frequently unstable catchments. Their flood plains will be either so confined and erosive that the development of terrace sequences has not been possible, or will be subject to cyclic erosion and side slope instability over engineering time-scales to an extent that any preserved terrace surfaces cannot be regarded as safe for road alignment. In such situations, valley floor road alignments should be avoided altogether, otherwise frequent loss of significant sections of road will be inevitable.

Where a valley floor is comparatively mature, and ancient high level terraces are well preserved, then a road alignment located at the back of these terraces, combined with intervening rock cut, may prove satisfactory. If valley side rock mass conditions are not especially adverse to stability, it is usually preferable to construct a road in full cut, or a combination of cut and retained fill through these rocky areas, with a freeboard above the highest anticipated flood level. Where valley side stability conditions are unfavourable, or where river flooding could cause erosion and slope failure to extend far enough upslope to undermine road foundations, it is advisable to examine the practicalities and costs of an alternative alignment altogether.

The cost of constructing roads in major river valleys in mountainous terrain is high and largely independent of traffic levels.

The various design considerations associated with road construction in valley floor locations are discussed below.

9.6.2 Freeboard

It is usual to provide the road surface and associated structures with a freeboard of 2m above design flood level to accommodate surface waves and to provide some leeway in the estimation of flood level. The freeboard can be reduced to 1-1.5m in cases where the hydraulic analysis is more reliable. However, the calculation of the design flood is a particularly difficult task when rainfall and flow gauging data are limited or non-existent; and where a catchment run-off regime is subject to short term fluctuations brought about by road construction, land use change, extreme rainstorms and cycles of slope instability, channel incision and sedimentation. Although widely appreciated, it is also important to remember that flood levels can be substantially higher on the outside of meander bends than anywhere else along a given reach.

9.6.3 Flood plain scour and embankment protection

Flood plain scour, flood plain deposition and valley side instability usually occur at predictable locations. However, external influences, such as tributary fan incursions onto the flood plain, temporary landslide dams and engineering structures, can cause significant short-term modifications to flood plain processes and flow patterns. These should be identified and monitored during the course of construction and maintenance, with appropriate steps taken to protect or locally realign affected sections of road.

It can be assumed that maximum velocities around the concave (outside) banks of river bends and in valley constrictions are between 1.5 - 2 times greater than average or calculated velocities. On highly active flood plains with mobile bed material, predicted and actual scour depths can frequently exceed 5m, and occasionally 10m. Foundation excavations for road retaining walls and other structures are often impracticable at these depths, given the nature of the bed material and the requirements for dewatering the excavation.

Mortared masonry walls are more durable than gabion walls in abrasive riverside locations and they have the potential to arch over small areas of scour, where gabion walls are more likely to deform. Even when heavy-duty selvedge wire is used, gabion boxes are easily broken open by debris-laden water flowing at velocities greater than 4m/s, which is not unusual.

Where there is no choice but to construct a retaining wall within the zone of highly erosive floodwaters, it is worthwhile extending foundation excavations deeper than the depth required for bearing capacity considerations alone, in the expectation that bedrock will be encountered, to obtain a stable foundation for a masonry wall. Alternatively, where the foundation is composed of a significant proportion (usually 50% or greater) of large boulders, the softer materials can be excavated and replaced by concrete to provide a stable foundation for a masonry wall.

However, it is frequently the case that neither of these foundation conditions is achievable within practicable excavations depths, and especially on the outside of river bends where scoured bedrock and boulders have been replaced by finer-grained materials. The potential for foundation scour in these situations will usually dictate that a flexible gabion structure is adopted in preference to a more rigid masonry one, and combined with whatever scour protection works are feasible under the circumstances. Foundation stability can be improved by constructing the retaining wall on a concrete raft, thus reducing differential settlements. Sacrificial walls, double thicknesses of gabion mesh, gabion mattresses and stone rip-rap are likely to prove effective during small and medium-sized flood events only, and will require regular repair or replacement. Reinforced concrete rip-rap can be fabricated in situ if sufficiently large local stone rip-rap is unavailable or cannot be transported to the site, as is often the case. However, the cost of fabricating rip-rap to the required dimension (3m in some cases) is usually prohibitive, and it is usual to adopt a compromise solution under conditions of extreme scour potential.

9.6.4 Cross drainage and tributary fan crossings

Where alignments are located on the lower slopes of steep valley sides, cut slopes can truncate drainage channels with the result that, during heavy rain, sediment and water may overshoot culvert inlets and discharge directly onto the road surface. This is usually remedied by constructing a large catch-wall between the culvert inlet and the road edge, or by providing a dished (concave) concrete causeway. On occasions, concentrated run-off and slope failures will erode new gullies that will require some form of culvert or other drainage provision. A causeway is likely to be the only practicable remedy.

Tributary fans present a range of problems for road alignments. It is useful to differentiate between:

- Mature and stable high level fans;
- Equilibrium fans;

- Immature and unstable fans.

Mature and stable fan surfaces are usually preserved as old, high level landforms that have become incised by rejuvenated stream channels. The principal problem for road construction on high-level fans, other than alignment constraints, is the choice of a suitable site to cross the incised channel, bearing in mind that its banks will be composed of unconsolidated and erodible materials.

In the case of equilibrium fan surfaces, all sediment supplied to the fan is transported out of the catchment by one or a number of well-defined channels. Equilibrium fans, and their wide flood plains, will usually comprise a number of distributary flow channels with only one or two of them occupied during normal flow conditions. Other channels may become occupied every 2-3 years or so, in response to floods or landslide (generated debris flows from further upstream). These fans are usually associated with terrace sequences on the adjacent valley floor and, therefore, represent a stage of drainage development between mature high level fans and immature, active fans on flood plains (described below).

A thorough understanding of the flow patterns across equilibrium fan surfaces is required before a road alignment and bridging structures are designed. Artificially increased channelisation and bank protection of the normal flow channel may increase its definition and capacity in order to allow the design of a road crossing that consists of:

- A relatively short span bridge;
- Approach embankments;
- Vented causeways and drifts (multi-culverted embankments to cater for other distributary channels.

See Volume 2 for detail on raod crossing alternatives..

Immature and unstable fan surfaces are usually characterised by cyclical regimes of erosion and deposition across the whole fan surface during the course of individual storms, and a general process of fan aggradation from one year to the next. The crossing of these fans presents severe problems to valley floor alignments. Sediments will accumulate wherever flow velocity decreases as a result of an abrupt concavity in the channel profile or a sudden increase in channel width. Ideally, valley floor alignments should cross fans immediately upstream of these concavities and, if possible, at the fan apex.

Bridge clearance of at least 5 - 7m should be provided above the existing fan surface level wherever a fan is actively aggrading and its tributary catchment is unstable. However, it is not always possible to conform with this recommendation due to alignment constraints, unstable valley sides adjacent to the fan apex, or the fact that the apex is poorly defined and the fan itself extends upstream into the tributary valley. Under these circumstances, a combination of the following may be the only viable option:

- Gabion check-dams in the stream channel above the fan and erosion control in the catchment above, to control the stream bed level;
- River training and scour protection works upstream and downstream of the bridge, to control the stream course;
- A commitment to regular maintenance and waterway clearing operations, to keep flow within the channel and to provide room for the accumulation of debris during fan-building episodes.

Design strategies for crossing unstable fan surfaces are summarised below.

1. Where rates of fan deposition are low and where the flow path across the fan is reasonably consistent, a road can be formed on a causeway, preferably constructed in reinforced concrete or gabion. If gabion construction is used, no wire baskets should be left exposed to abrasion by passing rocks. They should be protected with a mortar rendering or equivalent durable surface.
2. Cross the fan via a track that is re-cut after every aggrading or eroding storm flow. This approach will require the following considerations:
    - Vehicular access must be prohibited during and for a few hours after each flood;
    - As the fan surface builds up over time, temporary access will have to be cut deeper into the fan surface and may eventually become waterlogged and impassable during the entire wet season;
    - An alternative to the above is an ever-enlarging detour downstream across the fan, eventually coming to an end when the detour reached the flood plain at the base of the fan;
    - Flood flows will tend to run down either side of the fan and erode the road on the fan approaches.
3. Select a relatively narrow channel across or, preferably to one side of the fan surface (depending on drainage pattern). Use river training gabions and excavation to concentrate flow through this channel. Construct a bridge over the entire width of the fan with at least 7m clearance. This approach will require the following considerations:
    - River training gabions will tend to be scoured and undermined towards the fan apex;
    - Deposition of fine-grained material towards the end of each storm may bury the river training gabions to the extent that during the next storm a new channel will be formed and the existing gabions may be outflanked or destroyed;
    - If the bridge does not extend the full width of the fan, there is a risk that it may be outflanked by changes in flow pattern across the fan surface leading to bridge redundancy and erosion of the approach embankments.
4. Extending the concept of river training further, construct a continuous masonry or concrete spillway from the fan apex to a point downstream of the bridge. The slope and cross-section of this structure must be such that flow velocities are sufficient to transport bedload from the apex of the fan to the flood plain downstream. This approach will require the following considerations:
    - Flow along the external margins of the structure, leading to undermining, is likely to occur unless its inlet is adequately keyed into both banks of the upstream channel;
    - During peak run-off the floor of the spillway may be scoured and eventually destroyed by passing boulders;
    - During the later stages of storm run-off, the channel might still become blocked by fine- grained sediment, which will require clearing- the shape of the channel should be made to facilitate this and access to it provided for machinery.
5. Install check dams in the gulley upstream of the fan apex to retain sediment. This approach will require the following considerations:
    - The checkdams may be destroyed during the first few storms in a channel where aggradation of the fan itself is rapid;
    - The volume of sediment that can be trapped behind a check dam system is usually insignificant in comparison with the volume transported and transportable material;

- Artificially raising the channel bed upstream of the fan apex could easily lead to increased rates of aggradation.

References.

USAID, 2006. *Bridge design manual*. MRB, GoSS

USAID, 2006. *Drainage design manual*. MRB, GoSS.

10 Earthworks and Roadside Slope Design and Stabilisation

10.1 Introduction

In order to comply with horizontal or vertical geometric guidelines and thus permit reasonable access for users, LVR alignments in hilly or mountainous areas may require the construction of cuts or embankment earthworks. On low plain areas liable to flood it may be necessary to raise roads on embankment. In general terms these earthworks should be designed to minimise subsequent slope failure by implementing designs and construction procedures that are compatible with the engineering properties of the excavated soil-rock or the placed fill, whilst at the same time taking into account the impact of these earthworks on existing slopes or foundations.

The aim of any low cost approach to earthworks design is to excavate to safe slope angles without having to resort to extensive use of support structures. However, the interaction of LVR route alignment and the geometry or instability of the natural slopes may be such that construction to recognised safe angles is not an economical or engineering feasibility Engineered stabilisation may have to be considered, particularly in areas of identified natural hazard. If temporary road closures and debris clearance can be tolerated and allowed for in maintenance, then a steeper slope may be more economic.

10.2 Cut-slopes

Where possible, LVR cut slopes are generally designed on precedent or modified precedent principles, based on past experience with similar soil and rock materials. Cut slopes greater than 3-5m in height may require a more detailed engineering geological assessment depending on the complexity of the ground conditions. This would include an assessment of the strength of the soil-rock materials and the mass structure (See Chapter 5 and Appendix E).

The slope angles indicated in Table 10.1 have been provided as a general guide for LVRs. Note that these angles cannot be applied without due consideration of the ground conditions.

Table 10.1 Suggested Cut-Slope Gradients

Soil –Rock Classification		Slopes (V:H) for Various Cut Heights		
		< 5 m	5-10 m	10-15 m
Hard rock (without adverse structure)		1:0.3 – 1:0.8		
Soft rock		1:0.5 – 1:1.2		
Sand	Loose, poorly graded	1:1.5		
Sandy soil	Dense or well graded	1:0.8 – 1:1.0	1:1.0 – 1:1.2	-
	Loose	1:1.0 – 1:1.2	1:1.2 – 1:1.5	-
Sandy soil, mixed with gravel or rock	Dense, well graded	1:0.8 – 1:1.2		1:1.0 – 1:1.2
	Loose, poorly graded	1:1.0 – 1:1.2		1:1.2 – 1:1.5
Cohesive soil		1:0.8 – 1:1.2		-
Cohesive soil, Mixed with rock or cobbles		1:1.0 – 1:1.2	1:1.2 – 1:1.5	-

Cuttings in strong homogenous rock masses can often be very steep where adverse structure is not present, but in weathered rocks and soils it is necessary to use shallower slopes. In heterogeneous slopes, where both weak and hard rock occur, the appropriate cut-slope angle can be determined on the basis of the location, nature and structure of the different materials and the variations in permeability between the different horizons. One of the most effective ways to decide upon a suitable cut slope is to survey existing cuttings in similar materials along other roads or natural exposures in the surrounding areas. Generally, new cuttings can be formed at the same slope as stable existing cuttings if they are in the same material with the same overall structure. In rock excavations, persistent joint, bedding or foliation surfaces may determine the final cut slope profile.

Excavation of rock slopes should be undertaken in such a way that disturbance, for example due to blasting, is minimised. It should also be undertaken in a manner to produce material of such size that allows it to be placed in embankments in accordance with the requirements.

Cut slope profiles can be single-sloped, or benched. Single-sloped profiles are usually cut in uniform soil or rock materials or excavations less than 5-10m. Benched slopes are generally used in deeper cuts or where layered soil rock profiles are encountered. The construction of benches should be considered to intercept falling debris and control the flow of water. There is no hard rule regarding the dimension of benches, but a preliminary approach is to provide bench widths that are one third of the height of the cut immediately above. Outward sloping benches are generally not recommended because this may concentrate and erode channels through the bench if the bench is in weathered rock or soil. If the bench is in strong, unweathered rock then this erosion will not occur and outward sloping benches are permitted. In weaker materials the water should be encouraged to drain along the bench to a discharge point rather than over it. Maintenance of these drains is important to prevent water accumulating on the bench.

10.3 Embankments

Embankments may be required to:

- Raise the road above flood level on low-lying flat ground;
- Reduce steep gradients and minimise excess spoil in hilly terrain;
- Facilitate suitable access in steep hilly or mountainous terrain.

Embankment design must accommodate two related elements; the design of the embankment itself using available materials and the strength or compressibility of its foundation. Embankment slopes should be designed taking into account both elements; angles for embankment fill on sound foundations are presented in Table 10.2.

Table 10.2 Suggested Fill Slope Gradients

<table>
<tr><th rowspan="2">Fill materials</th><th colspan="4">Embankment Side-slope (V:H) for Various Heights</th></tr>
<tr><th>5m</th><th>5-10m</th><th>10-15m</th><th>15-20m</th></tr>
<tr><td>Well graded sand, gravels, sandy or silty gravels</td><td colspan="2">1:1.5 – 1:1.8</td><td>1:1.8 – 1:2.0</td><td></td></tr>
<tr><td>Poorly graded sand</td><td colspan="3">1:1.8 – 1:2.0</td><td></td></tr>
<tr><td>Weathered rock spoil</td><td colspan="3">1:1.5 – 1:1.8</td><td>1:1.8 – 1:2.0</td></tr>
<tr><td>Sandy soils, hard clayey soil and hard clay</td><td colspan="2">1:1.5 – 1:1.8</td><td>1:1.8 – 1:2.0</td><td>--</td></tr>
<tr><td>Soft clayey soils</td><td colspan="2">1:1.8 – 1:2.0</td><td>-</td><td>--</td></tr>
</table>

Fill slopes over 3m in height or any embankment on soft soils, in unstable areas, or those on expansive clays may require site-specific geotechnical assessment depending on specific ground conditions. Fill placed near or against a bridge abutment or foundation, or that can impact on a nearby structure, may require specific stability analysis.

For embankments founded on soft soils the most usual design option in low-cost road engineering is recommend excavation down to satisfactory strength materials where possible. Where this is not feasible then detailed geotechnical analysis will be required. The options of access route alignment to avoid soft soils areas is the most suitable course of action.

The overall stability of a fill slope on a hillside may be difficult to assess. Before constructing a fill slope on side-long ground, it is necessary to terrace or step the formation in order to prevent a possible slip surface from developing at the interface between the fill and the natural ground. The potential for failure along a deeper surface in the ground beneath should be considered, although this rarely happens since the strength of soils tends to increase with depth. Problems can occur when strata or foliations in the rock masses beneath the fill are dipping parallel to the ground slope, or where the groundwater table is at or very close to the surface.

10.4 Cut-fill Cross Sections

Cut-fill cross sections are a combination of excavation into hillside above the alignment and placement of the excavated fill on the “down” side. Although the cut-fill option is attractive in terms of cut-fill balance and is a common situation in many hill or mountainous access routes, it also a frequent cause of access failure unless adequate design and construction precautions are adopted; Figure 10.1.

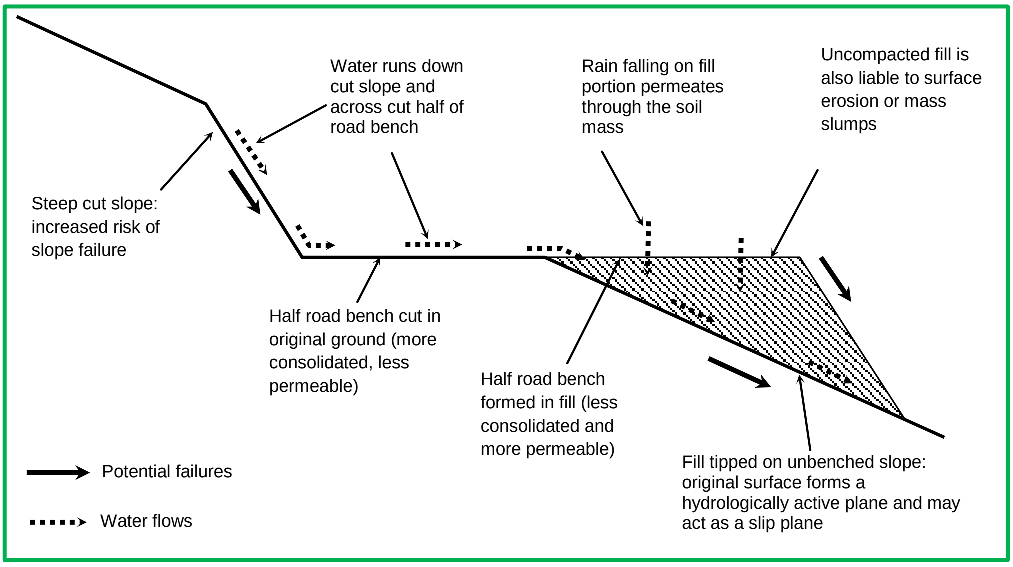


Figure 10.1 The Cut-Fill Situation

Key requirements for an adequate design are:

- Suitable cut slope excavation (see above);
- Fill section key-in to natural slope;
- Adequate drainage to prevent pore pressure build-up or lubrication of the cut-fill interface;

- Specification for compaction of fill in layers and not simply dumped over the alignment edge;
- Specification of complete removal of vegetation and organic material prior to construction;
- construction of embankments on loose spoil material derived from earlier excavations;
- Prevention of erosion on slopes immediately below the embankment.

10.5 Roadside Slope Instability

Unstable natural slopes, cuts and embankments in South Sudan have the potential to disrupt traffic flow and create a considerable problem to road users, particularly during rainy seasons. These slope failures or landslides typically occur where a natural slope is too steep, a cut slope in soil and/or weathered rock contains weak materials or adverse joints, or fill material is not properly compacted. In all three cases, the change in groundwater regime following rainfall can lead to an overall reduction in stability and possibly failure. Once slope failures are initiated they can develop rapidly.

Erosion can also take place on unprotected fill slopes adjacent to river channels, especially downstream of culverts, bridges and roadside turnouts. In addition, uncontrolled runoff can erode the roadside drain, road pavement and the edge of the road (Chapter 9). Sediment derived from the erosion not only impacts on the road, but also on the wider environment. Large landslides can also contribute significant volumes of debris to watercourses, with significant downstream effects.

Slope stabilisation and erosion control can employ a range of methods to reduce the causes of failure, together with measures to improve the stability of slopes. It is important to select affordable methods that are relevant to the class of the road, the type of landslide, the materials involved and the extent of the slope instability problem. Techniques commonly used to prevent the occurrence of landslides and to stabilise the existing slope failures include earthworks (cuts and fills), retaining structures and revetments, surface and sub-soil drainage and bioengineering. Stabilisation methods that involve more substantial engineering works involve anchoring, piling and deep subsurface drainage, but these are rarely used on low volume roads. For LVRs, a combination of bioengineering, low cost retaining walls such as gabions, dry-stone and mortared masonry walls, and surface drainage structures is a cost-effective method to stabilise slopes.

It should be noted that whilst this chapter is based on international best practice, the recommendations may not be the only options needed to stabilise slopes and mitigate the effects of landslides in South Sudan. The engineer should combine these recommendations with effective existing local practice.

For most minor slope failures, any remedial work will often rely on visual observation and the use of simple measures such as debris clearance, trimming, and the removal of overhangs. While this may be acceptable for many situations along low volume roads, there are occasions when additional measures are required.

10.6 Instability Types

Roadside instability may involve one or more of the following situations

- Above alignment erosion or failure of cut-slopes;
- Below alignment erosion or failure of embankment slopes;
- Failure in natural ground.

Figure 10.2 and Table 10.3 summarise common instability scenarios.

Table 10.3. Common types of erosion and slope failure

Mechanism	Description	Depth
Erosion on the surface.	Rills and gullies form in weak, unprotected surfaces. Most common on fill and tipped spoil. Erosion should be expected on all bare or freshly prepared slopes.	Usually in the top 0.1 metre, but can become deeper if not controlled.
Gully erosion.	Erosion that is established on the slope continues to develop and grow bigger. Large gullies often have small landslides along the sides.	Usually in the top 0.5 metre, but can become deeper if not controlled.
Shear failure (translational landslide, planar or debris slide).	Mass slope failure on a shallow slip plane parallel to the surface. This is the most common type of landslide, slip or debris fall. The plane of failure is usually visible but may not be straight, depending on site conditions. It may occur on any scale, and large areas of subsidence may also be due to these.	Frequently 0.5 metre or less below surface (or along a local discontinuity) but may be several metres deep.
Shear failure (rotational landslide).	Mass slope failure on a deep, curved slip plane, with the toe of the debris rising slightly. Some small, deep landslides in residual soil are the result of this process, but generally they are not common.	Often more than 1.5 metres deep, even in a small failure.
Slumping or flow of material when very wet.	Slumping or flow where material is poorly drained or has low cohesion between particles and liquefaction is reached. These sometimes appear afterwards like planar slides, but are due to flow rather than sliding. The resulting debris normally has a rounded profile. They may occur on steeply cultivated land following intense rainfall.	Frequently 0.5 metre or less below surface.
Rock or debris fall or collapse.	Collapse due to failure of the supporting material. This normally takes the form of a rock fall where there is a weakness or fracture in a rock mass, or where a weaker band of material has eroded to undermine a harder band above.	0.5 to 2 metres in road cuts; deeper in natural cliffs.
Debris flow.	In gullies and small, steep river channels (bed gradient usually more than 15°), debris flows can occur following intensive rain storms. This takes the form of a rapid but viscous flow of liquefied mud and debris. The depositional area may cover a broad area below the outlet of the channel.	The flow depth is usually 1 to 2 metres deep.

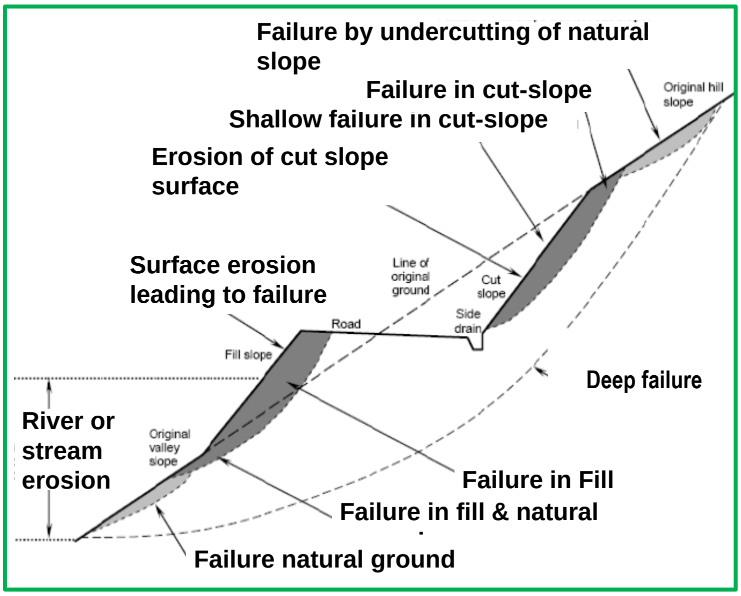


Figure 10.2 Typical Roadside Slope Failure Scenarios

10.6.1 Above-road instability

The types of slope failures and erosion processes commonly observed above a road alignment include:

- Erosion of cut slope surface;
- Failures in cut slope;
- Failures in cut slope and hill-slope;
- Failures in hill-slope;
- Deep failure in original ground.

10.6.2 Below road instability

The types of slope failures and erosion processes commonly observed above a road alignment include:

- Erosion of fill slope surfaces;
- Failure of embankment slopes;
- Failure of embankment foundation;
- Combination of the above.

10.6.3 Embankments on soft and organic soils

Embankments on soft soils, in unstable areas require site-specific geotechnical assessment depending on specific ground conditions. Some options for designing and constructing embankments on weak or problem spoils are outlined below.

Replacement: The weak or problem soil is removed, either partly or completely, and replaced by suitable material. Removal deposit solves stability and settlement problems, the embankment will be founded on firmer ground and settlement will be greatly reduced. In the partial excavation of soft materials the remaining soft deposit is later consolidated. If necessary, surcharging is provided to accelerate settlement so that the majority of settlement will be completed during construction.

Replacement by excavation method needs a considerable quantity of suitable material. Borrow material should be available within acceptable economical hauling distance. Therefore this method would be most suitable in cut and fill sections of alignment where fill material is available from the cutting areas. Granular free draining material (sand, gravel or a mixture of sand and gravel) should be used as fill material when filling is to be done below water. Cohesive soil can be used when the excavation is dry and the fill material can be compacted in lifts as normally specified.

In partial excavation a layer of free draining material may be required as a drainage blanket at the base of the fill to speed up consolidation of the remaining soft layer during construction.

The economic limits to full removal would be around 3-4 m.

Counterweight berms: The principle of counterweight berms is to add weight to the toe of the embankment to increase the resistance against slip or lateral spreading. When used in front of approach fill to a bridge this method will increase stability thus reducing lateral pressure on the substructure. This option is very effective in solving stability problems with soft soils but will not solve the long term settlement problem that may be particularly associated with organic materials.

Surcharging: Surcharging involves placing temporary additional load onto the proposed embankment to increase primary settlement. The load applied should be sufficient that the settlement during the construction period is equal to the total expected settlement from the embankment less the allowable post construction settlement. When the desired settlement has been achieved the surcharge is removed. The effectiveness of this method depends on the following factors:

- Thickness of the soft soil;
- Permeability of the soft soil;
- The presence of drainage layers;
- Available construction time;
- Shear strength of the soft soil.

The time required to achieve a certain degree of consolidation is proportional to the square of the length of the vertical drainage path. A relatively shallow or thin layer of soil can be consolidated faster so that the desired amount of settlement can be achieved during construction. Thick layers of soft compressible clayey soil could require tens of years to achieve 90% consolidation.

Staged construction: As consolidation progresses in the soft soil under the embankment load, the void ratio in the subsoil decreases and hence density increases and the undrained strength increase and increase in shear strength of the subsoil is a function of the degree of consolidation. Therefore the rate of filling can be controlled to allow sufficient consolidation to provide the required strength increase. This method should be considered when the design height of the embankment exceeds the critical height that can be safely supported by the subsoil.

Use of light material: The stability and amount of settlement of road embankments constructed on soft soil depend on the weight of the embankment; therefore reducing the weight of the embankment will reduce stress in the subsoil and reduce excessive settlement and instability. By using lighter fill material than ordinary fill the weight of embankment will be reduced.

10.6.4 Embankments in an expansive soil environment

Expansive soils are those which exhibit particularly large volumetric changes (swell and shrinkage) following variations in moisture contents.

Expansive soils may be thick and laterally widespread which makes the implementation of countermeasures costly, particularly for LVRs. Any such measures for dealing with such soils need to strike a balance between the costs involved and the benefits to be derived over the design life of the road.

Many countermeasures would be prohibitively expensive and difficult to economically justify for application to LVRs. Nonetheless, there are a number of relatively low-cost measures that can be adopted based on practical experience in a number of African countries. Countermeasures that could be considered for LVRs are discussed in Appendix E

10.7 Slope Protection and Stabilisation

10.7.1 General approaches

The techniques commonly used to protect and stabilise slopes and prevent the occurrence of landslides above a road alignment, especially along low volume roads, are summarised in Tables 10.4 and 10.5.

The use of these techniques depends on site-specific conditions such as the size of the slide, soil type, road use, and the cause of failure. Appropriate site investigations may be required to define the slope problem accurately within the overall geotechnical environment. (Chapter 5).

Table 10.4 Stabilisation options for above the road problems

Instability	Stabilisation options	Drainage options	Protection options
Erosion of the cut slope surface	None	Usually none; Occasionally a cut-off drain above the cut slope can reduce water runoff; however, these are difficult to maintain and can contribute to instability if blocked or otherwise disturbed.	In most cases, bio-engineering is adequate, usually grass slip planting; Where gullies are long or slopes are very steep, small check dams may be required; Sometimes a revetment wall at the toe helps to protect the side drain.
Failures in cut slope	Reduce the slope grade and if this is feasible, then add erosion protection; A retaining wall to retain the sliding mass; For small sites where the failure is not expected to continue, a revetment might be adequate.	A subsoil drain may be required behind a wall if there is evidence of water seepage; Herringbone surface drains may be required if the slope drainage is impeded.	Bio-engineering can be important to prevent surface erosion and increase the resistance of the surface soil. Will have no effect on deeper failure prevention or stabilisation
Failures in cut slope and hill slope	Reduce the slope grade, and if this is feasible, then add protection; A retaining wall to retain the sliding mass. This may need to be quite large, depending on the depth of the slip plane.	A subsoil drain may be required behind a wall if there is evidence of water seepage; Herringbone surface drains may be required if the slope drainage is impeded.	Bio-engineering can be important to prevent surface erosion and increase the resistance of the surface soil. Will have no effect on deeper failure prevention or stabilisation
Failures in hill slope but not cut slope	Reduce the slope grade, and if this is feasible, then add protection. A retaining wall to support the sliding mass, as long as foundations can be found that do not surcharge or threaten the cut slope.	A subsoil drain may be required behind a wall if there is evidence of water seepage; Herringbone surface drains may be required if the slope drainage is impeded.	Bio-engineering can be important to prevent surface erosion and increase the resistance of the surface soil. Will have no effect on deeper failure prevention or stabilisation
Deep failure in the original ground underneath the road	Consider re-alignment of road away from instability. If slow moving, short term option may be to repave or gravel the road.	Ensure road-side drainage is controlled.	Bio-engineering will not be effective.

Table 10.5 Stabilisation options for below the road problems

Instability	Stabilisation options	Drainage options	Protection options
Erosion of the fill slope surface	None	Ensure road-side drainage is controlled	Bio-engineering a key option
Failures in fill slope	Re-grade or remove, replace and compact fill; Before replacing fill, cut steps in original ground to act as key between fill and original ground; A new road retaining. wall may be the only option	Ensure road-side drainage is controlled	Bio-engineering can be important to prevent surface erosion and increase the resistance of the surface soil. Will have no effect on deeper failure prevention or stabilisation
Failure in fill slope and original valley slope	Re-grade or remove, replace and compact fill; Before replacing fill, cut steps in original ground to act as key between fill and original ground; A new road retaining wall may be the only option.	Ensure road-side drainage is controlled	Bio-engineering can be important to prevent surface erosion and increase the resistance of the surface soil. Will have no effect on deeper failure prevention or stabilisation
Failure in original valley slope	Re-grade if sufficient space between road and valley side; A new road retaining wall may be the only option.	Ensure road-side drainage is controlled	Bio-engineering can be important to prevent surface erosion and increase the resistance of the surface soil. Will have no effect on deeper failure prevention or stabilisation
Removal of support from below by river erosion	May need extensive river training works to prevent further erosion.	None	Slope protection (walls and rip-rap etc) may be necessary – possible with additional bioengineering options

10.7.2 Slope drainage

Slope stability is greatly influenced by hydrology, either by the erosive impacts of surface water or the changes in pore pressure resulting from rainfall infiltration and concentration within the slope mass. Water may decrease pore suction in the underlying soil, increase pore water pressure, thereby reducing the effective stress and hence the stability of the slope. Hence, the construction of surface and sub-surface drainage structures is vital to ensure that excess water can be intercepted and conveyed to a safe location where it will not create further instability problems.

Principal earthwork drainage options are summarised below,

Cut-off drains are used to reduce surface runoff at the crest of a cut slope or slope failure. In order to reduce the likelihood of continuing slope movements breaching the drain, they are sometimes located many tens of metres above the failure crest. The potential problem with cut-off drains is that unless they are regularly maintained, they can create their own instability problem. It is not recommended that cut-off drains be constructed unless regular maintenance can be assured.

Herringbone (or chevron) drains are constructed herringbone fashion on slope faces to collect surface seepages and surface runoff. They are often quite shallow (about 1m deep), but can be much deeper. Care needs to be taken to ensure that the construction of the drain does not lead to further instability, and to ensure that the drain can still function in the event of minor downslope movements.

Counterfort drains are used to depress a high water-table. These drains are constructed at right angles to the toe of the slope and are often dug to a depth of 3 metres or more at intervals of 3-10 metres depending on the permeability of the subsoil.

Horizontal drains are used to intercept groundwater and seepage at depth. They require the use of plastic pipes and specialist drilling equipment that may not always be available, and they are not easy to install.

Lined channels or cascades are likely to be necessary if a watercourse or gully is a direct cause of the instability in the first place. A lined channel may be necessary to divert an existing watercourse from the failed area, or to train the watercourse within defined limits. The lining itself may be impermeable (mortared masonry and/or concrete) or permeable (gabion). The structure may comprise cascades, chutes and check dams. As a general rule, gabion structures are preferred since they are flexible and allow water ingress provided they are located below the wet season groundwater table.

Check dams are necessary where undue scour would otherwise occur from the stream flow of water.

10.7.3 Retaining walls

Retaining walls must be designed to withstand the pressure exerted by the retained material attempting to move forward down the slope due to gravity. The lateral earth pressure behind the wall depends on the angle of internal friction and the cohesive strength of the retained material. Lateral earth pressures are smallest at the top of the wall and increase towards the bottom. The total pressure may be assumed to be acting through the centroid of a triangular load distribution pattern, one-third above the base of the wall. The wall must also withstand pressure due to material placed on top of the fill behind the wall (“surcharge”).

Groundwater behind the wall that is not dissipated also exerts a horizontal hydrostatic pressure on the wall and must be taken into account in the design. Dissipation of ground water is normally achieved by constructing horizontal drains behind the wall with weepholes.

Gravity walls depend on their weight to resist pressures from behind the wall that tend to overturn the wall or cause it to slide. A factor of safety of 1.5 should be applied to the calculations of overturning and sliding. Gravity walls are normally designed with a slight "batter" to improve stability by leaning the wall back into the retained soil. The foundations should be wide enough to ensure that excessive pressure is not applied to the ground.

This manual covers the design and construction of gravity retaining walls, including gabion walls, dry stone walls and mortared stone walls.

Gabion walls are built from gabion baskets tied together. A gabion basket is made up of steel wire mesh in a shape of rectangular box. It is strengthened at the corners by thicker wire and by mesh diaphragm walls that divide it into compartments. The wire should be galvanized, and sometimes PVC coated for greater durability. The baskets usually have a double twisted, appropriate size, hexagonal mesh, which allows the gabion wall to deform without the box breaking or losing its strength.

Gabion walls are cost effective because they employ mainly locally available rock and local labour. Gabion structures are commonly used for walls of up to 6m high. Gabion walls are usually preferred where the foundation conditions are variable, the retained soils are moist, and continued slope movements are anticipated.

Because of their inherent flexibility, they are not preferred as retaining walls immediately below and adjacent to sealed roads due to the likelihood of movement of the backfill behind the wall and subsequent pavement cracking. Where gabion walls are used to support a sealed road, care should be taken to locate the base of the wall on a good foundation, in order to reduce the potential for movement.

Gabion walls have the following advantages:

1. Gabions can be easily stacked in different ways, with internal or external indentation to improve the stability of the wall;
2. They can accommodate some movement without rupture;
3. They allow free drainage through the wall;
4. The cross section can be varied to suit site conditions;
5. They can take limited tensile stress to resist differential horizontal movement.

Their disadvantages include:

Gabion walls need large spaces to fit the wall base (this base width normally occupies about 40% to 60% of the height of the wall);

The high degree of permeability can result in a loss of fines through the wall.

For road support retaining walls this can result in potentially problematic settlement behind the wall, although this can be prevented by the use of a geo-textile (filter fabric) between the wall and the backfill.

Dry-stone walls are constructed from stones without any mortar to bind them together. The stability of the wall is provided by the interlocking of the stones. The great virtue of dry stone walls is that they are free-draining. The durability of dry-stone walls depends on the quality and amount of the stone available and the quality of the work. In a slope management situation, they are useful as revetments for erosion protection and as a means of supporting soil against very shallow movement. Dry stone walls should not exceed 5m in height.

As with gabion walls and dry stone walls, a mortared masonry wall design uses its own weight and base friction to balance the effect of earth pressures. Masonry walls are brittle and cannot tolerate large settlements. They are especially suited to uneven founding levels but perform equally well on a flat foundation. Mortared masonry walls tend to be more expensive than other gravity wall options. If the wall foundation is stepped along its length, movement joints should be provided at each change in wall height so that any differential settlement does not cause uncontrolled cracking in the wall.

Mortared masonry walls require the construction of weep-holes to prevent build-up of water pressure behind the wall. Weep holes should be of 75mm diameter and placed at 1.5m centres with a slope of 2% towards the front of the wall. A filter of lean concrete or geo-textile should be placed at the back of the weep holes to permit free drainage of water.

Further detail on the design of retaining wall options is included in Volume 2 of the Manual

10.8 Bio-engineering

10.8.1 General

Bio-engineering can be broadly defined as the use of vegetation, either alone or in conjunction with engineering structures, and non-living plant material, to reduce erosion and shallow-seated instability on slopes. In bio-engineering applications there is an element of slope stabilisation as well as slope protection in which the principal advantages are:

- Vegetation cover protects the soil against rain splash and erosion, and prevents the movement of soil particles down slope under the action of gravity;
- Vegetation increases the soil infiltration capacity, helping to reduce the volume of runoff;.
- Plant roots bind the soil and can increase resistance to failure, especially in the case of loose, disturbed soils and fills;
- Plants transpire considerable quantities of water, reducing soil moisture and increasing soil suction;
- The root cylinder of trees holds up the slope above through buttressing and arching;
- Tap roots or near vertical roots penetrate into the firmer stratum below and pin down the overlying materials.;
- Surface run-off is slowed by stems and grass leaves.

In summary, vegetation is important in the control of erosion and shallow forms of instability (1-3m depth at most). However, it is also important to appreciate that the beneficial effects may be insignificant under extreme conditions of rainfall or drought.

10.8.2 Key factors

The main factors to be addressed when selecting the particular species for use in bio-engineering works are as summarized as (Hunt et al, 2008):

1. The plant must be of the right type to undertake the bio-engineering technique that is required. The possible categories include:
    - A grass that forms large clumps;
    - A shrub or small tree that can be grown from woody cuttings;
    - A shrub or small tree that can grow from seed in rocky sites;
    - A tree that can be grown from a potted seedling;
    - A large bamboo that forms clumps.

2. The plant must be capable of growing in the location of the site.
3. There is no single species or technique that can resolve all slope protection problems.
4. It is always advisable to use local species which don't invade and harm the environment, and were able to protect the slope from sliding in the past.
5. Large trees are suitable on slopes of less than 3H:2V or in the bottom 2m of slopes steeper than 3H:2V -maintaining a line of large trees at the base of a slope can help to buttress the slope and reduce undercutting by streams.
6. Grasses that form dense clumps generally provide robust slope protection in areas where rainfall is intense. They are usually best for erosion control, although most grasses cannot grow under the shade of a tree canopy.
7. Shrubs (ie woody plants with multiple stems) can often grow from cuttings taken from their branches, plants propagated by this method tend to produce a mass of fine, strong roots. These are often better for soil reinforcement than the natural rooting systems developed from a seedling of the same plant.
8. In most cases the establishment of full vegetation cover on unconsolidated fill slopes may take one to two rainy seasons. Likewise, the establishment of full vegetation on undisturbed cut slopes in residual soils and colluvial deposits may need 3 to 5 rainy periods. Less stony and more permeable soils have faster plant growth rates, and drier locations have slower rates.
9. Plant roots cannot be expected to contribute to soil reinforcement below a depth of 500mm.
10. Plants cannot be expected to reduce soil moisture significantly at critical periods of intense and prolonged rainfall.
11. Grazing by domestic animals can destroy plants if it occurs before they are properly grown. Once established, plants are flexible and robust. They can recover from significant levels of damage (eg flooding and debris deposition).

10.8.3 Preparation

Before bio-engineering treatments are applied, the site must be properly prepared. The surface should be clean and firm, with no loose debris. It must be trimmed to a smooth profile, with no vertical or overhanging areas. The object of trimming is to create a semi-stable slope with an even surface, as a suitable foundation for subsequent works.

Trim soil and debris slopes to the final desired profile, with a slope angle of between 30° and 60°. (In certain cases the angle will be steeper, but review this carefully in each case). Trim off excessively steep sections of slope, whether at the top or bottom. In particular, avoid slopes with an over-steep lower section, since a small failure at the toe can destabilise the whole slope above.

Remove all small protrusions and unstable large rocks. Eradicate indentations that make the surrounding material unstable by trimming back the whole slope around them. If removing indentations would cause an unacceptably large amount of work, excavate them carefully and build a buttress wall. Remove all debris from the slope surface and toe to an approved tipping site. If there is no toe wall, the entire finished slope must consist of undisturbed material.

When materials form the lower parts of slopes to be trimmed, the debris can be used for backfilling. In this case, compact the material in layers, by ramming it thoroughly with tamping irons. This must be done while the material is moist.

10.8.4 Recommended techniques

Table 10.6 provides the different types of bio-engineering techniques recommended for various kinds of slopes and soil materials for both cut and fill situations.

Particular plants species must be selected that are compatible with the specific South Sudan environment

Tables 10.6 Recommended general bio-engineering procedures

Site characteristics	Recommended techniques
Cut-Slopes	
Cut slope in soil, very highly to completely weathered rock or residual soil, at any grade up to 1H:2V.	Grass planting in lines, using slip cuttings.
Cut slope in colluvial debris, at any grade up to 1H:1V (steeper than this would need a retaining structure).	
Trimmed landslide head scarps in soil, at any grade up to 1H:2V.	
Roadside lower edge or shoulder in soil or mixed debris.	
Cut slope in mixed soil and rock or highly weathered rock, at any grade up to about 1H:4V.	Direct seeding of shrubs and trees in crevices.
Trimmed landslide head scarps in mixed soil and rock or highly weathered rock, at any grade up to about 1H:4V.	
Fill Slopes	
Fill slopes and backfill above walls without a water seepage or drainage problem; these should first be re-graded to be no steeper than 3H:2V.	Brush layers (live cuttings of plants laid into shallow trenches with the tops protruding) using woody cuttings from shrubs or trees.
Debris slopes underlain by rock structure, so that the slope grade remains between 1H:1V and 4H:7V.	Palisades (the placing of woody cuttings in a line across a slope to form a barrier) from shrubs or trees.
Other debris-covered slopes where cleaning is not practical, at grades between 3H:2V and 1H:1V.	Brush layers using woody cuttings from shrubs or trees.
Fill slopes and backfill above walls showing evidence of regular water seepage or poor drainage; these should first be re-graded to be no steeper than about 3H:2V.	Fascines (bundles of branches laid along shallow trenches and buried completely) using woody cuttings from shrubs or trees, configured to contribute to slope drainage.
Large and less stable fill slopes more than 10m from the road edge (grade not necessarily important, but likely eventually to settle naturally at about 3H:2V).	Truncheon cuttings (big woody cuttings from trees).
The base of fill and debris slopes.	Large bamboo planting; or tree planting using seedlings from a nursery.

References

Scott Wilson, 2008. Slope Maintenance Site Handbook. SEACAP 21 Report to Ministry of Public Work and Transport, Lao PDR.

TRL, 1997. ORN 16.Principles of low cost road engineering in mountainous regions.

11 Maintenance

11.1 What is Maintenance?

Maintenance is the range of activities necessary to keep a road and associated structures (culverts, drifts, bridges and retaining walls) in an acceptable condition for road users, to achieve the economic and social benefits of access and travel, as intended when the road works were designed and constructed.

It is important to appreciate that ALL roads and structures deteriorate over time due to the effects of weather (particularly the resulting water flows) and traffic, and require maintenance from time to time. The amounts and types of maintenance required depend on a number of factors including: surface type, standard and quality of construction, road width, rainfall and intensity, terrain, road gradient, and traffic.

"THERE IS NO SUCH THING AS A NO-MAINTENANCE ROAD"

LVRs are constructed with limited resources and budgets, so that more roads can be constructed for the funds available. However it is vital to know the maintenance liabilities of the road assets belonging to or under the care of an authority or organisation, so that Maintenance can be properly planned, funded, resourced and implemented in a timely way. If this is not done, there will be a high risk of rapid road deterioration and even failure, and the wasting of the investments made at the time of construction. This of course is in addition to the higher vehicle operation costs and implications of poor or severed access suffered by road users if maintenance is deficient.

"ROADS ARE EXPENSIVE VITAL ASSETS AND THE MAINTENANCE AND PRESERVATION ARE SIMPLY COMMON SENSE, AS WELL AS ECONOMICALLY JUSTIFIABLE" [1]

11.2 What is the Essence of Road Maintenance?

For Low Volume Roads, maintenance can be summarised in three basic aims:

- Keep the road surface in good condition (for example, repair ruts and potholes);
- Maintain the road surface camber to shed water to the side of the road;
- Maintain the drainage system (including structures) to safely lead water away from the road.

All maintenance activities are organised to carry out or support these basic aims.

Despite relatively low initial low construction costs, it is important to appreciate that even under a Basic Access and Spot Improvement strategy it is essential to arrange the necessary Regular maintenance of the Engineered Natural Surface and any gravel surface and drainage, and Occasional maintenance of the improved surface sections and structures, to preserve the initial construction investment.

Gravel roads and bitumen paved roads will require even higher levels of resources for maintenance over their service lives.

[1] Economic returns on road maintenance are usually many times greater than the benefit-cost relationship for road construction.

11.3 What Maintenance needs to be done?

From the moment that a road is constructed or upgraded, it will deteriorate due to the effects of weather and traffic. Maintenance is required to be carried out from time to time to restore or preserve its condition to be close to its as-constructed state. If maintenance is not carried out the road will continue to deteriorate making passage increasingly difficult, uncomfortable and expensive to road users. The road may even become impassable for part or all of the year.

There have been many manuals and reference books written on maintenance, however it must be observed that:

1. It is not common to see good maintenance practice actually practiced.
2. Many manuals do not appreciate the particular challenges of maintaining LVRs in a limited resource environment.
3. Maintenance Specifications and Standards BoQs have not yet been developed for South Sudan application.

This Manual and the companion document Volume 3: 'LOW VOLUME ROAD MAINTENANCE BOOKLET' (2013) set out the aims and approaches to maintenance of LVRs in a straightforward and rational way. These documents will help any authority or other organisation responsible for maintenance activities to understand the work required to be carried out.

It is convenient to view **Maintenance** as correcting **Defects.**

In practical terms it is useful to identify and quantify the **Defects**, and then arrange the necessary **Maintenance** to be carried out. It is sensible to group **Defects** and **Maintenance** activities into the following colour coded groups: Roadside Activities, Drainage and Structures or Road Surface.

Regular Maintenance (Routine)

Roadside Activities

Drainage

Road Surface

- **Earth Road**
- **Gravel Road**

Structures

Occasional Maintenance (Periodic)

Road Surface

- **Gravel Road**
- **Paved Road**

Structures

This Manual and accompanying Booklet (Volume 3) covers the treatment of about 30 common Defects. From time to time, other defects/activities may be required. Advice should be obtained from the MRB or State road authorities for any problem or road aspect not covered in this Manual or the accompanying Maintenance Booklet. The categorisation of defects and maintenance activities used in these documents is provisional, pending development of MRB Maintenance Specifications.

11.4 Regular Maintenance

These are the maintenance activities that are likely to be required somewhere on a road link every year. Most of the tasks may be carried out manually. Mechanised or equipment based alternatives are available for some tasks as indicated in the Booklet.

Regular Maintenance is conveniently divided into four main groups of activities that are often carried out on a seasonal basis:

Roadside Activities
Drainage
Road Surface
• **Earth Road**
• **Gravel Road**
Structures

Roadside Activities

Defect	Maintenance Activity
1. Trees and bushes growing on roadside	131 Brush clearing
2. Shoulder uneven or eroded, or does not drain properly	132 Shoulder Rehabilitation (manual)
3. Shoulder erosion	133 Plant grass and water
1. Grass on shoulder or in drain requires cutting	134 Cut grass
2. Shoulder uneven or eroded, or does not drain properly (minor)	240 Shoulder Blading (mechanised)
2. Shoulder uneven or eroded, or does not drain properly (major)	241 Shoulder Rehabilitation (mechanised)

Drainage

Defect	Maintenance Activity
4. Culvert silted/obstructed	121 Culvert Cleaning
5. Ditch silted	122 Ditch Clearing (Manual)
6. Ditch or slope eroded (minor)	123 Repair Erosion Damage (Selected Fill)
7. Ditch or slope eroded (major)	124 Repair Erosion Damage (rockfill)
7. Slope eroded (major)	129 Wattling
8. Mortared Masonry damaged	125 Mortared Masonry Repair
9. Dry Masonry damaged	126 Dry Masonry Repair
10. Gabion structure damaged	127 Gabion Structure Repair
11. Erosion in ditch	128 Build wooden/stone scour check
5. Ditch silted	230 Ditch clearing (mechanised)

Road Surface

Defects and maintenance requirements depend on the road surface type.

Earth Road

Defect	Maintenance Activity
12. Road surface potholed, rutted or uneven, and does not drain to edge	112 Reshape & Compact Earth Road Camber

Gravel Road

Defect	Maintenance Activity
13. Road Surface potholed	110 Spot Repair Selected Material
13. Road Surface potholed	111 Spot Repair Crushed Aggregate
14. Road Surface rutted or uneven, and does not drain to edge (Minor: <3cm))	220 Blade Gravel Road (light)
15. Road Surface rutted or uneven, and does not drain to edge (Major: >3cm)	221 Blade Gravel Road (heavy)

Structures (Bridges/Drifts/Large Culverts)

Some of these activities will require skilled personnel

Defect	Maintenance Activity
16. Debris or vegetation affecting or endangering structure	400 Cleaning, Clearing, Sweeping, De-silting, Unblocking or Removal of vegetation or flood/wind borne debris (Structure/ inlets/outlets)
17. Connectors/fixings are loose/ damaged/missing	401 Repair of loose/missing connectors/fixings
18. Planks/kerbs are damaged/missing	402 Replace damaged or missing Planks or Kerbs
19. Paintwork defective or damaged	403 Paint main or minor parts of structure/furniture
20. Danger or evidence of insect or moisture attack of timber components	404 Apply wood preservative or insect treatment to timber components
21. Masonry or concrete or joints defective (minor)	405 Pointing or repair of masonry/concrete
22. Structure furniture defective	406 Repair parapets, marker posts, safety barriers, signs or other furniture

11.5 Occasional Maintenance

These are the maintenance activities that may be required somewhere on a gravel or paved road section or link, or on a structure, after a period of a number of years. The category of repair depends on the type of road surface constructed. Some of the Occasional Maintenance tasks may be carried out manually with the aid of simple tools or equipment. Others will require skilled personnel or large equipment. Transport may be required for the haulage of materials. Many of the activities will require careful planning and mobilisation of the necessary resources.

Gravel or Paved Road

Defect	Maintenance Activity
23. Gravel layer too thin	317 Gravel Resurfacing (Selected Material) 318 Gravel Resurfacing (Crushed Aggregate)
24. Paved road pothole or surface defect	113a Spot /pothole Repair (Macadam) 113b Spot /pothole Repair (Stone setts) 113c Spot /pothole Repair (Mortared stone) 113d Spot /pothole Repair(Dressed stone) 113e Spot /pothole Repair(Emulsion chip seal) 113f Spot /pothole Repair(Emulsion sand seal) 113g Spot /pothole Repair(Emulsion gravel/slurry seal) 113h Spot /pothole Repair(Un-mortared brick) 113i Spot /pothole Repair(Mortar jointed brick) 113j Spot /pothole Repair(Non- reinforced concrete) 217 Pothole Reinstatement (cold mix) 219 Pothole (Base Failure Repair)

Structures (Bridges/Drifts/Large Culverts)	
Defect	**Maintenance Activity**
25. Random stone filling defective	410 Repair Random Stone filling
26. Retaining wall defective	411 Retaining wall repairs
27. River or stream bed scoured adjacent to structure	412 Watercourse scour repairs
28. Gabion walls or mattress defective	413 Gabion basket repairs
29. Structural repairs for the following serious defects: Structural timber decay, splitting or insect attack, bulging masonry, cracked concrete or masonry, honeycombed concrete, spalling concrete, serious rust or chemical stains, exposed or corroding reinforcement or pre-stressing steel, damp patches on concrete, seriously corroded structural steelwork, damaged/distorted structural steelwork, missing/loose rivets, bolts or other fixings, cracks in structural steelwork, settlement of deck, piers, abutments or wingwalls, expansion joint or bearing defects, erosion requiring piling works.	414 Major structural repairs. These will require the expertise of an Engineer to assess and design/specify the remedial works in response to the scale and nature of the defects

All of the maintenance defects and activities, and discussion of the management of maintenance, are presented in more detail in the 'LOW VOLUME ROAD MAINTENANCE BOOKLET' (Volume 3).

11.6 Maintenance Implementation Options

There are a number of ways that maintenance work can be organised depending on the financial and human resources available, and 'in-house' capacity of the responsible authority or organisation.

In practical terms, the maintenance of Low traffic Volume Roads (LVR) will be principally carried out by labour methods with possible occasional support of intermediate or heavy equipment. The last option is usually too expensive to mobilise and inefficient for remote rural road works.

All maintenance implementation options will require appropriate levels of training and mentoring, and management arrangements.

The main work organisation options are detailed in this section with their typical advantages and disadvantages. The Works Options are:

- Option 1- Small Contractor (Private);
- Option 2 - Force Account;
- Option 3- Community Group;
- Option 4 - Length Person or Family Contract;
- Option 5 - Compulsory/Voluntary Labour;

- Option 6 - Hire-in equipment;
- Option 7- Large Contractor Based System.

Option 1- Small contractor (Private)

The small enterprises will be based in the state or local area of the road. They may be general or building contractors with established contracting experience in earthworks, masonry and concrete. They would be expected particularly to make use of local labour, and may have access to light equipment such as a small compacter, concrete mixer or tractor. This implementation option can be suitable for All Maintenance activities and for all types of road surface.

Advantages:

- Overheads lower than big contractor;
- Low mobilisation and demobilisation costs;
- Construction experience of the enterprise;
- Available range of building and maintenance skills;
- Local enterprise committed to the community;
- Good prospects for local employment and money being injected into the community

Disadvantages:

- Time, resources and costs involved with preparing and managing the contract;
- Market for maintenance works currently not developed so prices may be distorted (guideline unit costs should be available from MRB or local authorities);
- Small contractor may have to hire in some equipment;
- May initially require some training/ mentoring, or a higher level of supervision than large contractors;
- May have difficulty in obtaining credit for purchases, or financing cash flow;
- Insufficient funds currently available to pay for this approach for all maintenance work (but may be suitable for selected works – see also Option 6);
- Risks of disputes over interpretation of contract responsibilities.

Option 2 – Force account (sometimes called Direct Labour)

This option makes use of a permanently employed and equipped workforce to carry out the maintenance work such as local road management units. This implementation option can be suitable for All Maintenance activities and for all types of surfaces.

Advantages:

- Direct response to all maintenance needs;
- Rapid mobilisation when funds are available;
- Retain skills and experience within organisation, familiarity with the network, standards, work methods;
- Minimum of works documentation requirements;
- Dealings/ disputes with outside parties minimised.

Disadvantages:

- In some cases no budget or funds are currently available for this option;
- Difficulties in equipment procurement & the lowest initial purchase cost policy can hinder the standardisation and efficiency;

- Poor mobility of the workforce around the network unless transport is provided (at considerable cost);
- Paid labour and equipment may be standing if no funds available for works;
- Possible low efficiency and poor management/use of available resources, poor cost-awareness;
- Little pressure to try new solutions/ technologies;
- High mobilisation and demobilisation costs if sourced from state or national level

Option 3– Community group

The use of a group of persons based within the community and organised specifically to carry out the maintenance works under an agreement or contract with the community or local authority. This can be for a single route, or a number of routes serving the community. This approach differs from the Length person or Family contract approach only in that the number of persons expected to be involved would be greater, and that consequently work would probably be concentrated at a particular time or times of the year. Possibility of organising annual or regular community 'day of road action' when the whole community works on the road for nominal payment or arrangement. This implementation option can be particularly suitable for the Regular Maintenance activities.

Advantages:

- Low cost compared to most other forms of contract (due to low overheads, low mobilisation and demobilisation costs, absence of profit component, and by local participation);
- Can be cash or in-kind payment according to community circumstances;
- Simple contract/agreement required;
- Direct response to Regular maintenance needs – Rapid mobilisation, or planned seasonal inputs;
- Retain skills and experience within the community, familiarity with the network and any problem sections;
- Close control of the works personnel;
- Pride of 'ownership' for the network;
- No dealings/disputes with parties outside of the community;
- Employment and money/resources recycled within the community;
- Employment can be targeted at poor or disadvantaged persons in the community.

Disadvantages:

- Possibly insufficient cash funds available to pay for this approach in poor communities;
- Possible difficulties in controlling output and quality;
- Not suitable in areas of dispersed or low population density;
- No equipment capability;
- May not have access to construction quality hand tools.

Option 4 – Length person or family contract

A contract or agreement is drawn up for an individual or family to carry out specified Regular maintenance activities on a section of road, at certain times of the year, for a payment in cash or in-kind for work on a full or part time basis.

Usually a labourer is appointed for a distinct section of road close to his/her home, typically 1 to 2 km in length. The person walks or cycles to the work site each work day. He or she is provided with all the necessary hand tools to carry out all the regular maintenance activities as instructed by the local authority. An advantage is that regular maintenance of the entire road can be arranged at all times and one person can be made fully responsible of a road section. A disadvantage is that supervision has to mobile and frequent to ensure that performance does not deteriorate.

Advantages:

- Low cost compared to most other forms of contract (due to low overheads, low mobilisation and demobilisation costs, absence of profit component, and by local participation);
- Can be cash or in-kind payment according to community circumstances;
- Simple contract/agreement required;
- Flexible approach to seasonal needs;
- Rapid mobilisation by person living 'on site';
- Pride of 'ownership' for the network;
- No dealings/disputes with parties outside of the community;
- Employment and money/resources recycled within the community
- Employment can be targeted at poor or disadvantaged persons in the community.

Disadvantages:

- Possibly insufficient cash funds available to pay for this approach in poor communities;
- Possible difficulties in controlling output and quality;
- Not suitable in areas of dispersed or low population density;
- No equipment capability;
- May not have access to construction quality hand tools;
- System will degenerate if supervisor is not continuously mobile and effective in management.

Option 5 – Compulsory/voluntary labour

The use of local (community) labour to carry out maintenance works on the roads is one of the options for maintaining community roads. The approach can be suitable for Regular Maintenance activities. If the whole community can be persuaded to attend a 'maintenance day' once or twice a year with their hand tools, there will be sufficient labour resources to carry out the necessary maintenance work under the guidance of a trained supervisor. This is the cheapest way to maintain a LVR and involves no taxation or levy to the community. Everybody contributes and benefits equitably. Wealthier inhabitants, traders or other well-wishers could contribute hand tools, equipment hire or food to create a community occasion.

Advantages:

- No financing or cash accounting involved;
- In richer communities, individuals can elect to pay cash instead - this can provide funding for materials, hand tools and equipment hire, or even paid labour;
- Minimum of works documentation requirements;
- Direct response to all maintenance needs;
- Rapid mobilization;
- Retain skills & experience within community;
- Direct supervision of works;
- Pride of 'ownership' for the network;

- No dealings/disputes with outside parties.

Disadvantages

- All persons contribute equally, whether rich or poor;
- Can be a severe burden on the community's poorest persons;
- Difficulties in controlling output and quality;
- Not suitable for work during the agricultural 'high' season;
- Not suitable in areas of dispersed or low population density;
- Few prospects for PAID community employment or money being injected into the community;
- No equipment capability;
- May not have access to construction quality hand tools;
- May initially require some supervisor and 'gang leader' training/ mentoring.

Option 6 – Hire-in equipment

This is an option to supplement the other options to provide equipment for specific operations such as towed grading or haulage. The funding could be provided by the local authority if available, or a benevolent trader, farmer or other well-wisher.

Option 7 – Large Contractor Based System

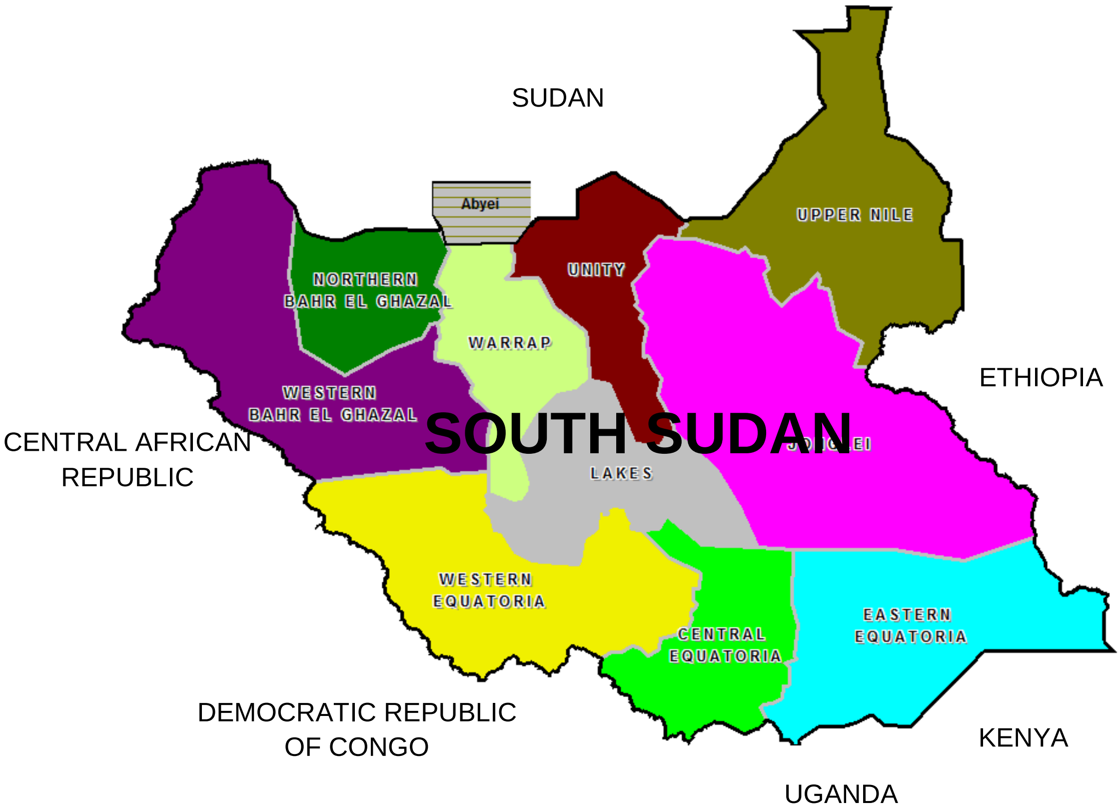
The employment of a large equipment-based contractor may be considered. They are usually based in state centres or Juba and their overheads, mobilisation and demobilisation costs and profit components would be very high. Therefore, the costs would be extremely high and unlikely to be affordable by the community or local authority. In cases where a contractor is funded externally to construct a road, this contractor may be engaged as part of the contract to maintain the road for some years after the final construction acceptance is finalised.

11.7 In Summary

For further guidance on LVR road and structures maintenance, including recommended references and further knowledge sources, refer to the MRB (Volume 3)

'LOW VOLUME ROAD MAINTENANCE BOOKLET'.

SOUTH SUDAN
LOW VOLUME ROADS
DESIGN MANUAL



Volume 2
CROSS DRAINAGE AND SMALL STRUCTURES
June 2013

Ministry of Roads and Bridges
Government of South Sudan

SOUTH SUDAN

LOW VOLUME ROADS DESIGN MANUAL

Volume 2

CROSS DRAINAGE AND SMALL STRUCTURES

May 2013

ABBREVIATIONS & ACRONYMS

> : Greater than
< : Less than
% : Percentage

A

AADT: Annual Average Daily Traffic
AASHTO: American Association of State Highway and Transportation Officials
AFCAP: Africa Community Access Programme
AIDS: Acquired Immune Deficiency Syndrome,
ALD Average Least Dimension
ARRB: ARRB Group, formerly the Australian Road Research Board
ARVs: Anti retrovirals
ASTM: American Standard Test Methods

B

BDS: Bid Data Sheet

C

CB : Clay Brick (fired)
CBO: Community Based Organisation
CBR: California Bearing Ratio
CI: Complementary Interventions
CMG : Crown Agents Core Management Group
COLTO: Commission of Land Transport Officials (South Africa)
CPT: Cone Penetrometer Test
CS : Cobblestone
CSIR: Council for Scientific and Industrial Research (South Africa)

D

DBM:: Drybound macadam
DC : Design Class
DCP: Dynamic Cone Penetrometer
DF: Drainage Factor
DFID: UK Government's Department of International Development
DMT: Dilatometer Test
DS : Dressed Stone
DV : Design Vehicles

E

EDCs: Economically emerging and Developing Countries
EF : Equivalency Factor
e.g. : For example (abbreviation for the Latin phrase exempli gratia)
EIA : Environmental Impact Assessment
EMP: Environmental Management Plan

ENS: Engineered Natural Surfaces
EOD: Environmentally Optimised Design
ERA: Ethiopian Roads Authority
esa : Equivalent standard axles
EVT : Equiviscous Temperature

F

FACT: Fine Aggregate Crushing Test
FED: Final Engineering Design

G

g/m²: Grams per Square Metre
GDP: Gross Domestic Product
GM : Grading Modulus
GoSS: Government of South Sudan
gTKP: Global Transport Knowledge Partnership
GVW: Gross Vehicle Weight

H

ha : Hectare
HDM 4: Highway Development and Management model
HIV : Human immunodeficiency virus
HPS: Hand Packed Stone
HQ : Headquarters
HVR: High Volume Road

I

ICB : International Competitive Bidding
ICT : Information Communication Technology
IDA : International Development Agency
i.e. : That is (abbreviation for the Latin phrase id est)
ILO : International Labour Organisation
IMT : Intermediate Means of Transport
IRR : Internal Rate of Return
ITB : Instructions to Bidders

K

km : Kilometre
km² : Square Kilometre
km/h: Kilometres per hour

L

LB : Labour Based
LIC : Labour Intensive Construction
LVR : Low Volume Road

M

m : Metre
m² : Square Metre

m^3 : Metres Cubed
MAF: Ministry of Agriculture and Forestry
MCB: Mortared Clay Brick (fired)
MCS: Mortared Cobblestones
MDS: Mortared Dress Stone
Mesa: Million equivalent standard axles
mg/m^3: Milligram per metre cubed
mm : Millimetre
mm^2: Square Millimetre
mm^3: Millimetres Cubed
m/s : Metres per second
MC : Medium Curing
MPa Megapascal (a unit of pressure equal to 1000 kilopascals (kPa)
MS: Mortared Stone
MPI: Ministry of Physical Infrastructure
MRB: Ministry of Roads and Bridges
MSSP: Mortared Stone Setts or Pavé

N

NBP: Non-Bituminous Pavement
NCB: National Competitive Bidding
NCT: National Competitive Tendering
NGO: Non-Government Organisation
nm : Nanometre
NMT: Non-Motorised Transport
NRC: Non-reinforced concrete
NRCP: Non-reinforced concrete pavement

O

OMC : Optimal Moisture Content
ORN: Overseas Road Note

P

PCU: Passenger Car Unit
PDM: Pavement Design Manual
Pen.: Penetration
PI : Plasticity Index
PIARC: World Road Association
PM : Pressure Meter
PPA: Public Procurement Agency
PPP: Public Private Partnership
PSD: Particle Size Distribution

Q

QA : Quality Assurance

R

R : Radius
RC : Reinforced concrete

Ref : Reference
RFP: Request for Proposals
RS : Road Safety
RTS : Road Transport Services

S

SADC: Southern Africa Development Community
SBL : Sand Bedding Layer
SDMS: Surfacing Decision Management System
SE : Super Elevation
SMEs: Small and Medium Enterprises
SS : South Sudan
SSP: Stone Setts or Pavé

T

TBA : To Be Advised
Tc : Time of Concentration
ToR : Terms of Reference
TRL : Transport Research Laboratory

U

UK : United Kingdom
UKAID: Development assistance provided by the DFID
UNOPS United Nations Office for Project Services
USAID: States Agency for International Development
USCS: Unified Soil Classification Systtem
USD: United States Dollar
UTRCP: Ultra Thin Reinforced Concrete Pavement

V

VI: Impinging Velocity
VAVE: Average Velocity
VP: Parallel Velocity
vpd: vehicles per day
VOCs: Vehicle Operating Costs
VST: Vane Shear Test

W

WBM: Waterbound Macadam
WC : Wearing Course
WLC: Whole Life cycle Costs

GLOSSARY OF TECHNICAL TERMS

Aggregate (for construction)
A broad category of coarse particulate material including sand, gravel, crushed stone, slag and recycled material that forms a component of composite materials such as concrete and pre-mix asphalt.

Apron
The flat invert of the culvert inlet or outlet.

Asphalt
A mixture of inert mineral matter, such as aggregate, mineral filler (if required) and bituminous binder in predetermined proportions (Sometimes referred to as Asphaltic Concrete or Asphalt Concrete). Usually pre-mixed in a plant before transport to site to be laid and compacted. Expensive and usually only used on main roads. Also used as an alternative term for Bitumen in some regions, and may be a petroleum processing product or naturally occurring in deposits.

Atterberg Limits
Basic measures of the nature of fine-grained soils which identify the boundaries between the solid, semi- solid, plastic and liquid states.

Basin
A structure at a culvert inlet or outlet to contain turbulence and prevent erosion.

Berm
A low ridge or bund of soil to collect or redirect surface water.

Binder, Bituminous
Any bitumen based material used in road construction to bind together or to seal aggregate or soil particles.

Binder, Modified
Bitumen based material modified by the addition of compounds to enhance performance. Examples of modifiers are polymers, such as PVC, and natural or synthetic rubbers.

Bitumen
A non-crystalline solid or viscous mixture of complex hydrocarbons that possesses characteristic agglomerating properties, softens gradually when heated, is substantially soluble in trichlorethylene and is usually obtained from crude petroleum by refining processes. Referred to as Asphalt in some regions.

Bitumen, Cutback
A liquid bitumen product obtained by blending penetration grade bitumen with a volatile solvent to produce rapid curing (RC) or medium curing (MC) cutbacks, depending on the volatility of the solvent used. After evaporation of the solvent, the properties of the original penetration grade bitumen become operative.

Bitumen, Penetration Grade
That fraction of the crude petroleum remaining after the refining processes which is solid or near solid at normal air temperature and which has been blended or further processed to products of varying hardness or viscosity.

Bitumen emulsion
An emulsion of bitumen and water with the addition of an emulsifier or emulsifying agent to ensure stability. Conventional bitumen emulsion most commonly used in road works has the bitumen dispersed in the water. An invert bitumen emulsion has the water dispersed in the bitumen. In the former, the bitumen is the dispersed phase and the water is the continuous phase. In the latter, the water is the dispersed phase and the bitumen is the continuous phase. The bitumen is sometimes fluxed to lower its viscosity by the addition of a suitable solvent.

Bitumen Emulsion, Anionic
An emulsion where the emulsifier is an alkaline organic salt. The bitumen globules carry a negative electrostatic charge.

Bitumen Emulsion, Cationic
An emulsion where the emulsifier is an acidic organic salt. The bitumen globules carry a positive electrostatic charge.

Bitumen Emulsion Grades
Premix grade: An emulsion formulated to be more stable than spray grade emulsion and suitable for mixing with medium or coarse graded aggregate with the amount smaller than 0.075mm not exceeding 2%.
Quick setting grade: An emulsion specially formulated for use with fine slurry seal type aggregates, where quick setting of the mixture is desired.
Spray grade: An emulsion formulated for application by mechanical spray equipment in chip seal construction where no mixing with aggregate is required.
Stable mix grade: An emulsion formulated for mixing with very fine aggregates, sand and crusher dust. Mainly used for slow-setting slurry seals and tack coats.

Black Cotton Soil
An expansive clay found widely in the North East of the country that expands and looses most of its strength when wetted.

Blinding
a) A layer of lean concrete, usually 5 to 10 cm thick, placed on soil to seal it and provide a clean and level working surface to build the foundations of a wall, or any other structure.
b) An application of fine material e.g. sand, to fill voids in the surface of a pavement or earthworks layer.

Brick (fired clay)
A hard durable block of material formed from burning (firing) clay at high temperature.

Bridge
A structure usually with a span of 5 metres or more, providing a means of crossing above water, a railway or another obstruction, whether natural or artificial. A bridge consists of abutments, deck and sometimes wingwalls and piers, or may be an arch.

Camber
The road surface is normally shaped to fall away from the centre line to either side. The camber is necessary to shed rain water and reduce the risk of passing vehicles colliding. The slope of the camber is called the Crossfall. On sharp bends the road surface should fall directly from the outside of the bend to the inside (superelevation).

Cape Seal
A multiple bituminous surface treatment that consists of a single application of binder and stone followed by one or two applications of slurry.

Carriageway
The road pavement or bridge deck surface on which vehicles travel.

Cascade
A drainage channel with a series of steps, sometimes with intermediate silt traps or ponds, to take water down a steep slope.

Catchpit
A manhole or open structure with a sump to collect silt.

Catchwater Drain
See **Cutoff**.

Causeway or Vented Drift
Low level structure constructed across streams or rivers with openings to permit water to pass below road level. The causeway may become submerged in flood conditions.

Cement (for construction)
A dry powder which on the addition of water (and sometimes other additives), hardens and sets independently to bind aggregates together to produce concrete. Cement can also be used to stabilise certain types of soil. Cement is also sometimes used as a fine filler in bituminous mixes.

Chippings
Clean, strong, durable pieces of stone made by crushing or napping rock. The chippings are usually screened to obtain material in a small size range.

Chip Seal, Single
An application of bituminous binder followed by a layer of stone or clean sand. The stone is sometimes covered with a fog spray.

Chip Seal, Double
An application of bituminous binder and stone followed by a second application of binder and stone or sand. The second seal usually uses a smaller aggregate size to help key the layers together. A fog spray is sometimes applied on the second layer of aggregate.

Chute
An inclined pipe, drain or channel constructed in or on a slope.

Cobble Stone (Dressed stone)
Cubic pieces of stone larger than setts, usually shaped by hand and built into a road surface layer or surface protection.

Coffer Dam
A temporary dam built above the ground to give access to an area which is normally, or has a risk of being, submerged or waterlogged. Cofferdams may be constructed of soil, sandbags or sheetpiles.

Collapsible soil
Soil that undergoes a significant, sudden and irreversible decrease in volume upon wetting.

Compaction
Reduction in bulk of fill or other material by rolling or tamping.

Complimentary Interventions
Actions or initiatives that are implemented through a roads project which are targeted toward the communities that lie within the influence corridor of the road and are intended to optimise the benefits brought by the road and to extend the positive, and mitigate the negative, impacts of the project.

Concrete
A construction material composed of cement (most commonly Portland cement, but occasionally using other available cementitious materials such as fly ash and slag cement), aggregate (generally a coarse aggregate such as gravel or crushed stone plus a fine aggregate such as sand), water, (and sometimes chemical admixtures to improve performance or for special applications).

Concrete Block Paving
A course of interlocking or rectangular concrete blocks placed on a suitable base course and bedded and normally jointed with sand.

Counterfort Drain
A drain running down a slope and excavated into it. The excavation is partly or completely filled with free draining material to allow ground water to escape.

Cribwork
Timber or reinforced concrete beams laid in an interlocking grid, and filled with soil to form a retaining wall.

Crossfall
See **Camber**

Crushed Stone
A form of construction aggregate, typically produced by mining a suitable rock deposit and breaking the removed rock down to the desired size using mechanical crushers, or manually using hammers.

Curing
The process of keeping freshly laid/placed concrete moist to prevent excessive evaporation with attendant risk of loss of strength or cracking. Similarly with cement or lime stabilised layers, the measures to minimise moisture loss during the initial period of strength development.

Cut-off/Catchwater Drain
A ditch constructed uphill from a cutting face to intercept surface water flowing towards the road.

Debris Rack or Grill
Grill, grid or post structure located near a culvert entrance to hold back floating debris too large to pass through the culvert.

Deck
The part of a bridge that spans between abutments or pier supports, and carries the road traffic.

Design speed
The maximum safe speed that can be maintained over a specified section of road when conditions are so favourable that the design features of the road govern the speed.

Dispersive soil
Soil in which the clay particles detach from each other and from the soil structure in the presence of water and go into suspension.

Distributor
A vehicle or towed apparatus comprising an insulated tank, usually with heating and circulating facilities, and a spray bar capable of applying a thin, uniform and predetermined layer of binder. The equipment may also be fitted with a hand lance for manual spraying.

Ditch (Drain)
A long narrow excavation designed or intended to collect and drain off surface water.

Drainage
Interception and removal of ground water and surface water by artificial or natural means.

Drainage Pipe
An underground pipe to carry water.

Dressed Stone
See **Cobble Stone**

Drift or Ford
A stream or river crossing at bed level over which the stream or river water can flow.

Dry-bound Macadam
A pavement layer constructed where the voids in a large single-sized stone skeleton are filled with a fine sand, vibrated in with suitable compaction equipment.

Earth Road
See **ENS.**

Embankment
Constructed earthworks below the pavement raising the road above the surrounding natural ground level.

ENS (Engineered Natural Surface)
An earth road built from the soil in place at the road location, and provided with a camber and drainage system

Expansive soil
Typically clayey soil that undergoes large volume changes in direct response to moisture changes.

Filler
Mineral matter composed of particles smaller than 0.075mm.

Flow Spreader
A structure designed to disperse the flow at the outfall of a ditch or drain to minimise the risk of erosion down stream.

Fog Spray/Seal
A light application of diluted bitumen emulsion to the final layer of stone of a reseal or chip seal, or to an existing bituminous surfacing as a rejuvenating maintenance treatment.

Ford
See **Drift**

Formation
The shaped surface of the earthworks, or subgrade, before constructing the pavement layers.

Gabion
Stone-filled wire or steel mesh cage. Gabions are often used as retaining walls or river bank/bed scour protection structures.

Geocells
Used in construction for erosion control, soil stabilisation on flat ground and steep slopes, channel protection, and structural reinforcement for load support and earth retention. Typical cellular confinement systems are made with ultrasonically-welded high-density polyethylene (HDPE) or Novel Polymeric Alloy strips that are expanded on-site to form a honeycomb-like structure which may be filled with sand, soil, rock or concrete.

Gravel
A naturally-occurring, weathered or naturally transported rock within a specific particle size range. In geology, gravel is any loose rock that is larger than 2mm in its largest dimension and not more than 63mm. Gravel is typically used as a pavement layer in its natural or modified condition, or as a road surface wearing course. Suitable gravel may also be used in a graded gravel seal in appropriate circumstances.

Hand Packed Stone
A layer of large, angular broken stones laid by hand with smaller stones or gravel rammed into the spaces between stones to form a road surface layer.

Heavy Equipment
Sophisticated civil engineering equipment is typically designed for, and manufactured in, high-wage, low-investment-charge economies. It is expected to operate with close support and high annual utilisation; usually designed for a single function with high efficiency operation. Currently imported ‘Heavy Equipment’ dominates the South Sudan road sector. It is expensive to own and operate in the local environment.

Incremental paving
Road surface comprising small blocks such as shaped stone (setts) or bricks, jointed with sand or mortar.

Intermediate Equipment
Simple or intermediate equipment is designed for low initial and operating costs, durability and ease of maintenance and repair in the conditions typical of a limited-resource environment, rather than for high theoretical efficiency. It is preferable if the equipment can also be manufactured or fabricated locally/regionally. Modern Agricultural Tractors are a low cost mobile power source and with various attachments can be used to substitute for heavy equipment for a proven range of tasks in the road sector.

Invert
The lowest point of the internal cross-section of a ditch, pipe or culvert.

Labour Based Construction

Economically efficient employment of as great a proportion of labour as is technically feasible throughout the construction process to produce the standard of construction as demanded by the specification and allowed by the available funding. Substitution of equipment with labour as the principal means of production. The principally labour operations may be supported by simple or heavy equipment for some operations, such as compaction or long haulage. Labourers usually walk or cycle to work each day from their homes for greatest efficiency and social benefits.

Labour Intensive Construction

Works using large numbers of labourers with the prime objective of creating temporary or permanent employment, often with achieving sustainable and durable infrastructure as a secondary concern.

Layby

An area adjacent to the road for the temporary parking of vehicles.

Lime

Lime in a material derived from the burning of limestone or chalk. It is normally obtainable in its ‘hydrated’ form (slaked): Calcium Hydroxide. It can be used for the drying, improvement and stabilisation of suitable soils, as an anti-stripping agent in the production of bituminous mixes and as a binder in masonry or brick work mortars.

Local Resources

These can be human resources, local government, private, NGO, and community institutions, local entrepreneurs such as contractors, consultants, industrialists and artisans, local skills, locally made or fabricated intermediate equipment, local materials such as local produced aggregates, bricks, timber and marginal materials, locally raised finance or provision of materials or services in kind. **Local Resource Based Road Works** aim to deliver the maximum benefits to local communities and development.

Low Volume Road

Roads carrying up to about 300 motor vehicles per day and intended to carry less than about 1 million equivalent standard axles over their design life.

Macadam

A mixture of broken or crushed stone of various sizes (usually less than 3cm) laid to form a road surface layer. Bitumen macadam uses a bituminous binder to hold the material together. Tarmacadam uses tar for the same purposes. Bound macadams are usually expensive for use on LVR.

Manhole

Accessible pit with a cover forming part of the drainage system and permitting inspection and maintenance of underground drainage pipes.

Margins

The right of way or land area maintained or owned by the road authority or owner.

Mitre Drain (Turn Out Drain)

Leads water away from the Side Drains to the adjoining land.

Otta Seal

A carpet of graded aggregate spread over a freshly sprayed hot bituminous ‘soft’ binder and rolled in with heavy roller.

Outfall
Discharge end of a ditch or culvert.

Parapet
The protective edge, barrier, wall or railing at the edge of a bridge deck.

Pavé
See **Sett**

Paved Road
A paved road is a road with a Stone, Bituminous, Brick or Concrete surfacing.

Pavement
The constructed layers of the road on which the vehicles travel.

Penetration Macadam
A pavement layer made from one or more applications of coarse, open-graded aggregate (crushed stone, slag, or gravel) followed by the spray application of bituminous binder. Usually comprising two or three applications of stone each of reducing particle size, each grouted into the previous application before compaction of the completed layer.

Permeable Soils
Soils through which water will drain easily e.g. sandy soils. Clays are generally impermeable except when cracked or fissured (e.g. 'Black Cotton' soil in dry weather).

Prime Coat
A coat of suitable bituminous binder applied to a non-bituminous granular pavement layer as a preliminary treatment before the application of a bituminous base or surfacing. While adhesion between this layer and the bituminous base or surfacing may be promoted, the primary function of the prime coat is to assist in sealing the surface voids and bind the aggregate near the surface of the layer.

Reinforced Concrete
A mixture of coarse and fine stone aggregate bound with cement and water and reinforced with steel rods or mesh for added strength.

Reseal
A surface treatment applied to an existing bituminous surface.

Rejuvenator
A material (which may range from a soft bitumen to petroleum) which, when applied to reclaimed asphalt or to existing bituminous surfacing, has the ability to soften aged, hard, brittle binders.

Riprap
Stones, usually between 5 to 50 kg, used to protect the banks or bed of a river or watercourse from scour.

Road Base and Subbase
Pavement courses between surfacing and subgrade.

Road Maintenance
Suitable regular and occasional activities to keep pavement, shoulders, slopes, drainage facilities and all other structures and property within the road margins as near as possible to their as constructed or renewed condition. Maintenance includes minor repairs and improvements to eliminate the cause of defects and avoid excessive repetition of maintenance efforts.

Roadway
The portion within the road margins, including shoulders, for vehicular use.

Scarifying
The systematic disruption and loosening of the top of a road or layer surface by mechanical or other means.

Scour - Defect:
Erosion of a channel bed area by water in motion, producing a deepening or widening of the channel.

Scour Checks
Small checks in a ditch or drain to reduce water velocity and reduce the possibility of erosion.

Scuppers
Drainage pipes or outlets in a bridge deck.

Seal
A term frequently used instead of “reseal” or “surface treatment”. Also used in the context of “double seal”, and “sand seal” where sand is used instead of stone.

Selected layers
Pavement layers of imported selected gravel or soil materials used to bring the subgrade support properties up to the required structural standard for placing the subbase or road base layer.

Sett (Pavé)
A small piece of hard stone trimmed by hand to a size of about 10cm cube used as a paving unit.

Shoulder
Paved or unpaved part of the roadway next to the outer edge of the pavement. The shoulder provides side support for the pavement and allows vehicles to stop or pass in an emergency.

Site Investigation
Collection of essential information on the soil and rock characteristics, topography, land use, natural environment, and socio-political environment necessary for the location, design and construction of a road.

Slope
A natural or artificially constructed soil surface at an angle to the horizontal.

Slurry
A mix of suitably graded fine aggregate, cement or hydrated lime, bitumen emulsion and water, used for filling the voids in the final layer of stone of a new surface treatment or as a maintenance treatment (also referred to as a slurry seal).

Slurrybound Macadam
A surfacing or pavement layer constructed where the voids in single-sized stone skeleton are filled using bituminous slurry.

Sods
Turf but with more soil attached (usually more than 10 cms).

Soffit
The highest point in the internal cross-section of a culvert, or the underside of a bridge deck.

Spray Lance
Apparatus permitting hand-application of bituminous binder at a desired rate of spread through a nozzle.

Squeegee
A small wooden or metal board with a handle for spreading bituminous mixtures by hand.

Stringer
Longitudinal beam in a bridge deck or structure.

Subbase
See **Road Base.**

Subgrade
The native material or earthworks formation underneath a constructed road pavement.

Sub-Soil Drainage
See **Underdrainage.**

Surface Dressing
A sprayed or hand applied film of bitumen followed by the application of a layer of stone chippings, which is then lightly rolled.

Surface Treatment
A general term incorporating chip seals, slurry seals, micro surfacing, or fog sprays.

Surfacing
The road layer with which traffic tyres make direct contact. Consists of wearing course, and sometimes a base course or binder course.

Tack Coat
A coat of bituminous binder applied to a primed layer or to an existing bituminous surface as a preliminary treatment to promote adhesion between the existing surface and a subsequently applied bituminous layer.

Tar Binder
A binder made from processing coal.

Template
A thin board or timber pattern used to check the shape of an excavation.

Traffic Lane
The portion of the carriageway usually defined by road markings for the movement of a single line of vehicles.

Transverse Joint
Joint normal to, or at an angle to, the road centre line.

Turf
A grass turf is formed by excavating an area of live grass and lifting the grass complete with about 5 cms of topsoil and roots still attached.

Turn Out Drain
See **Mitre Drain.**

Underdrainage (Sub-Soil Drainage)
System of pervious pipes or free draining material, designed to collect and carry water in the ground.

Unpaved Road
A road with a soil or gravel surface.

Vented Drift
See **Causeway.**

Waterbound Macadam
A pavement layer constructed where the voids in a large single-sized stone skeleton are filled with a fine sand, washed in by the application of water.

Wearing Course
The upper layer of a road pavement on which the traffic runs and is expected to wear under the action of traffic. This applies to gravel and bituminous surfaces.

Weephole
Opening provided in retaining walls or bridge abutments to permit drainage of water in the filter layer or soil layer behind the structure. They prevent water pressure building up behind the structure.

Windrow
A ridge of material formed by the spillage from the end of the machine blade or continuous heap of material formed by labour.

Wingwall
Retaining wall at a bridge abutment to retain and protect the embankment fill behind the abutment.

VOLUME 2,

1 INTRODUCTION

Volume 2 of the South Sudan LVR Manual deals with small drainage and watercourse crossing structures, typically up to 10 metres span, and associated retaining structures. It provides detailed guidance on the processes involved with the planning and design of small drainage and other structures for low volume roads.

It is clear that road structures are an important aspect of road design. Unfortunately it is an aspect that is often given little or insufficient attention, which is shown by the fact that when roads become impassable it is usually where they cross a watercourse. Although the length of road structures forms only a very small fraction of the total road length the time spent on their design must be a much greater portion of the total planning and design process.

There are manuals for the design of structures on South Sudan's main roads[1]. For these structures the predominant construction materials used are concrete and steel. However, little guidance has hitherto been available concerning small structures, particularly with respect to the optimum use of resources such as labour, local skills (which may include masonry and carpentry), local materials and small local enterprises, while still achieving durable and adequate structures. Intelligent use of these resources will often produce the lowest cost structures. This is particularly important in the limited resource environment expected to prevail in the LVR sector in South Sudan for some time. It is certainly not advisable to blindly apply standards, practices and 'rules of thumb' derived from rich economies for use in South Sudan where the balance of influential factors such as labour wage rates, availability and cost of standard materials and equipment, skills, access to finance and the support environment can be very different.

This manual aims to assist engineers and technicians in the planning and provision of road structures by:

- Providing concise and complete information in one document;
- Explaining the steps required in the design process;
- Providing different levels of information depending on the complexity of the structure;
- Providing guidance on costing of structures;
- Assisting in the approval and adoption of low cost structural designs.

The lack of access for designers and planners to design information and other resources requires this Manual to provide all the basic information needed in the design of small structures up to about 10 metres in span.

Volume 2 of this Manual has been written as a design guide, to complement existing national design codes and standards from the Ministry of Roads and Bridges. It is also intended that this part of the Manual will assist in the process of establishing more comprehensive and appropriate planning, design and maintenance procedures and practices for small structures.

Investigations and fieldwork have shown that steps in the design process are often missed or neglected. Therefore the steps that should be carried out and the reasons for undertaking them are explained along with the type and detail of data that are required and how they should be used in order to undertake a design.

[1] USAID / Ministry of Roads and Bridges, Road and Bridge Design Manual 2006

1.1 Definition of a Small Road Structure

For the context of this Manual a road structure is a construction which provides support and/or drainage to the road carriageway or associated road works. Roads form a barrier to the natural drainage of surface water from the surrounding land into streams, lakes and rivers. In the absence of any control arrangements the water would find its own way across the road, resulting in gullies and washouts along the road. An effective drainage system is therefore the most important part of a low volume road and should protect the road from damage due to water. The most basic drainage provision is the camber of the road carriageway, which directs water off the road to each side. Water is then removed from the road by the side and mitre (turn-out) drains. In some cases it may be necessary for water to be moved across the road at a low point in the alignment or at a stream, for example. As quantities of runoff water build up in the side drains at low points in the alignment or at watercourses, it will be necessary to allow water to cross from the high side of the road to the lower. This Part of the Manual deals with the road structures required to manage the drainage of water across a road. The other features of the drainage system are dealt with in Chapter 9, Volume 1 of the Manual with the design standards shown in Part B.

1.2 Scope of the Guidance

The scope of Small Structures guidance in the Manual includes:

1.2.1 Rural / urban Roads

Although the Manual primarily discusses issues associated with the design and construction of structures on low (traffic) volume rural roads, many of the ideas and design factors discussed are applicable to urban and peri-urban roads. In these cases it will be necessary to consider pedestrian issues in more detail. Existing built infrastructure and planned development can also influence options with regard to the siting, type, size and ancillary works associated with structures design.

1.2.2 Paved / unpaved roads

The majority of low volume roads will be unpaved. However, many of the structures discussed in this Manual will also be suitable for low volume paved roads. Roads may initially be built to earth or gravel surface standard and then upgraded by spot improvements or comprehensive paving to partial or fully sealed/paved roads at a later date. Road structures designed and constructed with reference to this.

The Manual will be suitable for paved roads provided that possible increased loadings and higher design standards such as roadway widths are satisfied.

1.2.3 Structural assessment

Although this Manual is primarily a design guide, principally dealing with the design and construction of road structures, it may also serve as a useful reference for the assessment and maintenance of existing structures. As assessment is a check of an existing design, the Manual highlights structural aspects which should be checked during an inspection and assessment under an appropriate asset management and maintenance regime.

1.2.4 Reconstruction / construction / maintenance

The Manual primarily deals with new structures; however, the design principles are the same for reconstruction, rehabilitation, extension and upgrading of existing structures. In these cases it may be possible to make use of elements of existing structures, for example, using an old drift slab as downstream protection for a new piped drift built adjacent to the existing structure.

1.2.5 Better use of local resources

Adoption of the recommendations in this Manual will increase the use of local material and labour resources. This will help to relieve the constraints that road authorities face due to a shortage of funding and may allow a foreign exchange saving, as fewer materials may have to be imported. The increased use of local labour will assist in stimulating the local economy and greatly reduce the mobilisation costs of road construction.

Unskilled and semi-skilled labour could be utilised for a range of tasks in the construction of road structures, such as timber growing preparation and formwork, quarrying dressing and crushing stone, fired clay brick production, local transport, masonry and brickwork in structures, retaining walls, ditch linings and culverts, collection and preparation of river gravel for structural fill, and construction of components such as gabion baskets. The creations of jobs in the area will not only provide socio-economic development but will also allow the development of skills, which will have three benefits. Firstly, there will be the capacity in the local community and enterprises to undertake maintenance on the structures as the skills required will be established during the construction phase within the local community; secondly, there will be an increase in employment opportunities in other construction sectors for the labourers employed on the road works; and thirdly, studies have also shown the employment generation multiplier effect of jobs created on rural infrastructure works.

1.3 Types of structures

The Manual covers a wide range of drainage structures from drifts to small bridges (Chapter 4 describes the characteristics of these structures). These structures vary in complexity and are ranked in order of increasing complexity as follows:

- Drifts;
- Simple culverts;
- Vented fords;
- Large bore culverts;
- Small bridges.

It is difficult to define the boundaries between the categories above: for example, when does a large bore culvert become an arched bridge? The background information, site data and technical knowledge and support required to undertake the design also vary significantly. This Manual therefore addresses the information required for the more complex structures but also indicates the reduced level of survey and technical knowledge required to design more simple structures. Other road structures, which are not covered in the Manual, include large bridges and viaducts. Further information on these structures can be found in the current version of the MRB Bridge Design Manual.

The Manual does not cover steel girder or lattice frame structures, as these structures require specialist design and erection expertise. Neither does the Manual cover modular panel steel bridges. These bridges are intended as a temporary steel structure that can be erected at short notice from panels that would normally be held in a store.

Modular panel bridges are suitable for short term measures where an unforeseen flood disrupts access at a critical location. The steel panel bridges can also be readily dismantled and the units returned to store once a permanent solution has been constructed on the access alignment. For such structures the specialist manufacturers' manuals should be used.

This Manual also excludes suspension and suspended steel cable bridges for pedestrian, animal and light motor traffic.

Chapters 1 to 7 cover planning and initial design assessment of structures. Chapter 8 focuses on detailed design. Standardising designs will result in:

- Reduced design costs and economies of scale, leading to an improvement in cost and quality;
- Increased speed of construction, as labourers, supervisors and engineers will become more familiar with the standardised design;
- Simplified approval procedures

For complex structures, for bridges with main spans of more than 10 metres or bridges expected to be trafficked with trucks of gross weight more than 6 tonnes, the current MRB Bridge Design Manual should be used.

1.4 How to use Volume 2

There is a logical sequence of work that must be undertaken in the selection and design of any road structure. This Part of the Manual is laid out in sequence with each chapter covering one aspect of the process shown in the diagram, Figure 1.1. The two initial tasks which should be carried out are to identify the problem or task (Chapter 2) and determine the design criteria (Chapter 3) for the structure. The initial design data may then be collected (Chapter 2) to enable the preliminary design to be carried out. Preliminary design, shaded yellow in the flow diagram, involves four different stages which may be performed a number of times before a design solution is proposed. It is suggested that a review of structural options (Chapter 4) is initially undertaken followed by an appraisal of a potential construction site (Chapter 5). The water flow characteristics of the watercourse (Chapter 6) should then be considered before a selection of the most appropriate structure is made (Chapter 4). It is likely that the preliminary design loop will need to be followed a number of times to review different potential structures and construction sites.

Following completion of the preliminary design the proposed design solution should be checked to ensure that it complies with the design criteria. Detailed design of the structure can then be undertaken (Chapter 8) which will require further reference to be made to chapters covering site selection and appraisal (Chapter 5) and watercourse characteristics (Chapter 6). It will also be necessary to review the options for construction materials (Chapter 7) that may be available.

During supervision of the construction work it will be necessary to ensure materials used in the structure meet and are used according to the specifications. This may require additional reference to Appendix B “Laboratory Testing of Soils and Rocks” and Appendix C “Marginal materials” of Volume 1. Chapter 11 of Volume 1 and Volume 3 cover the maintenance requirements of structures after they have been built and highlights the problems that may be encountered if maintenance is not carried out.

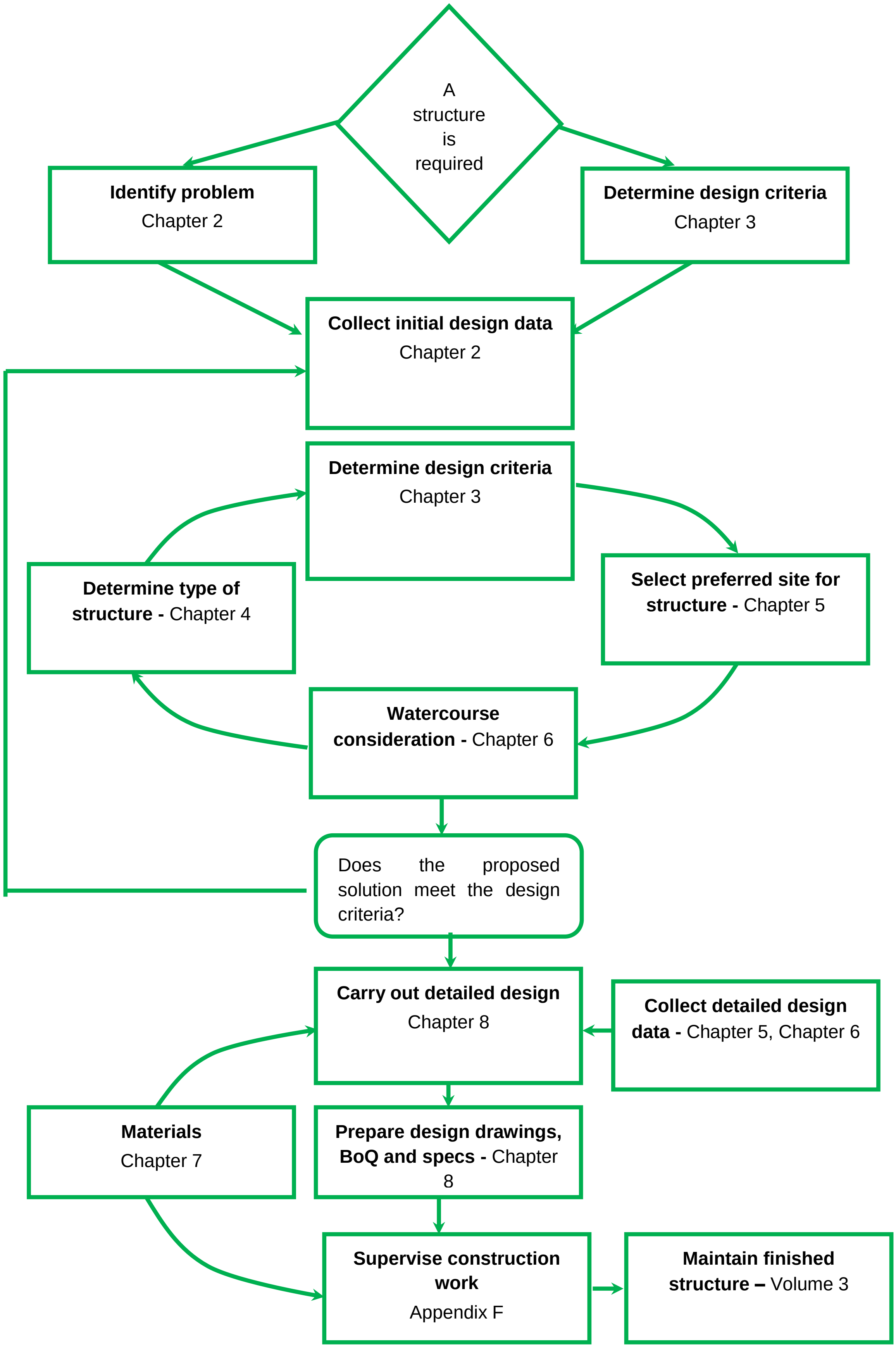


Figure 1.1 Flow diagram of the planning, design and construction process

Depending on the complexity of the structure, the level of work and detail required at each stage will vary. Although each stage of the design process shown in the Figure must be covered, it may be possible to skip more detailed issues in each chapter for simple structures such as drifts or culverts. Throughout the subsequent chapters there is guidance to indicate which sections may be ignored depending on the type of structure to be built.

For complex structures, for those with main spans of more than 10 metres, and structures crossing other roadways or railways, the current MRB Bridge Design Manual should be used.

A qualified civil, highway or structural engineer should certify all bridge and completed structures as fit for purpose.

2 PROJECT PLANNING

2.1 Setting Priorities

The approach adopted assumes that a road network and the associated structures are the responsibility of a road authority. From time to time there will be a requirement for new, rehabilitated or upgraded structures. The approach is also applicable for a 'one-off' initiative to provide, replace or rehabilitate a structure by an authority or community group. It may take many years to construct all the roads and associated structures to all-weather standard required by a community due to the limited financial resources and the capacity of the available equipment and labour. Priorities must therefore be set on the order that work should be undertaken. It may be possible to build a high priority road in the short term, but construct some of the structures at a later date. However, these roads may be seasonally impassable until the structures have been completed. A more pragmatic strategy with limited resources may be to initially provide all of the structures and durable surfacing on problem sections of the route (Basic Access strategy), and provide an engineered earth surface to the remainder of the route until additional resources are available to attain a more durable road surface throughout. This can be termed a stage construction, spot improvement or differential upgrading strategy. In setting priorities the following factors should be taken into account. The Spot Improvement approach is dealt with specifically under Chapter 11 of Volume 1 of this Manual. When selecting which required structures to address and the type of structure to be constructed the spot improvement and staged construction approach should be considered at the planning stage for the South Sudan environment. Improvement of stream and river crossings is critical to both approaches. The following are further considerations.

General

- The first question to be answered is "will a low cost drift suffice until resources for a more expensive structure can be mobilised?"
- Reconstruction of a damaged structure may have a higher priority over provision of a new structure in a different location.

Road network / location

- The level of priority given to the road/structure within the road inventory;
- The location of the road in relation to other structures/roads. For example, is there an alternative route with an acceptable detour?
- The requirements of access for construction. Is it necessary to construct a new road or upgrade an existing alignment before work can commence on the structure?
- Proximity to other work in order to avoid transportation of labour equipment and materials over long distances.

If there are 3 potential structures that are required and two are close together while the other is a long distance away it will be more efficient to construct the two structures that are close together at the same time as labour and equipment can easily be transferred between the two sites. If the programme requires the construction of two structures that are a long distance apart it would be less efficient to move labour and equipment between the two sites as the construction demand varied.

Road category

- The class of road and hence its strategic importance within the road network;
- The design level of structure required on the road network, which will determine the resources and time, required for construction.

Work status

Any work that has already commenced should be given the highest priority for funding in order to be completed so that the benefits of the investment already made will be realised.

Justification

A simple cost benefit analysis and assessment of social benefits can be useful, both to raise the finances and compare the various options to utilise the available resources.

Need: An assessment of the number of people who will benefit from the construction of the road or structure coupled with the availability of other access in their area. Improved access to important services such as health centres should also be considered.

Costs: The cost of providing one road or structure should be compared against providing another. For example, if a budget of 200,000 South Sudan Pounds is available would the best option be to construct one structure which costs 200,000 SSP or provide 5 smaller structures around the road network, which only cost 40,000 SSP each?

Resource availability

It will be necessary to make an assessment of the resources (equipment, labour, artisans, supervisors, materials, enterprises), which may be available in the locality. Assessments must also be made for the timeframe required to obtain equipment and materials from other areas.

Labour may not be so freely available in agricultural areas at certain times of the year. Specific skills may need to be trained or imported into the locality. It would also be easier to manage if the labour resource requirements were steady rather than increasing and decreasing throughout the year.

Availability of water for construction works may also be very limited in many areas, with a requirement to dig wells in many areas.

Equipment resources may also be quite limited, and type of equipment used should be carefully considered in light of this. Long distances over rough terrain to site will result in high mobilisation costs. In some instances an intermediate technology approach may be preferable, which will allow adaptable power sources (tractors) to be used, possibly resulting in more cost effective works for a lower mobilisation cost.

In South Sudan construction material availability is very limited in many areas, resultant haul distances are large, and construction costs are therefore high. This should be considered when considering the type of structure to propose. While a spot improvement or staged construction approach may be adopted the replacement cost of structures and importance of each structure when adopting said approaches should be taken into account.

For many authorities the expected timing of funding availability from internal/external sources (and possible conditionality) is an important consideration.

Climatic factors

In regions, which have a pronounced wet and dry season, or occasional flooding, it may only be possible (or much more straightforward) to undertake construction in the dry season. Drifts constructed in seasonal streams will not require the additional cost and time for diverting the water or providing cofferdams if they are built during the dry season.

2.2 Assessment of the Problem or Need

Information on Site investigations procedures appropriate for LVR small structure is included in Chapter 5 and Appendices B and E.

An example of a Structural Survey form is shown in Table 2.1. This Table can be used to assess the physical resources and financial costs required to provide the structures. It can also be utilised in assessing priorities and determining work plans for construction units.

The actual costs of structures will vary according to local resource costs and factors. The benefits of keeping a database of actual and estimated construction costs cannot be overemphasised. Because of the many factors that influence local costs and construction practices it is highly risky to transfer unit cost knowledge from one location to another, and most certainly between regions and countries. There is no substitute for careful consideration of all local cost components and variables.

Date:		Road From-To:								Surveyed by:				
		Existing Structures and Reference Points								Preliminary Survey Recommendations				
						Diameter / Height						Diameter / Height		
No.	Chainage	Type	Principle Material	Culvert Length* or Bridge Width* (m)	Culvert? Bridge Span (m)	Pipe Diameter (mm)	Height (m)	Structural Condition	Remarks	Culvert Length* or Bridge Width* (m)	Culvert? Bridge Span (m)	Pipe Diameter (mm)	Height (m)	Proposed Solution
1	0+260	PC	RC	6.00	0.60	1⊘600	0.60	Good	Silted					Remove silt and debris
2	0+477	PC	RC	6.50	1.00	2⊘1,000	1.00	Fair	Erosion base slab at RHS					Repair base slab
3	1+111	Bridge	RC	5.50	4.60	-	2.30	Good						No work required
4	1+864	Drift	Masonry	5.50	12.50	-	-	Fair	Erosion on LHS					Provide gabion protection
5	2+106	AC	Brick	5.50	1.20	-	0.80	Good	Headwall demolished by vehicle IHS					Rebuild brick headwall
6	2+750	Vented Drift	Masonry/ Concrete	6.00	8.50	1⊘600	0.60	Good	Channel erosion LHS downstream, substantial erosion around structure			2⊘1,000?		Prelim assessment indicates enlargement is required
7	3+113	BC	RC	6.50	1.20	-	0.60	Good	The culvert is 2/3 filled by soil and debris				1.2	Culvert installed too low, remove top slab and increase opening to 1.2m
8	3+367	PC	RC	6.00	0.60	1⊘600	0.60	Fair	Sever erosion at outlet RHS					0.6 metre step at outlet. Requires new catchpit structure and repairs downstream
9	3+960								Water crossing road but no structure exists			1⊘600		Provide new 1Ø600 culvert
10	4+335	Drift	Masonry	5.50	6.40	-		Poor	In centre of village with steep eroded approaches	6.50m	-6m			New bridge
11	4+900								Erosion on cutting face RHS				4.5	Cascade and catchpit required, reline cut-off ditch
12	5+215	Bridge	RC	6.50	5.50	-	4.00	Good	RHS parapet rail damaged					Replace one section of parapet rail.

Key
* Clear width across carriageway between headwalls or kerbs
PC = Pipe Culvert RC = Reinforced Concrete
BC = Box Culvert RHS = Right hand side in direction of increasing chainage
AC = ArchCulvert LHS = Left hand side in direction of increasing chainage

Table 2.1: Example of a structural survey format

3 DESIGN CRITERIA

3.1 Selecting Design Parameters

Internationally recognised design standards are being used for the primary road network in South Sudan. However, these standards may not be appropriate for the size and level of traffic on low volume roads. For example, vehicle loading is based on the largest long distance haulage trucks, which rarely use some minor roads in their fully loaded condition. Designs based on these standards would therefore usually incur excessive construction costs. Unfortunately, heavy and overloaded trucks are commonplace on some routes in South Sudan due to driver/operator discipline, economic pressures, or other local factors. This can lead to vehicle and axle loading being experienced well in excess of those in accordance with the national loading regulations. Such occurrences are usually related to haulage of particular products such as bulk fuel, minerals, construction materials and timber. Therefore, when designers are selecting design parameters for a particular structure they must ensure that they are appropriate for the conditions that will be experienced on that particular road. Examples of the factors, which designers should consider, are:

- What is the nature and loading of traffic currently using the route? (Carry out loading surveys if necessary).
- Are conditions likely to change substantially in the foreseeable future? (e.g. could new quarrying operations start up?)
- Are local design standards established for the relevant road category? Are these appropriate or achievable?
- If overloading is prevalent, are there realistic possibilities to physically restrict access?
- What are the cost implications relating to the loading criteria or restrictions?

It is impossible to state definitive design criteria in this Manual, as overall site conditions will vary between locations. The information given below should be considered as a guide to designers, and adapted according to specific conditions in the area or the structure being designed.

3.2 Design Life

The design life of a structure is the length of time that the structure can be expected to carry traffic without reconstruction or replacement of structural elements. It assumes that throughout the life of the structure regular standard maintenance is carried out.

When determining the structure’s design life, the factors which must be taken into account are:

- Expected life spans for different structure types and materials;
- Expected initial and recurrent costs for the design life options;
- Finance currently available and future maintenance / rehabilitation finance probability;
- Future changes in the use of the road (e.g. increased traffic volumes or loadings);
- Flood return periods (see below);
- Consequences of structural failure;
- Likely influence of climate change on future life of the structure, risk and consequences of failure.

The design life of the road itself (i.e. the length of time before the road will become obsolete or require substantial improvement) should also be taken into account. After consideration of all of the relevant local factors, it is probable that a design life of between 10 and 40+ years will be appropriate for an individual structure. The selected design life should be clearly stated in the design dossier.

3.3 Design Flood

One of the major design factors in the selection and size of road structures is the amount of storm water that will flow past the structure. Each year there will usually be a few heavy storms, which will result in peaks in the water-flow over or through the structure, but the largest of these peaks will vary in size each year. If the flows are recorded over a number of years, a longer period of recording will result in a larger maximum peak flow. The highest known flood that has ever occurred may be referred to as the high flood. For minor structures on low volume roads the designer cannot be expected to propose a design that is so large or wide that it could cope with a storm water flow of the high flood. Structures should therefore be designed to have the capacity to cope with a smaller flood; for example, the largest flood that occurs every 10 years. This flood is called the design flood and the time period between successive design floods is called the return period. The design flood is the largest flood that is practical and/or economic for design. Structures should withstand the design flood without any significant damage to the structure or adjacent road and/or embankments. Structures will have a design life greater than the return period between design floods. The designer should therefore consider the effects on a structure of a flood that is larger than the design flood to ensure that significant or unacceptable damage will not occur. Further information about return periods is given in Chapter 6 of this Volume the Manual.

In addition to the practical and economic considerations, the choice of return period for a design should be based on the risk of failure of the structure if a larger flow is encountered. It can be very difficult for the designer to undertake this risk analysis with the limited data that may be available. Table 3.1 therefore shows suggested return periods for design flood flows for different types of structures.

Table 3.1: Design storm return period (years)

Structure type	Geometric design standard (2)	
	DC4	DC5
Gutters and inlets (1)	2	2
Side ditches (1)	5	5
Ford (1)	5	5
Drift (1)	5	5
Culvert diameter <2m (1)	10	10
Large culvert diameter 2 - 6m	15	10
Gabion abutment bridge	20	15
Short span bridge 6 - 10m	25	15

Notes:

1. These periods should be doubled if the alternative route in the event of a drainage failure is more than an additional 75km, or no alternative exists.

2. For further guidance see Table 9.1 and 9.2 in Chapter 9 of Volume 1.

Clearly drifts and vented drifts may be overtopped during or after any storm. In these cases the design period would indicate a peak flow where it would be impossible for a vehicle to cross the structure safely for an extended period. This period would be determined according to the road's importance in the network. The strategic importance of a structure should also be considered. For example, will it be possible to use an alternative route if the structure is temporarily unusable or damaged? The selected storm return period should be clearly stated in the design dossier.

3.4 Traffic Categories and Widths

Careful consideration must be given to the types of vehicles, which may use the road, both at the present time and in the future after road improvements have been made. For example, if the road is close to quarries or a logging area, extremely heavy vehicles may travel down the road. While it may be possible to establish a weight restriction on vehicles using the road due to the loads that particular structures can carry, drivers and operators often ignore them. It may only take one overweight vehicle to destroy a structure and make the road impassable. Engineers should therefore design structures to withstand the load of any vehicle that could travel down the road. Typical loaded weights and vehicle dimensions are shown in Table 3.2.

Table 3.2: Typical loaded weights and dimensions of vehicles that may use low volume roads

Vehicle	Typical max. weight (kg)	Length (m)	Width (m)
Bicycles	250	-	-
Motorcycles	400	2	1
Carts	1500	-	-
Car / pick up	2500	5	1.75
4WD pick up	3000	5	1.75
Minibuses	5000	7	2
Tractor & trailers	12 000	10	2
2 axle small/medium trucks	17 000	8	2.5
Large buses	25 000	15	2.5
2/3 axle heavy trucks	30 000	10	2.5
5/6 axle heavy truck & trailer combinations (1)	60 000	18	2.5

Note:

1. Usually used for paved main road and urban routes only

Experience has shown that some locations are particularly prone to grossly overloaded vehicles. If vehicle overloading is common practice the suggested vehicle weights may be up to twice some of the values shown in Table 3.2. Likely vehicle loading should be carefully considered when choosing the type of structure. For example durability of corrugated steel pipe culverts on unpaved roads will be greatly affected when overloaded. Overloading may occur where there has been loss of fill over the culvert pipe due to traffic and climate. This will lead to eventual direct loading of the culvert pipes or increased loading of the culvert pipe due to lack of sufficient load spreading fill material. The culvert pipe was not designed for either of these load scenarios and cannot withstand this load. In such a situation the level of access provided will be greatly compromised through failure of the culvert.

If a type of vehicle can physically travel down a road then one of these vehicles will almost certainly pass down that road at some time in the life of the structure – therefore structures should be designed to withstand the weight of the heaviest vehicle, which can pass down the road.

Signage should be provided to clearly state the loading capacity of any structure if it is limited in any way. Local road network managers and administrators should also be made aware of any load limitations and the likely consequences of these being exceeded.

With the resources available, if it is not possible to construct a crossing which will withstand the largest vehicle that could travel down the road shown in Table 3.2, it will be necessary to install a robust non-removable barrier each side of the structure to prevent overloaded vehicles crossing.

When the structure is designed, the size of vehicle should also be taken into consideration to ensure that it can safely cross the structure without damage to the vehicle or structure.

The scope of this Manual covers low volume roads generally carrying up to 300 motor vehicles per day equivalent. However it is recognized that with double digit annual percentage increases in traffic typical of some rural routes, the current flow volumes could at least triple even in a 10 year design period. This is especially true for the South Sudan road environment where the road network is at such a very early stage of development. The width of a structure will substantially influence the initial construction cost; for bridges the cost is roughly proportional to deck area and for culverts, roughly proportional to barrel length. In a severely constrained resource environment a vital decision is therefore required with respect to whether one or two-way traffic flow will be accommodated over the structure. It is probable that two-way traffic for bridges will only be justifiable for some category DC4 roads and above; although local conditions may override this. The secondary decision is with respect to the safe width for the predominant traffic type and driver behaviour. These decisions become more important with the increasing size of the proposed structure.

For culverts, a typical provision rate for rolling terrain will be about two or three per Km. In severe terrain or in flat, floodable areas the frequency will be expected to be higher. However, it should be noted that a culvert or other drainage structure is required in all low points in a road. The cost of their provision is usually significant in the overall cost of the low volume road provision, particularly for unpaved roads. The frequent occurrence of culvert headwalls and width narrowing, and the difficulty for drivers to see them in advance, particularly for travel at night without public lighting and hazard signing, raises important safety issues. The provision of minimum two-lane width culverts can therefore often be justified in all except the most constrained finance resource situations. Furthermore, culvert headwalls should not restrict the general roadway width. They should be set back behind the carriageway and shoulder, and clearly marked or have guide stones at each end of the culvert to prevent vehicles driving into the inlets, outfalls or ditches when passing on-coming traffic. These requirements may be relaxed to provide only clear carriageway width in slow speed mountainous alignments.

The argument for restricting larger structures to one lane is more easily supported. At the very basic level, bridges for loaded motorcycle and bicycle traffic on village access tracks can be provided with a carriageway width from about 1.5 metres.

For single lane motor vehicle traffic the clear carriageway width (between kerbs or guide stones) is recommended to be a minimum of 3.65 metres.

If the traffic is mostly light in nature (motorcycles, cars, carts or light goods vehicles) then a 4.6 metres ‘one and a half’ lane option may be appropriate to allow for the occasional safe passage of a heavy goods vehicle.

Where justifiable, full two-lane motor traffic provision should allow a minimum of 6.5 metres between kerbs provided that vehicles are restricted to slow speed passage.

Where physical restrictions are necessary to prevent passage of heavy good vehicles these will need to limit free passage to about 2.3 metres.

It is recommended that the carriageway width (between kerbs or guide stones) should be between 3.75 and 4.5 metres for larger structures such as drifts, vented drifts and bridges. This width should allow easy single way traffic but restrict two vehicles from passing on the structure.

It is likely that these width restrictions will result in a reduction in the general road width which will require a clear indication that the roadway narrows (advance warning signs) as recommended by the national standards for the category of road shown in Chapter 6 of Volume 1. (Plate 1)

Although the widths given above should generally be followed, cross drainage structures are difficult to widen at a later stage. Consideration must therefore be given at the planning stage regarding the future use of the road and whether the traffic volumes are expected to increase significantly. It may prove more cost effective to construct a structure wider than current requirements in order to avoid reconstruction at a later date.

It is evident that close liaison is required with the road alignment designer in the selection of and decision on structures width.

3.5 Design Code

Bridge decks and structural components should be designed according to the Design code set out in the current version of the MRB Bridge Design Manual.

3.6 Serviceability

Vehicle Impact: One of the most common causes of damage to structures is vehicle impact. It is therefore important that reinforcement is placed in culvert headwalls and guide stones to prevent them being demolished by traffic. Safety barriers should be installed in the situations of particular hazards.

Fatigue Deflections: The majority of codes in use limit deflections to prevent fatigue damage to structural members by specifying permissible deflections as a function of length. Typically the permissible deflection is 1/800 of the span length. It will be suitable to relax this requirement to a deflection of 1/100 of the span for LVR small structures (i.e. a 6mm deflection on a 6m span bridge) if only one vehicle will be on the bridge at one time and this level of deflection will not be noticed by drivers when compared to the quality of ride on the approach roads.

3.7 Drainage of the Structure

There should be a camber or cross fall on any highway structure to ensure that water does not collect and lay on the structure, increasing the rate of deterioration or acting as a safety hazard. A minimum camber of 2.5% will normally be acceptable. Bridges should be constructed with adequate drainage arrangements, such as pipes, which drain water off or through the deck away from abutments or piers. Careful consideration should be given to water flow in the side drains along the road adjacent to the structure to ensure that it does not erode a deep channel along the side of the structure.

3.8 Maintenance Capability

When materials are chosen, consideration should be given to the predicted life of the material in relation to the design life of the whole structure. The resources required and frequency of maintenance should also be carefully reviewed. High mobilisation costs and long travel and haul distances to site will reduce the likelihood of maintenance being carried out and the development of local or community maintenance capacity is likely to be difficult in many areas due to low population densities.

3.9 Safety

Where there are a large number of pedestrians using the road, provision should be made for a 1.5m wide segregated footway across or on the side of the structure. If the structure is over 20m long but the number of pedestrians cannot economically justify a pedestrian footway it may be advisable to construct a limited wider section in the middle of the structure (or regular refuges) where pedestrians can wait safely while vehicles pass. In some cases it may be justifiable to construct a separate low cost, lightweight structure for pedestrian passage.

Guardrails and kerbs can be provided to prevent vehicles or pedestrians from falling off the structures. For structures, which have pedestrians regularly crossing, it is highly advisable to construct some form of guardrail to prevent pedestrian and child accidents. This guardrail will not normally be required to restrain vehicles from falling off the structure. The provision of guardrails or kerbs to prevent vehicle accidents will depend on the level of vehicle traffic. It is unlikely that vehicle guardrails can be economically justified where the vehicle flows are less than 50 vpd. If vehicle guardrails are not provided it is imperative that clearly marked kerbs or kerbstones are provided to indicate the extent of the roadway lanes.

Where the structure is designed to be overtopped it is necessary to indicate the depth of water over the roadway and whether it is safe to cross. As it will normally be safe to cross fast flowing water up to a depth of 200mm, guide stones on overtopped structures should be made at least 200mm high. The stones will then remain visible and mark the edge of the roadway when the structure is safe to cross and be submerged under the water when it is unsafe to cross. Guardrails should not be used on structures that are designed to be overtopped, as they will trap debris.

3.10 Future Changes in Road Use

During the initial design of the structure, careful consideration must be given to probable future changes in road use. For example, the type of traffic and number of vehicles of each type, which may affect the requirements of the structure, must be taken into account. The future changes should be reviewed for the predicted life of the structure but consideration should be given to the financial costs of building a larger structure if a smaller, simpler structure will be acceptable for the majority of the design life. A staged construction approach may be preferable to account for present need and funding as well as future tasks of the road network. A drift or vented ford may accommodate immediate to mid-term needs with replacement of the less expensive cross drainage structure with a bridge at a later date when funds allow and traffic volumes and type demand a higher level of service.

In selecting design parameters and ultimately the choice of structure, the economic benefits of different types of structures should be taken into account. These economic considerations not only include the physical costs of the structure and measurable benefits of increased access, lower transport costs, time savings and increased economic activity but also the social benefits of increased access. For example, it may be considered beneficial to provide a small bridge across a river, which will provide constant access to a health centre for a village on the opposite bank. A vented ford may be more suitable for the level of traffic using the road, but high flood flows may prevent a patient receiving treatment in an emergency.

In many cases, engineers will not have all the financial resources that they need to satisfy all the structures needs. If a structure is to be provided which does not fully meet the design requirements, the design should enable the structure to be upgraded at a later date with minimal reconstruction if further resources become available.

Within the South Sudan context a specific consideration for structures should be the cost of replacement of a structure. Staged construction requires an iterative approach to rural road design and construction in order to achieve the most cost effective solution – i.e. using the materials available locally, a wooden culvert may be constructed. At a later date when funds allow, the culvert could be replaced with a more durable option. However, at the design stage the likelihood of maintenance being carried out on the structure, the likelihood of the structure failing, and the cost of mobilising tools, equipment, materials and personnel to replace the structure, especially when there are large distances to the site, should be considered. The effects of failure of the structure should also be considered in terms of level of access provided – will the road link be impassable for a long period and is this acceptable? On some sections of road it may be more cost effective in the medium term to build fewer but more durable structures or more durable structures and less pavement / wearing course in a staged construction approach.

4 STRUCTURAL OPTIONS

The greatest potential cost savings for water crossing options is in the choice of structure type. This chapter considers different water crossing options, from drifts to small bridges with spans of <10m, explaining the characteristics of each and the conditions suitable for their use. The advantages and disadvantages associated with each structure are also discussed.

While structure types are presented individually it should be remembered that, for alluvial plains, a combination of a number of structures, perhaps constructed under adaption of a staged construction approach might be the most cost effective means of spanning the watercourse.

4.1 Drifts

Drifts are the most basic structure and can be the lowest cost form of watercourse crossing. There are two types of drift:

Relief drifts: relieve side drains of water where the road is on sloping ground and water cannot be removed from the uphill side drain by mitre drains, or as an alternative to a relief culvert.

Small watercourse (or stream) drifts: where stream flows are very small drifts may be used to allow the stream to cross the road (see Figure 4.1, Plate 2).

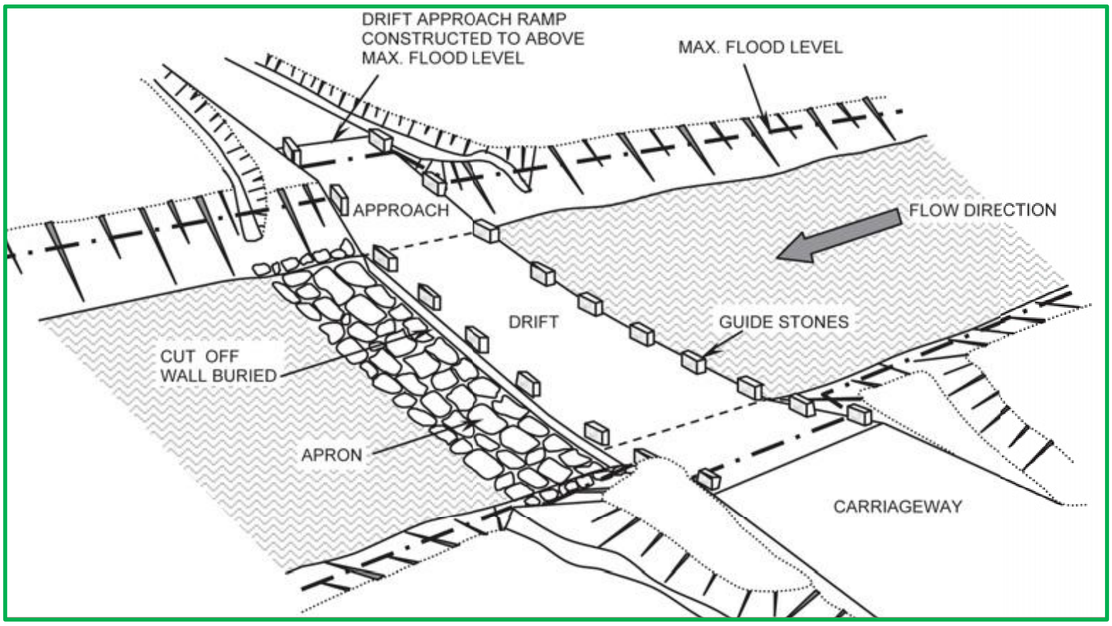


Figure 4.1: Key features of a stream drift

Drifts can also be referred to as Irish bridges, fords or splashes. The terms describe essentially the same structure, however, it is generally accepted that a ford or splash is constructed from the existing riverbed e.g. a sandy riverbed or level rock. A drift is a ford or splash with an improved running surface constructed from imported (or gathered) materials. A low water crossing is the collective term used to describe all drifts, fords, splashes and vented fords.

4.1.1 Key features

The key features of drifts are:

1. Stream drifts are structures which provide a firm place to cross a river or stream. Relief drifts transfer water across a road without erosion of the road surface. Water flows permanently or intermittently over a drift, therefore vehicles are required to drive through the water in times of flow.
2. Drifts are particularly useful in areas that are normally dry with occasional heavy rain causing short periods of floodwater flow.
3. Drifts provide a cost effective method for crossing wide rivers which are dry for the majority of the year or have very slow or low permanent flows.
4. Alternative solutions may be preferable for small permanent watercourses to prevent vehicles having to drive through the water.
5. Drifts are particularly suited to areas where material is difficult to excavate, thus making culverts difficult to construct.
6. Drifts are also particularly suited in flat areas where culverts cannot be buried because of lack of gradient.
7. If necessary, guide stones should be provided on the downstream side of the drift and be visible above the water when it is safe for vehicles to cross the drift.
8. Buried cut off walls are required upstream and downstream of the drift to prevent under cutting by water flow or seepage.
9. The approach road level will normally mean that approach ramps are required. Approach ramps should be provided to the drift in the bottom of the watercourse with a maximum gradient of 10%.
10. Drifts should not be located near or at a bend in the river.
11. Some form of protection is usually required downstream of a drift to prevent erosion.

The advantages and disadvantages of using drifts for water crossings are shown in Table 4.1.

Table 4.1: Drifts: advantages and disadvantages

Advantages	Disadvantages
• Low cost: at the most basic level, can be constructed and maintained entirely with local labour and materials; • Ease of maintenance and repair; • Volume of excavated material in most cases is minimal; • Do not block with silt or other debris carried by floodwater; • Can accommodate much larger flows than culverts; • Easier to repair than culverts; • Water flows over a wide area, resulting in less water concentration and erosion downstream than piped culverts.	• Drifts require vehicles to slow down when crossing; • The crossing can be impassable to traffic during flood periods; • Foot passage can be inconvenient or hazardous when water is flowing.

4.2 Culverts

Culverts are the next step upwards from drifts in terms of cost and complexity of structure. There are two types of culvert:

Stream culverts: which allow a watercourse to pass under the roadway.

Relief culverts: at low points in the road alignment or where there is no definable stream, but the topography of the ground requires a significant amount of cross drainage which cannot be accommodated by side drains (See Figure 4.2).

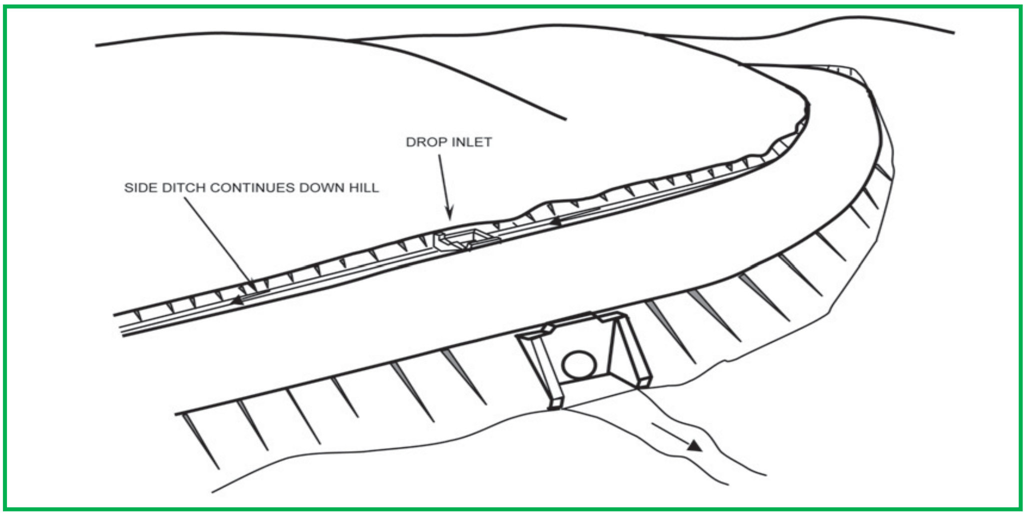


Figure 4.2: Key features of a relief culvert

4.2.1 Key features

The key features of culverts are:

1. Culverts are the most commonly used structures on low volume roads. They can vary in number from about one each km in dry and gently rolling terrain up to six or more for severe terrain with high rainfall. In flat areas with high rainfall, the frequency may also increase to allow water to cross the road alignment in manageable quantities.
2. Culverts channel water under the road, avoiding the need for vehicles to drive through the watercourse.
3. In addition to well-defined water crossing points, culverts should normally be located at low points or dips in the road alignment.
4. Relief culverts may be required at intermediate points where a side drain carries water for more than about 200 metres without a mitre drain or other outlet.
5. Culverts can be pipe, box, slab or arch type.
6. Headwalls are required at the inlet and outlet to direct the water in and out of the culvert and prevent the road embankment sliding into the watercourse. Wingwalls at the ends of the headwall may also be used to direct the water flow and retain material.
7. Aprons with buried cut off walls are also required at the inlet and outlet to prevent water seepage, scouring and undercutting.
8. Culvert alignment should follow the watercourse both horizontally and vertically where possible.
9. Gradient of the culvert invert should be between 2-5%. Shallower gradients could results in silting whereas steeper gradients result in scour.
10. Culvert invert levels should be approximately in line with the water flow in the streambed, otherwise drop inlet and/or long outfall excavations may be required.
11. Common culvert diameters are 600mm and 900mm.
12. Cross culverts smaller than 600mm in diameter should not be installed, as they are very difficult to clean.

13. Where foundation material is poor, culverts should be placed on a good foundation material to prevent settlement and damage. On very soft ground, it may be necessary to consider concrete, steel or timber piles to provide adequate foundations. This will require specialist design expertise not covered by this manual.
14. It is necessary to protect the watercourse from erosion downstream from the structure.
15. Culverts can exist in pairs or in groups to enable larger stream flows to be accommodated using standard unit designs. An example of a three-barrel corrugated steel culvert.
16. When silt supply is high, pipe culverts shall not be used.

The advantages and disadvantages of using culverts are shown in Table 4.2.

Table 4.2: Culverts: advantages and disadvantages

Advantages	Disadvantages
• Culverts provide a relatively cheap and efficient way of transferring water across a road; • Can be constructed and maintained primarily with local labour and local materials; • Culverts allow vehicle and foot passage at all times; • Culverts do not require traffic to slow down when they are crossed; • Culverts allow water to cross the road at various angles to the road direction for a relatively small increase in costs.	• Regular maintenance is often required to prevent the culvert silting up, or to remove debris blockage; • Culverts act as a channel, forcing water flow to be concentrated, so there is a greater potential for downstream erosion compared with drifts; • Culverts are not suited to occasional high volume flows.

4.3 Vented Fords and Causeways

These generally have higher capacity and construction costs than drifts or culverts. A typical vented ford/causeway is illustrated in Figure 4.3 and Plate 3.

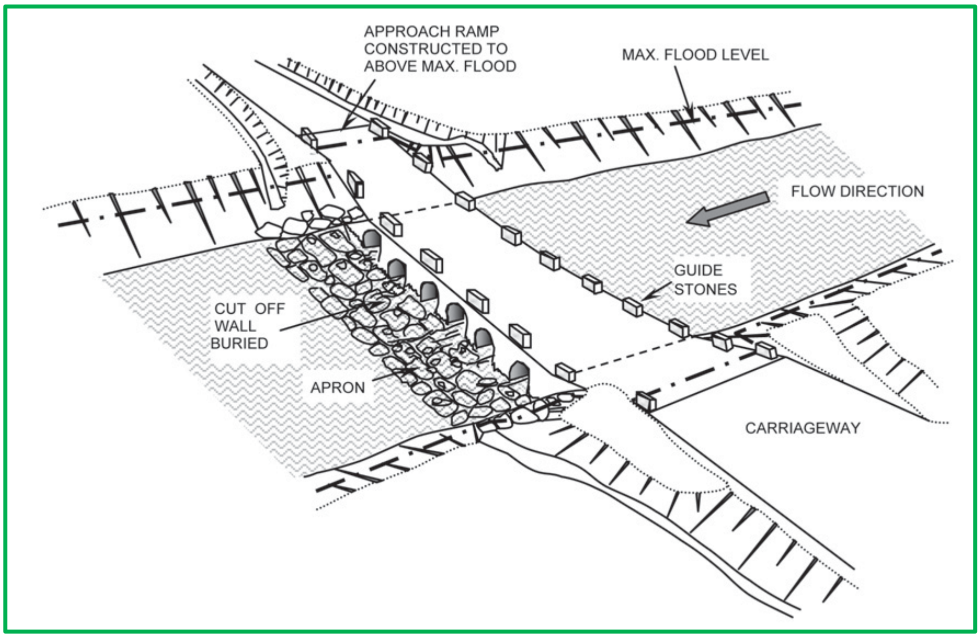


Figure 4.3: A typical vented ford / causeway

4.3.1 Key features

The key features of vented fords and causeways are:

1. These structures are designed to pass the normal dry weather flow of the river through pipes below the road. Occasional larger floods pass through the pipes and over the road, which may make the road impassable for short periods of time.
2. Vented causeways are the same concept as vented drifts but are longer with more pipes to cross wider watercourse beds.
3. The level of the road on the vented drift should be high enough to prevent overtopping except at times of peak flows.
4. There should be sufficient pipes to accommodate standard flows. The location of pipes in the drift will depend on the flow characteristics of the river.
5. Vented fords should be built across the whole width of the water- course.
6. A vented ford requires approach ramps which must be surfaced with a non-erodible material and extend above the maximum flood level.
7. Watercourse bank protection will be required to prevent erosion and eventually damaging the entire structure.
8. The approach ramps should not have a steeper grade than 10% (7% where there is significant heavy vehicle traffic).
9. The upstream and downstream faces of a vented drift require buried cut off walls (preferably down to rock) to prevent water undercutting or seeping under the structure.
10. An apron downstream of the pipes and area of overtopping is required to prevent scour by the water flowing out of the culvert pipes or over the structure.
11. There is also a requirement to protect the watercourse from erosion downstream from the structure. There will be considerable turbulence immediately downstream of the structure in flood conditions.
12. The road surface longitudinal alignment of the vented ford should be a slight sag curve to ensure that, at the start and end of overtopping, water flows across the centre of the vented drift and not along it.
13. There should be guide stones on each side of the structure to mark the edge of the carriageway and indicate when the water is too deep for vehicles to cross safely.
14. Vented fords can also be known as piped drifts

The advantages and disadvantages of using vented fords and causeways are shown in Table 4.3.

Table 4.3: Vented fords/causeways: advantages and disadvantages

Advantages	Disadvantages
• Vented fords can allow a large amount of water to pass without overtopping; • They are cheaper to construct and maintain than bridges; • Construction of vented fords is fairly straightforward compared with bridges; • Vented fords are well suited to cope with short high volume flows; • Can be constructed and maintained primarily with local labour and local materials.	• Vented fords can be closed for short periods during periods of flooding and high flow; • Floating debris can lodge against the upstream side of the structure and block pipes; • Foot passage can be inconvenient or hazardous when water is flowing.

4.4 Large Bore Arch Culverts

Large bore arch culverts are illustrated in Figure 4.4 and Plate 4.

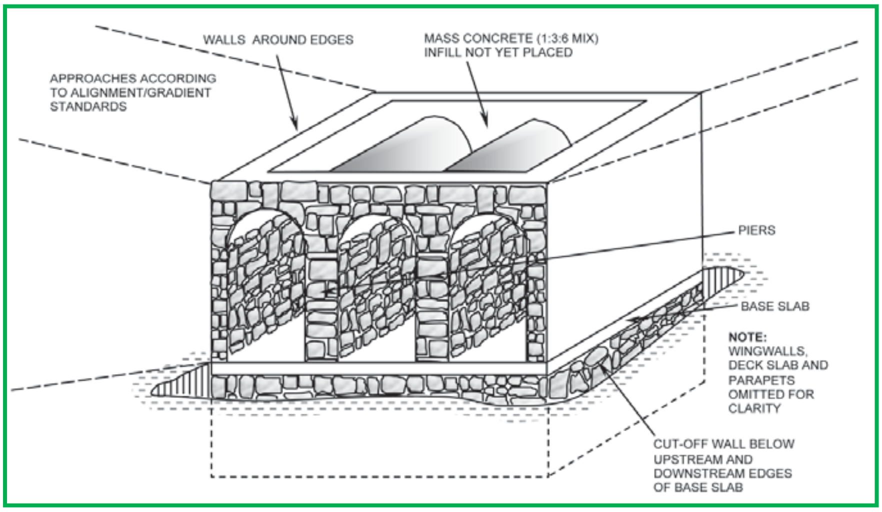


Figure 4.4: Key features of large bore culvert

4.4.1 Key features

The key features of large bore arch culverts are:

1. Large diameter culverts typically have openings greater than 1 metre and are capable of passing high flows, either through one large opening or a number of medium sized openings.
2. Very large bore arch culverts may also be called arch bridges.
3. Formwork is required to construct the openings. This formwork can be made from wood, stones or metal sheeting and either incorporated into the structure or removed once construction is complete.
4. Although these structures are not generally designed to be overtopped, they can be designed and constructed to cope with an occasional overtopping flood flow.
5. The road alignment needs to be a minimum of 2 metres above the bottom of the watercourse.
6. Approach embankments are required at each end of the structure.
7. Large bore culverts require solid foundations with a buried cut off wall on both upstream and downstream sides to prevent water seepage erosion and scouring.
8. These structures require large amounts of internal fill material during construction.
9. Guide stones or kerbs should be placed at the edge of the carriageway to increase vehicle safety.
10. If the crossing is to be used by pedestrians, consideration should be given to installing guardrails and central refuges for long crossings where pedestrians can move off the roadway to allow traffic to pass.
11. Water from the roadside drains should be carefully channelled into the watercourse away from the structure to prevent erosion of the bank or scour of the culvert structure.

The advantages and disadvantages of large bore arch culverts are shown in Table 4.4.

Table 4.4: Large bore culverts: advantages and disadvantages

Advantages	Disadvantages
• Large bore culverts are usually easier and cheaper to construct than bridges; • They can accommodate flows significantly higher than smaller culverts and vented fords; • Can be constructed and maintained primarily with local labour and materials, without the need for craneage; • They may easily be designed and constructed for occasional overtopping • Central 'piers' are not so susceptible to damage by scour and erosion compared with bridge piers; • They generally require less maintenance than conventional bridges.	• The water opening in large bore culverts is smaller than for a bridge of the same size, which reduces the potential flow rate past the structure at peak flows; • Large bore culverts can require a significant amount of internal fill material.

An alternative to a large or multi-bore culvert is a reinforced concrete box culvert. The Manual does not cover this type of structure. For guidance on such structures refer to the MRB Bridge Design Manual and publications such as TRL Overseas Road Note 9.

4.5 Bridges (arch or simply supported deck)

Bridges are generally the highest cost structures to construct. This Manual does not cover multiple span bridges, which may be simply supported or continuous over piers. For such structures and bridges with spans more than 10 metres, refer to the current MRB Bridge Design Manual. Simply supported bridge decks are illustrated in Figure 4.5, Plate 5.

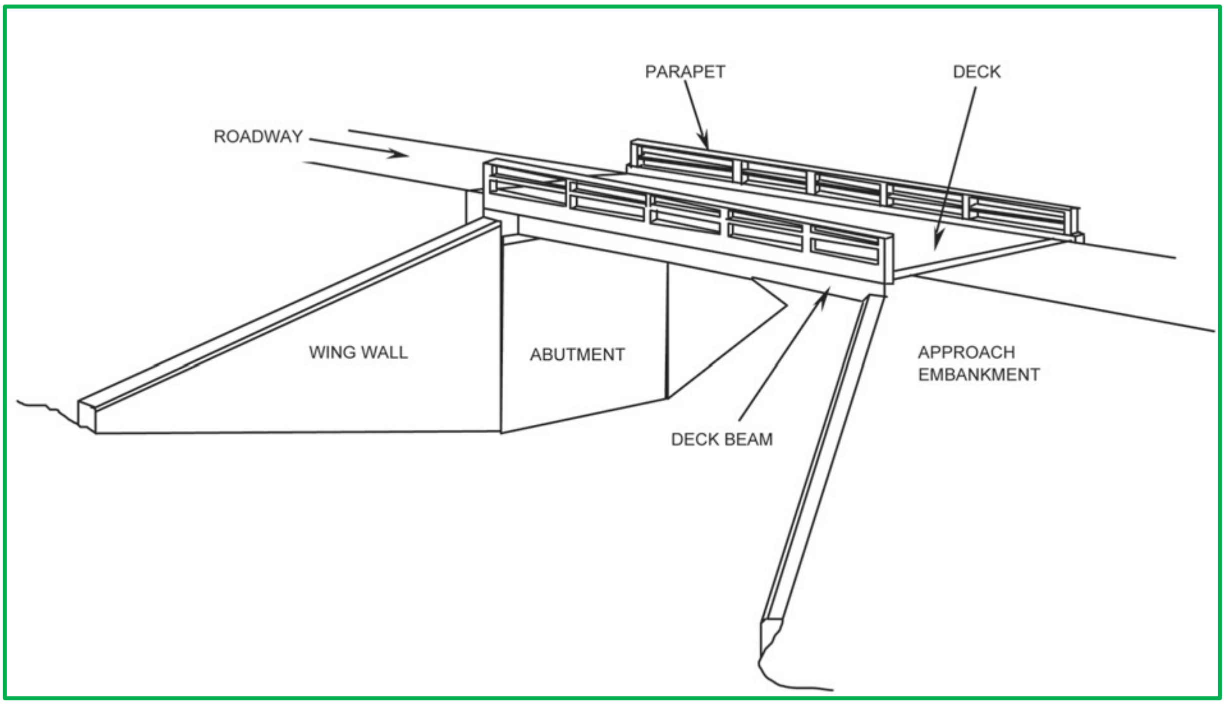


Figure 4.5: Key features of a simply supported deck bridge

4.5.1 Key features

Key features of the bridges covered in this Manual are:

1. The arch is the simplest form of bridge.
2. There are a number of different elements to a simply supported deck bridge. These are a superstructure (comprising deck, parapets, guide stones and other road furniture) and substructure (comprising abutments, wing walls, foundations, piers and cut off walls).
3. Bridges are generally the most expensive type of road structure, requiring specialist engineering advice and technically approved designs.
4. Bridges can be single span or multi span, with a number of openings for water flow and intermediate piers to support the superstructure.
5. The main structure is always above flood level, so the road will always be passable.
6. Abutments support the superstructure and retain the soil of the approach embankments.
7. Wing walls are needed to provide support and protect the road embankment from erosion.
8. Embankments must be carefully compacted behind the abutment to prevent soil settlement which would result in a step on the road surface at the end of the bridge.
9. Weep holes are needed in the abutment to allow water to drain out from the embankment, and avoid a build up of ground water pressure behind the abutment.
10. Bridges should not significantly affect the flow of water (i.e. the openings must be large enough to prevent water backing up and flooding or over topping the bridge).
11. The shape of the abutments and piers will affect the volume of flow through the structure and also the amount of scouring.
12. Bridges require carefully designed foundations to ensure that the supports do not settle or become eroded by the water flow. On softer ground this may require piled foundations which are not covered in this Manual.
13. Water from the roadside drains should be channelled into the watercourse to prevent erosion of the bank or scour of the abutment structure.
14. Guide stones or kerbs should be placed at the edge of the carriageway to increase vehicle safety.
15. If the crossing is to be used by pedestrians, consideration should be given to installing guardrails and a central refuge for long crossings where pedestrians can move off the roadway for passing traffic.

Advantages and disadvantages of bridges with spans <10 m are shown in Table 4.5.

4.5: Bridges: advantages and disadvantages

Advantages	Disadvantages
• The road is always passable because the structure should not be overtopped; • Simple arch bridges can be constructed primarily with local skills and local materials without the need for craneage, however, simply supported spans are more complex.	• Bridges are normally significantly more expensive than other road structures; • They are more complex than other structures and will require specialist engineering support for design and construction; • Additional height and earthworks in approach embankments; • Bridges may require heavy duty lifting cranes for the deck components; • Although all structures should be inspected for defects, bridges require regular detailed checks; • Bridges are likely to fail if flood flow predictions are incorrect and they are over topped; • A small amount of scour and erosion can often result in major damage to the structure.

4.6 Structure Selection

The objective in selecting a structure for a water crossing is to choose the most appropriate design for each location. This selection should be based on the factors outlined in the following sections.

4.6.1 Costs

Assessments will have to be made of the initial cost of construction. This should include materials, transportation, equipment, labour, and supervision as well as overheads (and for a contractor, the profit margin). An assessment will also have to be made of the on-going maintenance costs that will be required for each structure.

The example in Table 4.6 compares the costs of a timber bridge with a masonry vented ford. Initially it may appear that the timber bridge is the cheaper option but, even without inflation over the first 15 years, the masonry culvert can be shown to be the cheaper when whole life costs are considered. Furthermore, there may be risks that funding will not be available for maintenance, or that defects will not be identified and repaired in a timely manner on a high maintenance structure.

4.6.2 Amount of traffic per day / acceptable duration of traffic interruptions

The amount and type of traffic using the road each day will help determine carriageway width, and the acceptable length of time that the road may be closed due to overtopping during periods of peak flood. A two-lane traffic carriageway may be required for a route with higher traffic volumes whereas a single lane carriageway may be sufficient for routes with lower traffic volumes. If goods vehicles are using the route the length of time acceptable for the road to be closed may be reduced. Whereas if the road is used for local travel only and an alternate but longer route exists a longer period of impassability may be acceptable. The seasonality of traffic flows and relationships to likely flood periods should also be considered in terms of the risk to local perishable goods for example.

4.6.3 *Frequency of flooding*

The frequency and size of peak flows will determine the level of the structure's roadway to ensure that the road remains open for all but the largest peak flows.

4.6.4 *Emergency / principal route*

Principal routes such as access roads to local markets or emergency routes to a nearby hospital will require higher levels of access and shorter periods of closure due to high water levels.

4.6.5 *Availability of alternative route*

The proximity and distance of an alternative route will also affect the choice of structure because an alternative secure route with a short acceptable detour will allow the road to be closed for longer periods.

4.6.6 *Damage to land or property*

Whenever watercourses are channelled through pipes, such as in culverts and vented fords or through narrow openings in bridges, severe erosion can be caused to land and property downstream of the structure. If agricultural land or buildings are close to the proposed structure careful consideration must be given to erosion protection. Undersized structures can also cause water to back up causing flooding upstream and possible property damage.

4.6.7 *Uncertainties in flood prediction*

The choice and design of the structure will depend on the maximum water flow during flood conditions. If the maximum water flow is not known sufficiently accurately it may be necessary to provide a structure that can be over-topped during periods of unpredicted water flow.

4.6.8 *Bank elevation and bed material of the watercourse*

The resistance of the watercourse banks and bed to erosion will dictate the type of foundation bank protection and hence structure that can be built. For material which is easily erodible it will be necessary to have deep foundations and possibly extensive bed and bank protection or structures which are not susceptible to damage. The steepness of the banks and difficulty in excavating soil material will also determine the most convenient approach roads.

A major factor affecting the cost of building a structure is the amount of material which needs to be imported to or exported from the site. Where the road alignment is at a similar level to the riverbed it may be difficult to construct a structure that will not be overtopped without large approach ramps/ embankments as illustrated in Figure 4.6.

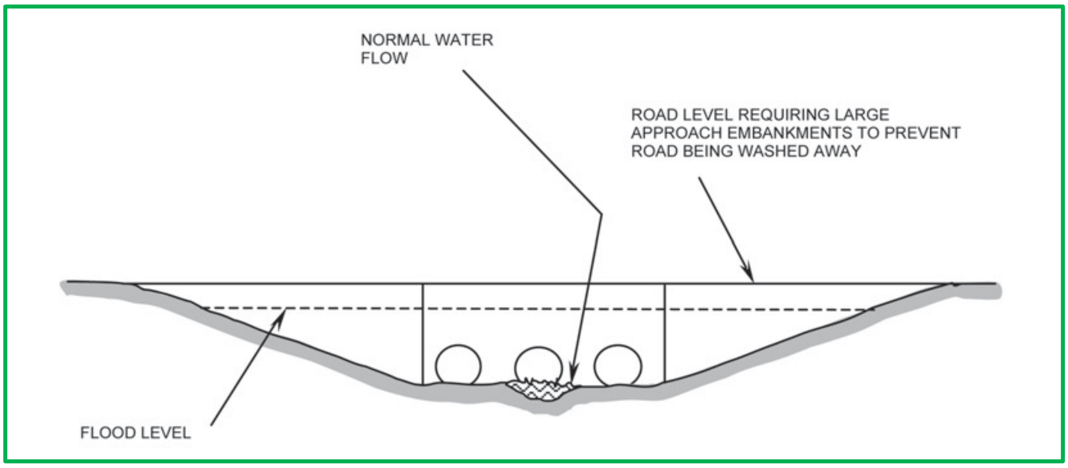


Figure 4.6: Large embankments required to prevent road flooding

4.6.9 Complexity of the structure

There is a general progression in complexity, and hence cost, of structures with the cheapest structure being a drift and the most expensive being a bridge (see Figure 4.7).

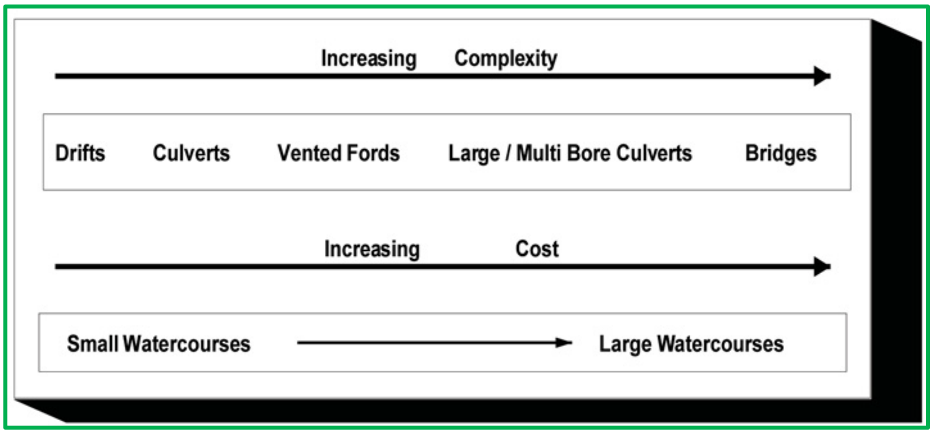


Figure 4.7: Complexity and cost

It may also be difficult to define the boundaries of different structures (for example, “when does a vented ford become a multi-bore culvert?”). In reality there are overlaps of suitability of each structure type so that in a particular situation more than one structure type may be suitable.

For small watercourses and relief structures the choice of structure will, in general, be between a culvert and drift and, for large watercourses, between a vented ford and a large bore culvert, or possibly a bridge. The choice of structure will be determined by all the factors discussed above, but particularly by the predicted maximum water flow, its seasonal variations and the length of road closures that can be tolerated.

The flow diagram in Figure 4.8 shows in more detail the questions and decisions that should be made when choosing a structure. Factors affecting the choice of structure are different for each location; therefore a number of questions need to be addressed. It should also be noted that Figure 4.8 only highlights the key issues and should only be used as a guide when determining the most appropriate structure.

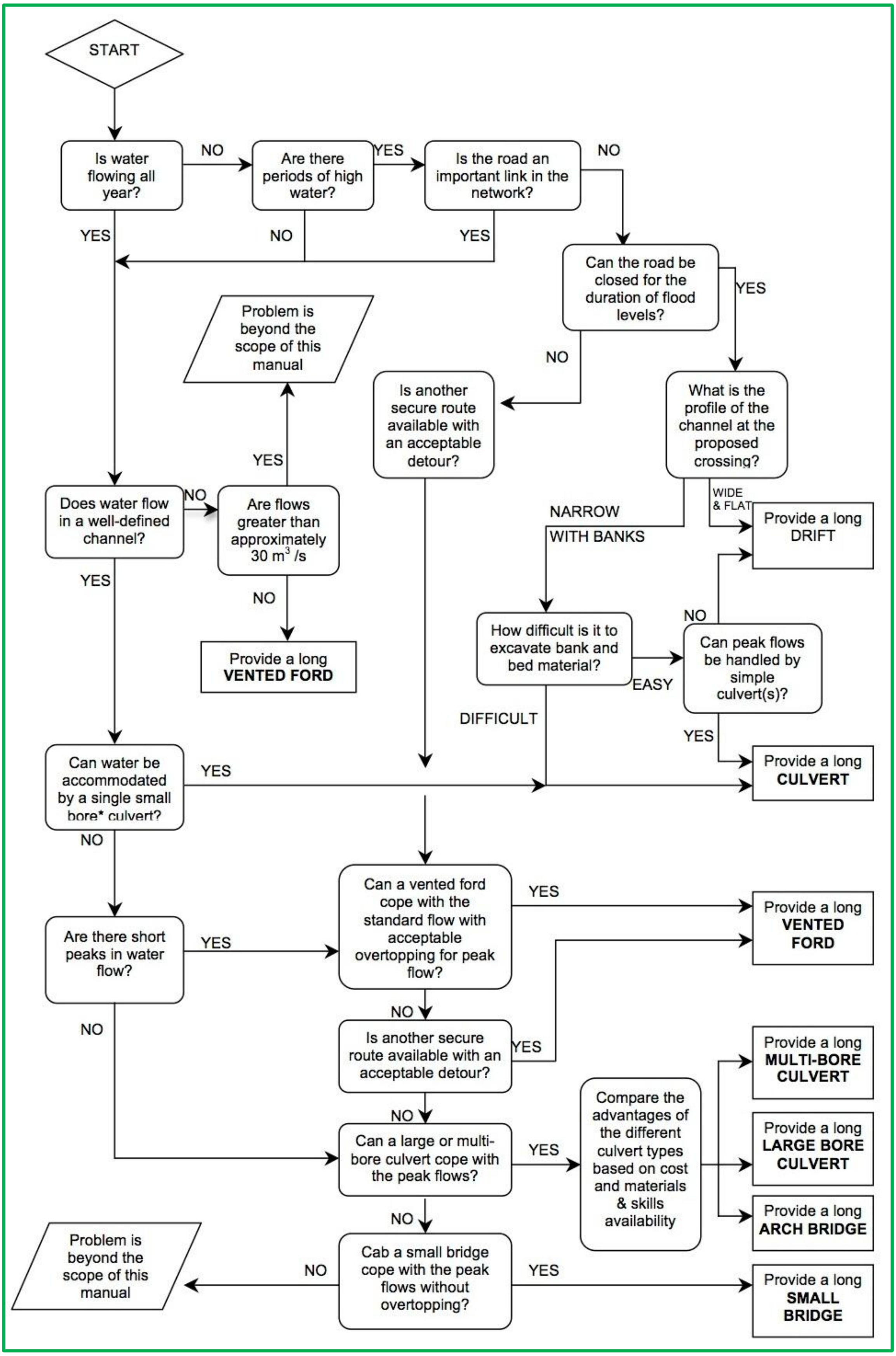
Figure 4.8 also asks questions regarding the permissible closure time for a road during floods. Each individual case will have to be assessed separately depending on it's particularly circumstances. In the absence of any local guidelines Table 4.7 gives suggested upper and lower bounds for closure times.

Table 4.7: Closure times

Criteria	Drift most favourable	Drift least favourable
Average daily traffic (ADT)	Less than 5 vehicles per day	More than 200 vehicles per day
Average annual flooding	Less than twice per year	More than 10 times per year
Average duration of traffic interruption per occurrence	Less than 24 hours	More than 3 days
Extra travel time for detour	Less than 1 hour	More than 2 hours/no detour

Due to the road environment in South Sudan (see Chapter 4, Volume 1) a combination of structures may often be the most cost effective solution. Wide perennial flood plains may be best crossed by vented fords with long approach embankments with relief culverts along their length. Similarly bridge lengths could be shortened in combination with relief culverts if erosion potential at the crossing point is found to be minimal due to flat terrain and stable material. This manual details the design of each individual structure type but consideration should always be given at initial design and cost estimation stage as to whether a combination of structures will be more cost effective for watercourse crossings.

When the problem is 'beyond the scope of this Manual', specialist bridge engineering skills should be mobilised.



* Small bore culvert is one which is less than 900mm diameter

Figure 4.8: "Route Map" for selection of a suitable structure

5 SITE SELECTION AND APPRAISAL

5.1 General Requirements

For minor structures such as drifts or culverts on existing routes there may be little choice available in site selection. Changing the existing road alignment could incur substantial additional road works costs.

For relief drifts or culverts that are necessary to allow the buildup of water in side drains to cross the road alignment, there is usually some flexibility in location. Normally side drains will be relieved by a turn out or cross structure after a maximum length of about 200 metres to avoid exceeding capacity or causing erosion in the drain or in the outfall watercourse. Ideal outfall sites are at field boundaries or where there is vegetation or stable ground to minimise the risk of damage or erosion downstream.

For larger structures and watercourses the selection of site location requires more attention (See Figure 5.1).

Careful site selection is essential to ensure ease of construction and to minimise the whole life cost of the structure. Poor site selection can result in a longer, wider or higher structure than is actually necessary. Poor siting can also lead to excessively high maintenance costs and, in extreme cases, a high risk of destruction of the structure. Regardless of the type of structure the following criteria should ideally be met when determining a site for a water crossing (other than at side drain relief, drift and culvert crossings):

1. The crossing should be located away from horizontal curves in the watercourse because these areas are unstable, with the line of the watercourse tending to move towards the outside of the bend with time. If no option is available a new channel should be made (See Figure 5.1).
2. The crossing should be at an area of uniform watercourse gradient. If the gradient is steepening there is a greater possibility of scour and erosion, and if the gradient is decreasing there is the potential for silt and other debris to be deposited near or inside the structure.
3. The crossing should, ideally, be at an area of the channel with a non-erodible bed. These areas are less prone to scour and therefore less scour protection is required;
4. The road should cross the watercourse at a point with well-defined banks where the stream will generally be narrower.
5. The watercourse should not be prone to flooding at the crossing point.
6. The skew angle shall be <15^{o}.

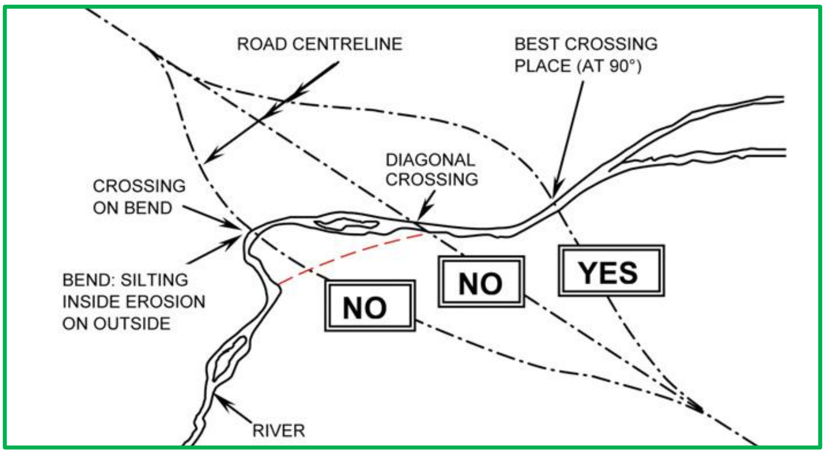


Figure 5.1 Suitable crossing points for larger structures

5.1.1 Road alignment

In addition to the watercourse requirements noted in Section 5.1, the road should:

1. Cross the watercourse at 90 degrees because this minimises the span length of the bridge or pipe. A comparison of length of culvert L1 with a culvert on a skew crossing L2 is shown in Figure 5.2.

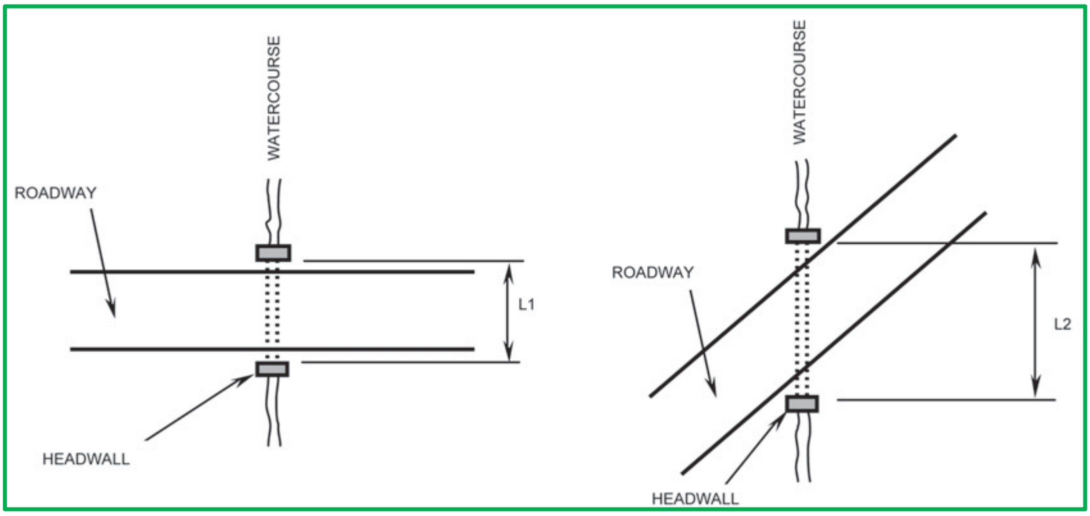


Figure 5.2: Right angle crossings reduce the length and cost of structure required.

2. Cross on a straight length of road rather than a curve to reduce the width of a bridge or length of a culvert. For bridges the minimum straight approach should where possible conform to the minimum Stopping Sight Distances in Table 3.3.
3. Be fixed vertically at the minimum elevation necessary to pass above the design flood flow (this is obviously not required for drifts and vented fords). If the road alignment is fixed too high, unnecessary costs will be incurred in abutment/wingwall/headwall construction and approach embankments.
4. Be centred above the centre line of the substructure.

5.1.2 Location

The site of the river crossing should be away from waterfalls and confluence zones. A site with a natural narrow channel width rather than a wide one should be used.

In locating a structure it is very rare that all the criteria above can be satisfied for each crossing, therefore a balanced consideration of the various factors is required. It is necessary to establish the most cost effective solution for each structure depending on individual circumstances.

5.1.3 Existing structure assessment

Where existing roads are being improved, existing drainage sites should already have been provided with an appropriate structure. However, it is possible that the structure is inadequate or the need for a structure had been overlooked. A common fault is that culverts have been installed at the wrong level; too high often results in erosion downstream; too low leads to repeated silting and a maintenance problem. When the road is inspected the following conditions indicate that further drainage work needs to be undertaken:

1. Small gullies exist on the road due to water flowing across the running surface.

2. Existing culverts are damaged due to standing water softening the soil around the culvert or insufficient capacity.
3. Sand and silt has been deposited on the road in patches due to standing water.
4. Culverts, inlets or outlets are silted due to incorrect design or installation.
5. Evidence of erosion around the structure or culvert.
6. Debris trapped at inlet due to incorrect type, sizing or lack of protection.

Figure 2.1 is an example of a completed structural assessment form used for assessing existing structures.

5.2 Specific Requirements

In addition to the general site selection criteria given above, the following factors should be taken into account for the different types of structures.

5.2.1 Drifts

The following site selection criteria should be considered when locating drifts:

1. Avoid areas with steep banks (greater than 1.5m) because these require a large amount of excavation to achieve acceptable approach gradient and erosion/siltation problems can occur.
2. The level of the drift should be as close as possible to the existing riverbed level. This is most important, as it will affect the amount of water turbulence and erosion that may occur around it.
3. The normal depth of water should be a maximum of 150mm and the maximum 5-year flow should be $6m^3$/second on the drift to allow traffic to pass.
4. The watercourse should be clearly defined and stable at the crossing point to ensure that the water will not alter its flow away from the drift slab.
5. In flat arid areas it may not be possible to determine the exact location of the low point in the alignment or occasional watercourse without a detailed level survey.

5.2.2 Culverts

The key features of culverts are presented in Section 4.2.1. As previously discussed a site investigation is required to determine the number and location of culverts. Table 5.5 suggests intervals between relief culverts on long grades as a general guidance. Culverts will also be required at points where a stream or waterfall crosses the road. These culverts may also be used as relief culverts to transfer the water across the road.

Table: 5.5: Minimum recommended relief culvert spacing

Road gradient (%)	Culvert interval (m)
12	40
10	80
8	120
6	160
4	200
2	>200

The location of a culvert will be determined from the foregoing considerations. On rural roads there is often insufficient attention paid to the alignment and forces related to the water flow, especially when this is infrequent. This often causes problems for the performance and maintenance of the culvert.

Careful selection of the culvert alignment and size is important to:

- Achieve good hydraulic performance;
- Ensure stability of the stream bed;
- Reduce risks for vehicles;
- Minimise construction and maintenance costs.

It is important to design the culvert to be free from sediment deposits, which tend to occur on the inside of stream bends, or where there is an abrupt change from the stream slope to a flatter grade in the culvert. For reasons of economy, culverts should always be laid on a straight alignment that may be perpendicular or skewed to the road centre line.

In rolling and mountainous terrain culverts usually operate as hydraulically short drainage structures under conditions of inlet control. The slope of the culvert invert should be 2-5%. Typically, they are sized to flow 75-90% full, with measures to reduce velocities at the outlet. In flat terrain the culvert slope should be the same as that of the stream or watercourse but should never be less than 1% to prevent siltation.

For relief cross culverts where sediment loads are low to moderate the combination of a nominally 1m deep catch-pit inlet, a moderately sloping culvert long-section, and sufficient energy dissipation and erosion protection works at the outlet, is recommended. A culvert catch-pit inlet area should be designed to be easily manually cleared of debris during maintenance operations. The catch-pit should have raised side walls or wing walls to contain water splash. Where sediment loads are high, a chute inlet, a wide culvert and greater erosion protection works at the outlet are usually required.

Typical examples of problems that could occur if attention is not given to appropriate horizontal and vertical road alignments are:

1. In flat ground the level of the surrounding ground should determine the invert of the culvert outfall. Box culverts and arch culverts are preferable in these circumstances because the flat invert slabs cause less disturbance to the flow of water. Barrel culvert inverts should be similarly determined, however, an outfall apron should be provided to ensure that the flow is stabilised and distributed horizontally before it reaches the natural ground downstream. If the invert is placed too low then the culvert outfall and opening will silt up. If the invert is fixed too high there will be ponding or silting upstream of the structure and the risk of erosion as the water drops to its natural vertical alignment downstream of the structure. This also results in the shifting of the streamline and changes in the stream morphology. It follows that the alignment of the road should be raised if necessary to provide the correct invert, adequate height for the structure and any necessary protective cover.
2. Where the road is on ground sloping along and across the alignment, a frequently observed mistake is to leave the road vertical alignment unchanged and ‘bury’ the culvert in order to achieve the required fill over the culvert. This results in a need for the outlet to discharge in a long trench with a flat grade to rejoin the natural streambed. Not only does this ditch often encroach substantially on the surrounding land, but it is also prone to silting and consequently to causing blockage of the culvert. Furthermore, vegetation growth and bank erosion are common related problems. In essence a maintenance problem is created. Localised raising of the road alignment can alleviate this potential problem (Figure 5.3). Long culvert outfall ditches should be avoided and their grade should not be less than 2% under normal conditions.

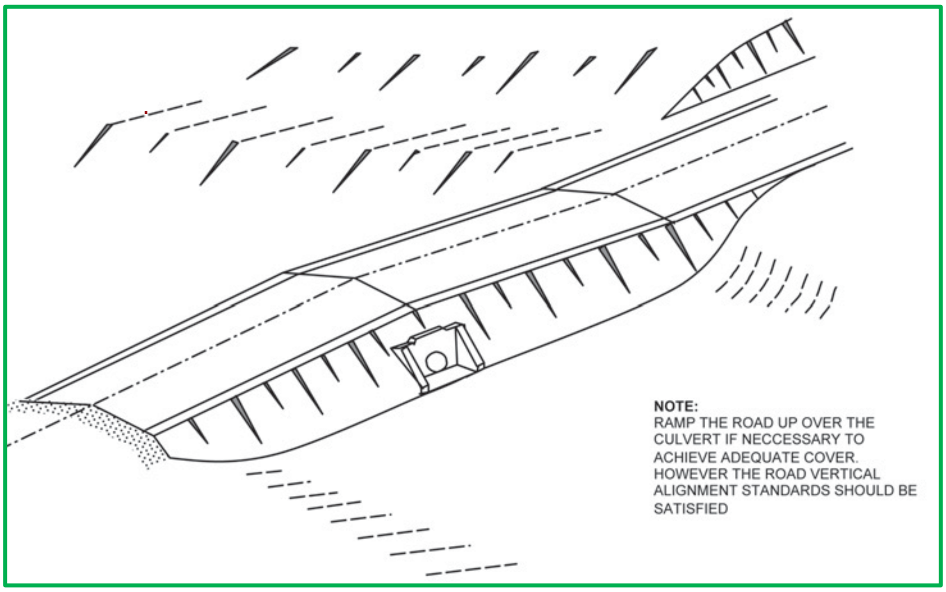


Figure 5.3: Road alignment raised over culvert (schematic)

3. On steep sidelong ground a key consideration is to minimise the erosion risk. In these circumstances there is usually more opportunity to 'bury' the culvert under the road and provide a short outlet ditch. A 'drop inlet" or 'catchpit' arrangement (Figure 5.4) is normally required at the inlet to provide a controlled drop in the water flow. Particular attention may still need to be paid to downstream erosion protection. Special arrangements such as energy dissipating cascades or gabions may be required in extreme cases. The drop inlet arrangements also need consideration to be made regarding risk of blockage and maintenance arrangements.

In all situations the road alignment standards and structure protection cover requirements should be complied with.

Although it is desirable for culverts to cross roads at 90 degrees to minimise the length and hence the cost of the culvert, it is not essential and various alignment options are shown in Figure 5.5. However, it is important to avoid abrupt changes in stream flow direction at the inlet or outlet of the culvert as this will result in severe erosion risk for the channel (without suitable control arrangements such as a drop inlet or erosion protection).

It is not possible to achieve this requirement for relief culverts which transfer water across the road from the high side channel to the low side channel. These culverts will have an abrupt bend at the inlet and require careful protection to ensure that erosion does not occur. The design of these inlets is discussed in more detail in Chapter 8.

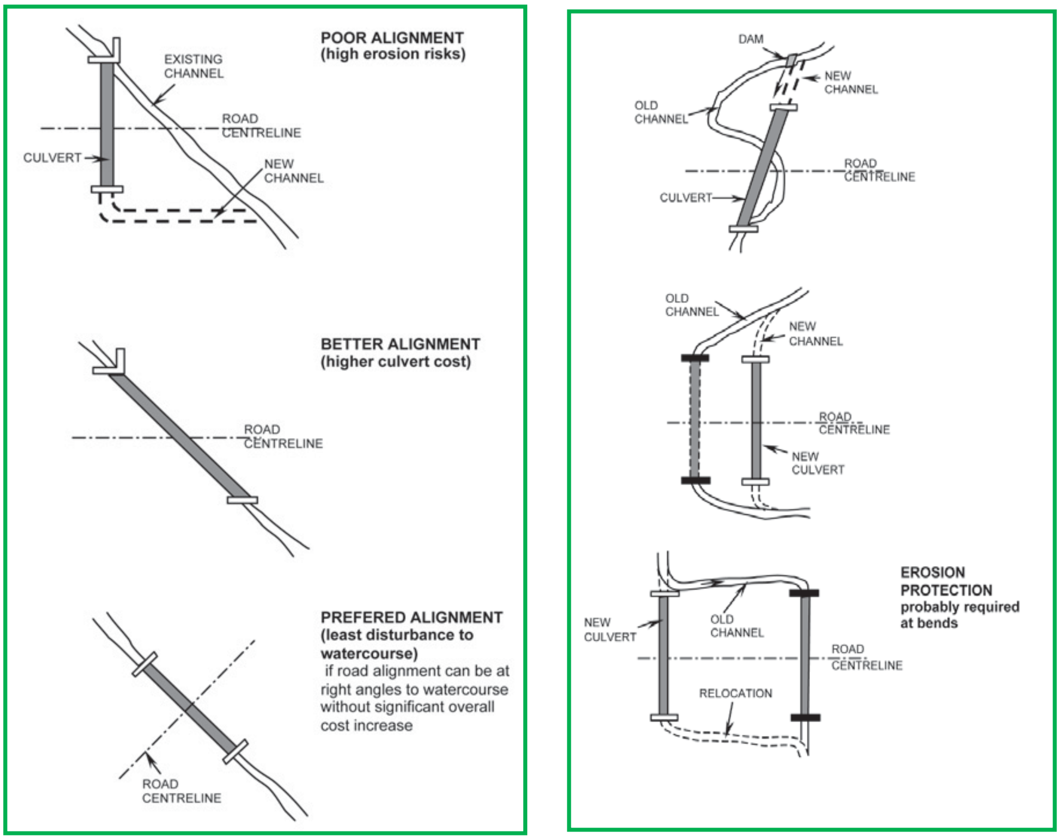


Figure 5.5: Culvert alignment options

5.2.3 Vented fords

As vented fords are designed to be overtopped during flood periods it is necessary for the watercourse to be well defined both for normal flows and flood flows. During flood flows the watercourse will generally be wider but should still have clearly defined banks to enable the position and size of the structure to be identified (see Figure 5.6).

A vented ford provides a constriction to the water flow due to the solid fill between the pipes. The proposed location should allow sufficient pipes to be constructed to prevent normal flows overtopping the structure. In areas where the flow level regularly varies, it is desirable that there are sufficient pipes to only cause overtopping for larger flood flows. The proposed site should require neither long approach embankments, as these will increase the cost of the structure, nor steep approaches, which will make the structure difficult for larger vehicles to cross.

Vented fords can be built on relatively weak ground as their dead weight is spread over the whole area of the structure. However, the ground should not be susceptible to long-term settlement under the dead weight of the fill material, as this could result in damage to the structure. To minimise the cost of the vented ford a suitable source for fill material should be available close to the proposed site.

If the volume of traffic using these structures cannot justify two-way traffic, the proposed site should allow drivers to see the opposite end of the crossing and have waiting areas at each end to allow vehicles to pass each other safely. On road networks where there is a long detour to avoid the vented ford when it is impassable, the proposed site should have a waiting area on both sides of the structure sufficiently large for the expected number of waiting vehicles. This waiting area may consist of widening the carriageway or an area where vehicles can pull off the road.

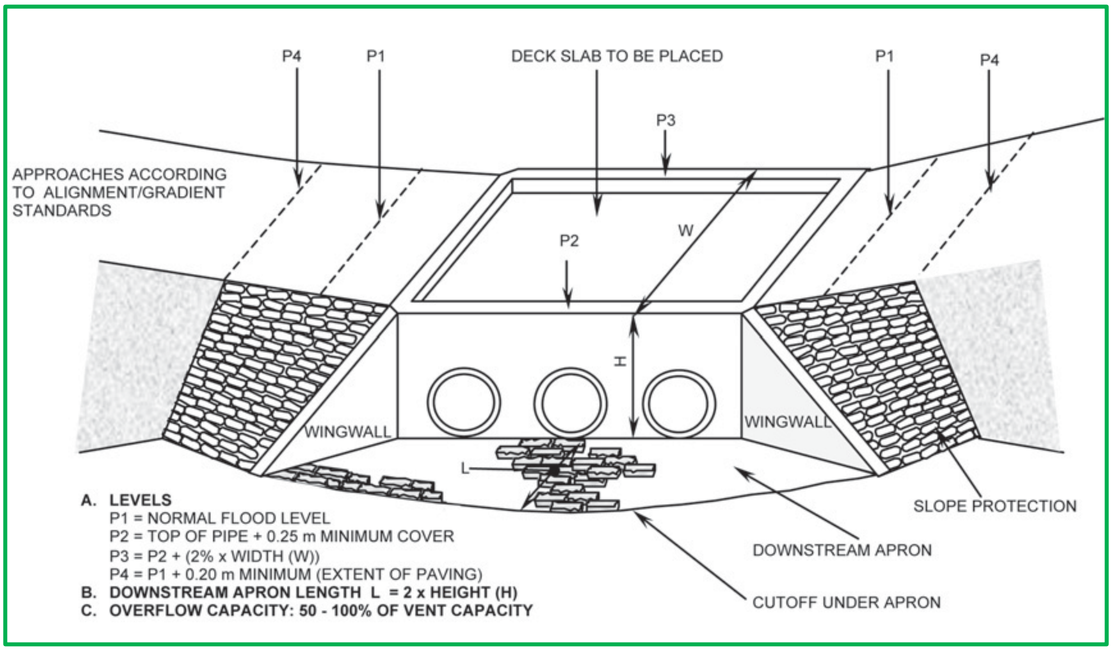


Figure 5.6: Key design criteria for a vented ford

5.2.4 Large bore culverts

Large bore culverts require the bed of the watercourse to be at least 2 meters below the proposed road level, to allow sufficient cover over the culvert barrel. Proposed sites for these culverts should have watercourse banks higher than 2 meters to prevent the need for long approach embankments which increase the cost of the structure.

If the crossing site requires more than one arch there should be suitable ground conditions to construct firm foundations for the piers as well as the abutments. Large arches can exert substantial forces on the ground at each end, and therefore usually require firm ground on each side of the watercourse. If the foundation strength is insufficient to support arch springing thrust blocks or pier foundations, it may be necessary to consider provision of a foundation slab across the entire structure.

Large bore culverts are usually not expected to be overtopped. Consideration of the consequences of a high flood and its potential to overtop the structure should be made for the proposed site.

As a substantial amount of fill material can be required for a large bore culvert, the total construction costs can be reduced if suitable fill material is available near the crossing site.

5.2.5 Bridges

The site selection of bridges often involves detailed site investigations which are beyond the scope of this Manual. For further guidance refer to the current MRB Bridge Design Manual or publications such as TRL Overseas Road Note 9. For bridges up to 10-metre spans the guidelines given below should be followed.

The most common cause of failure of bridges is scour of the abutments or piers. In addition to the factors discussed for all structures above, a site which can avoid the use of piers and has firm ground for abutment foundations is the overriding criteria in selecting a suitable site for a bridge crossing.

Additional factors, which should be taken into account:

- Artificial constriction of the watercourse due to the proposed position of the abutments should be minimised to reduce the depth of scour.
- The stream velocity should be modest (i.e. the watercourse should be on a shallow gradient to reduce the possibility of scour).
- The proposed site should require a minimal amount of work to be carried out underwater. Where work in the water is unavoidable, a site, which reduces the amount of underwater work, either by a simple cofferdam or construction during a dry period, is preferable.
- The bridge superstructure should be above the design flood level. Consideration should also be given to the possible consequences of a high flood on the bridge superstructure.

6 PEAK FLOW ESTIMATION

Road structures are constructed not only to remove water from the road and side drains but also to transfer water from one side of the road to the other where the road crosses a natural watercourse. These natural watercourses transfer rainfall from higher ground to lowlands and eventually, usually, into the sea. The water flowing in a stream or river is called the runoff and will usually be expressed as mm per unit area or a total volume in cubic meters for a stated period of time. There are many factors which will affect the runoff, or amount of water in a watercourse, and hence the type of structure which will be required:

- Rainfall;
  - Duration;
  - Intensity;
  - Distribution.
- Geological features;
  - Type and permeability of the soil;
  - Natural water storage characteristics of the catchment area;
  - Size of the catchment;
  - Shape of catchment.
- Topography;
  - The relief of the ground;
  - Character of the area: smooth or rugged.
- Land use;
  - Natural drainage of the area;
  - Vegetation cover.

A wide range of hydraulic information may be required for the design and construction of water crossing structures. The amount of information required and its accuracy will depend on the type and complexity of the proposed structure. Table 6.1 indicates hydraulic data and other information about the watercourse which is required for different structures along with the potential inaccuracies that may be encountered.

6.1 Rainfall Intensity

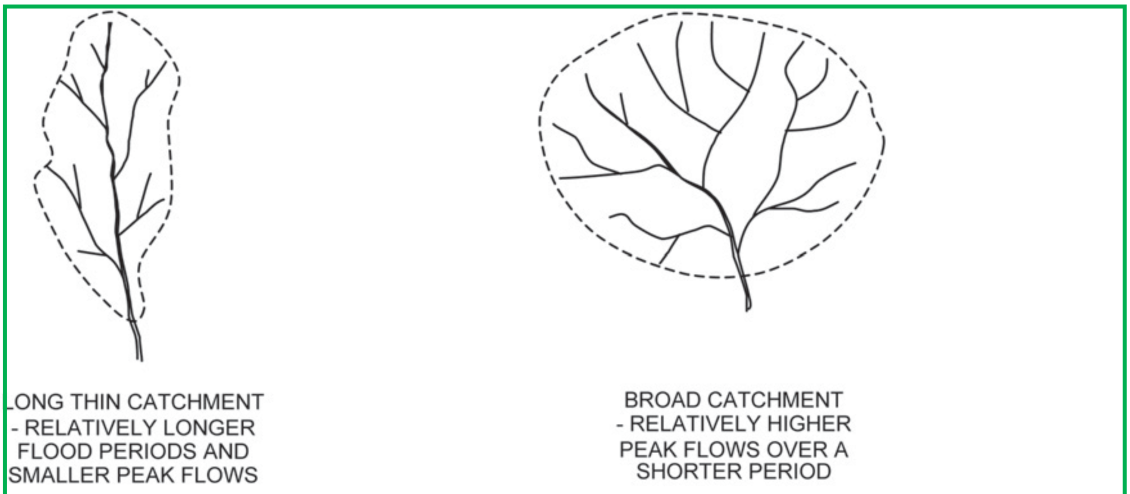
The rainfall intensity in the whole catchment area will affect the peak water flow after heavy rain.

6.2 Permeability of Soil

The permeability of the soil in the whole catchment area will affect the peak water flow after heavy rain. See the section on peak flow rate above. The permeability of the soil in the river banks at the proposed structure site will also affect the bearing capacity of the soil and hence the design of the structural foundations.

6.3 Catchment Area and Shape

The size of the catchment will determine the maximum peak runoff that may be experienced after heavy rain. It may be determined from topographical maps, if they are available, or from a simple field survey of the area. The shape of the catchment area may also be of interest to the designer as it will affect the size and duration of peak flows (see Figure 6.1).



A long thin catchment area results in a lower but sustained peak flow as the rainfall has a range of distances to flow to the proposed structure location.

A round or square catchment area will tend to have shorter but higher peak flows when compared with a long thin catchment area of the same area. The rainfall in this catchment area has a similar distance to flow to the proposed crossing site.

Figure 6.1: Catchment characteristics

6.4 Cross-sections at Crossing Point

The cross-section of the watercourse at the crossing point will affect the design of the structure (Figure 6.2). The watercourse should be surveyed and a section drawn with an exaggerated (5 or 10 times) vertical scale for the design process. It is also useful to know the cross-section of the watercourse above and below the crossing point, particularly in the case of incised rivers, because this information will give an indication of the 'movement' of the watercourse and possible additional erosion and training measures that may be required upstream of the structure.

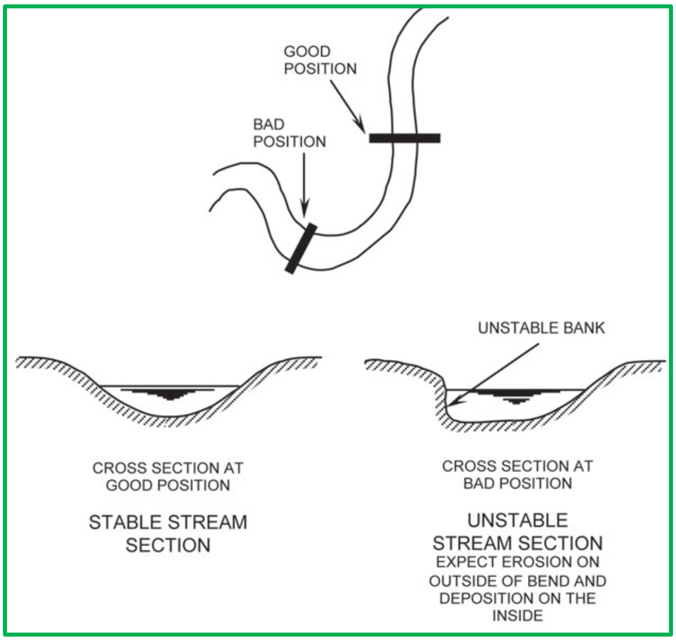


Figure 6.2: Stream crossing point cross-sections

6.5 Hydraulic Gradient Upstream and Downstream

The hydraulic gradient is the slope of the riverbed and is normally expressed as a fraction. The hydraulic gradient will determine how fast the water will flow and hence how much damage it can cause to the structure and riverbed. It will also help to determine how much downstream protection is required for the watercourse. Some simple surveying is required to determine the slope of the watercourse around the proposed crossing point. The extent of the survey will depend on the type of structure proposed.

6.6 Type of River (Incised or Alluvial)

A stretch of river may be described as incised or alluvial. The upper sections of a river are classified as incised, where the river is eroding the sides and bed of the watercourse. Incised water flows are, in general, irregular with faster and slower flowing sections. The lower sections of a river are typically alluvial, with the watercourse meandering across flat plains. Each of the river characteristics provides challenges for the designer:

6.6.1 Incised

This section of the river is particularly prone to scour, especially around piers and abutments, which requires careful consideration of protection measures.

6.6.2 Alluvial

The lower reaches of a river normally flow at a steadier rate. There is an equal amount of erosion and deposition of material in the channel as the stream is already carrying a large amount of sediment. Although scour will still occur around abutments and piers, an additional problem for a designer is that the watercourse is often unstable; changing its route. It may therefore be necessary to train the river to ensure that it continues to flow through the structure rather than breaking through the road alignment at an alternative point.

6.7 Watercourse Bank and Bed Characteristics

Visual inspections of the watercourse bank and bed should be carried out to determine the type of soil and, where feasible, the depth to a firm stratum or rock. The ground conditions will determine the size, depth and shape of the structures foundations. Watercourse characteristics will also determine the amount of protection required to the riverbank downstream of the structure. It is not necessary to dig trial pits in the actual riverbed unless piers are required in the watercourse. In this case a temporary cofferdam may be required to enable investigations if the bed does not dry out in the dry season. Pits in the sides of the watercourse around the site of the proposed structure foundations provide useful information.

Table 6.1: Hydraulic and watercourse data required to undertake design

Hydraulic Data	Drift	Culvert	Vented Ford	Large Bore Culvert	Bridge
Maximum peak flow	Use methods 1,2,4 described below, but see flood return period	Use methods 1,2,4 described below, but see flood return period	Use methods 1,2 & 4 as a cross check for method 3 described below	Use all methods described below and use worst case result. Accurate rainfall data is required	Use all methods described below and use worst case result. Accurate rainfall data is required
Duration of peak flow	Required	Not required	Required	Not required	Not required
Flow velocity	Desirable to know	Required	Required	Required	Required
Normal flow rate	Required	Not required	Required	May be required	May be required
Perennial / seasonal flow	Required	Not required	Required	Not required	Not required
Amount of debris in the watercourse	Not required	Required	Required	Required	Required
Type of watercourse (alluvial / incised)	Required	Required	Required	Required	Required
Watercourse bank and bed characteristics	25m above and below crossing point	25m above and below crossing point	25m above & 50m below crossing point	100m above & 200m below crossing point	200m above and below crossing point
Catchment areas & shape	May be required to calculate peak flow rate	May be required to calculate peak flow rate	Required	Required	Required
Cross sections at crossing point	Required	Required	Required	Required	Required
Cross section 100m above crossing point	Not required	Required	Required	Required	Required
Cross section 400m above crossing point	Not required	Not required	Not required	Not required	Required
Cross section 150m below crossing point	Not required	Not required	Not required	Required	Required
Hydraulic gradient up-and-downstream	50m above and 25m below cross point	100m above and 50m below crossing point	100m above and 50m below crossing point	250m above and 100m below crossing point	250m above and 100m below crossing point
Permeability of soil			Desirable for determining peak flow		
Rainfall intensity			Desirable for determining peak flow		

6.8 Flood Return Period

Each flood will have a different size and intensity. Over a period of years the maximum flood experienced each year will vary. Chapter 3 indicated that the maximum design flood that a structure should be able to accommodate will depend on the type of structure and be related to a number of years. A 100 year flood (the largest flood expected in 100 years) will be much greater than a 5 year flood (the largest flood expected in 5 years). Data may be available for the size of flood, or rainfall intensity, which will be predicated over a particular period (12.5 years and 100 years are popular record assessment periods).

However, designs for drifts and small culverts will suggest a shorter return period due to the less serious (physical and financial) consequences of storm damage and hence a smaller storm basis may be justified for their design. Table 6.4 provides factors to adjust the size of a given storm period to another period based on a 12.5 year flood.

Table 6.4: Flood period factors

Flood period	2	3	5	7	10	12.5	15	20	25	50	100
Adjustment factor	0.15	0.3	0.5	0.65	0.9	1.0	1.1	1.3	1.5	2.0	2.5

Example 1

The 12.5-year flood has a rainfall intensity of 35 mm/hour. What will be the rainfall intensity of a 5-year flood?

From Table 6.4, the 5 year flood factor is 0.5. Therefore rainfall intensity = 35 x 0.5 = 18 mm/hour. The Table can also be used to adjust flood flows for other return periods.

Example 2

The 25-year flood results in a flood flow of 12 m^3/s. What will the 10-year flood flow be?

From the Table the 25-year factor is 1.5 and the 10 year factor is 0.9. Therefore the 10 year flood flow = 12 x 0.9 / 1.5 = 7 m^3/s.

6.9 Maximum Peak Flow

The most important hydraulic factor for structures is the maximum peak flow (or runoff). Culverts and bridges must be capable of accommodating the peak runoff, after heavy rain, without overtopping and vented fords or drifts must be able to pass the peak runoff without erosion or other damage to the watercourse or roadway. In the case of drifts and vented fords the normal runoff or average flow will also be important to ensure that the drift will be passable or the pipes on the vented ford can accommodate normal flows.

There are a number of methods, which can be used to assess the maximum peak flow. These methods vary in complexity of calculation and accuracy. The option chosen will depend on the availability of topographical data and the accuracy required for the structure.

6.9.1 Method 1 - observation

It may be possible to observe previous high water marks from existing structures, trees or other vegetation near the watercourse. Small debris floating down the river will be caught on branches and twigs during floods and indicate the water level during a flood.

The highest flood is the most likely to be visible as it will often ‘rub off’ smaller flood tide marks. The problem with this method is that there is often no indication of how old the flood level indicators are and hence what the return periods will be. There may in the past have been higher floods but these marks may have been removed by natural weathering. This method will therefore give an indication of a recent high flood level but is not guaranteed to be the highest expected flood level. The information gathered by observation may be supplemented by interviews with local residents.

6.9.2 Method 2 - interviews

If there are people living near the proposed crossing point it will be possible to ask them how high the water level has risen in previous floods because these occurrences tend to intimately affect their activities. If this method is adopted, a number of people should be questioned because memories ‘fade’ over time and floods may ‘get bigger’ each time the story is told. It may be possible to ask people individually how high the biggest flood had been over the previous years and then take an average of the results obtained. Validation may be improved if enquiries are made for each bank independently and for different locations along the banks that provide information that can be correlated. Alternatively a group may be asked to collectively agree the maximum height of the floodwater. It will also be necessary to ask how often floods of the maximum size occur in order to determine the return period.

Methods 1 and 2 can often form a good crosscheck between the data obtained for each method.

The interviews shall also acquire information about changes to the upstream line such as diversion, overtopping, floods from adjacent streams, land use change and irrigation projects.

In South Sudan care should be exercised if relying on a combination of method 1 and 2 for design purposes. With a large land area and low population, interviews may not give a good indication or any of previous flood levels in areas where there are no permanent populations or have not been for many years. In such instances a conservative estimate of high flood level should be used in sizing structures.

6.9.3 Method 3 - rational method

This method is accurate for smaller catchments up to 15 km^2. The rational method may be used for larger catchments but the results obtained will tend to be larger than the actual floods encountered.

Table 6.2 Runoff coefficient: humid catchment

$q = 0.278\ c\ iA$	Where q = flood flow in m^3/s c = runoff coefficient (Table 6.2 and 6.3) i = rainfall in mm/hr A = drainage area contributing to runoff in Km^2

Table 6.3 Runoff coefficient: semi-arid catchment

Average Ground Slope	Soil Permeability			
	Very low (rock & hard clay)	Low (clay loam)	Medium (sandy loam)	High (sand and gravel)
Flat 0 - 1 %	0.55	0.40	0.20	0.05
Gentle1 - 4 %	0.75	0.55	0.35	0.20
Rolling4 - 10 %	0.85	0.65	0.45	0.30
Steep> 10 %	0.95	0.75	0.55	0.40

Table 6.4 Runoff coefficient: arid catchment

Average Ground Slope	Soil Permeability			
	Very low (rock & hard clay)	Low (clay loam)	Medium (sandy loam)	High (sand and gravel)
Flat 0 - 1 %	0.75	0.40	0.05	0.05
Gentle1 - 4 %	0.85	0.55	0.20	0.05
Rolling4 - 10 %	0.95	0.70	0.30	0.05
Steep> 10 %	1.0	0.80	0.50	0.10

Note:

The soil permeability will also be affected by the type of cultivation; these values may be increased by 0.1 for cultivated land and decreased by 0.1 for forested land.

The availability of topographical maps and rainfall data is critical for application of the Rational Method. Where rainfall data is not available the rainfall map of Figure 4.3 of Volume 1 may be referred to for guidance.

6.9.4 Method 4 - estimation

The main problem with the rational method is the requirement to have data available for the predicted rainfall intensity. In many regions these data may not exist or may be incomplete. For catchments up to 15 Km^2 an approximate maximum flood flow can be calculated by assuming a discharge of 1 - 2 m^3/s per 25 hectares of catchment area. It should be noted that such approximations of flow rates using this method are not related to any flood return period and as such are not peak flow discharges. Therefore this method is least preferable when determining peak flow discharge for design purposes.

6.9.5 Method 5 – slope-area method

For streams and watercourses with stable banks and bed, the cross section does not change significantly during the passage of a flood. In such a situation it is possible to estimate the flow using Mannings Equation:

$$\mathbf{V = (1/n)\, R^{2/3}\, S^{1/2}}$$

Where:

V = velocity in m/s

R = hydraulic depth (the area of the stream flow divided by the wetted perimeter as shown in Figure 6.3 below)

S = hydraulic gradient (the slope of the streambed over a reasonable distance either side of the crossing point)

n = roughness coefficient (see Table 6.5 below)

The peak discharge is then calculated from:

$$Q = VA$$

Where A is the cross-sectional area of flow (this may be estimated using method 1 and 2 for a known large flood event).

Thus the peak discharge is given by the following equation:

$$Q = (1/n)\ A^{5/3} P^{-2/3}\ S^{1/2}$$

Where:

P = the perimeter of the watercourse (i.e. the cross sectional length of the banks and bed)

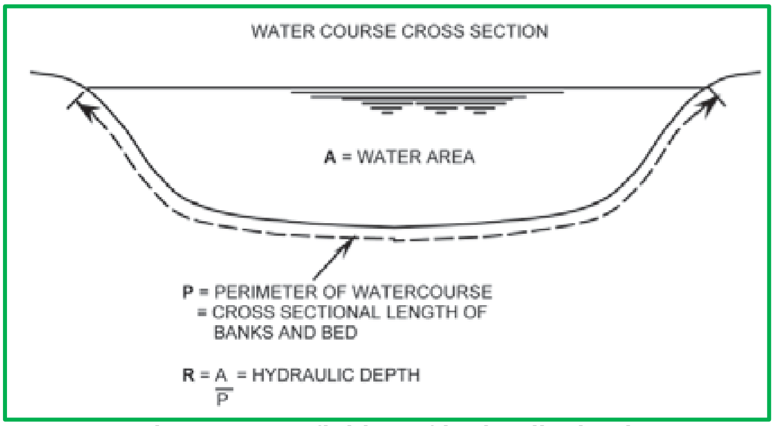


Figure 6.3: Definition of hydraulic depth

A combination of Method 1, 2 and 3 may, in some instances, be the only option where rainfall data does not exist and a higher degree of certainty is required for discharge estimation – i.e. for more expensive structures such as small or arch bridges or vented fords.

The following Table 6.5 gives values for roughness coefficient, n. It is difficult to define an exact value of n in tables. It is necessary for the engineer to relate the characteristics described above in relation to the watercourse being considered to interpret the value of 'n' to be used.

Table 6.5: Roughness coefficients

Stream characteristics	**Ranges of values of n**
• Streams in upland areas	
• Gravels, cobbles and boulders with no vegetation	0.030 - 0.050
• Cobbles and large boulders	0.040 - 0.070
• Streams on plains	
• Clean straight bank with no rifts or pools	0.025 - 0.033
• Same as 1 but with some weeds and stones	0.030 - 0.040
• Winding watercourse, some pools and shoals but clean banks	0.035 - 0.050
• As 3 but straighter river with less clearly defined banks	0.040 - 0.055
• As 3 but with some weeds and stones	0.035 - 0.045
• As 4 but with stony sections	0.045 - 0.060
• River reaches with weeds and deep pools	0.050 - 0.080
• Very weedy river reaches	0.080 - 0.150
• Stream out of channel flowing across grass	0.030 - 0.050
• Stream out of channel flowing through light bush	0.040 - 0.080

6.9.6 Other methods and the South Sudan environment

Another method which may be used for estimation of peak discharge is the Soil Conservation Method (SCM). This is detailed in the MRB Road and Bridge Design Drainage Design Manual 2006. It is not presented here primarily because the method relies on rainfall data and a reasonable estimation of rainfall intensity. Given the low density of rainfall stations within South Sudan at present and the isolated nature of most low volume roads, the required data is not likely to be available for use in South Sudan in the medium term.

Caution should be exercised when applying the Rational Method in large parts of South Sudan. Large areas of the country are predominantly flat which will result in very large catchment areas which in turn do not favour application of the Rational Method. More accurate estimates of peak discharge may be determined from a combination of Methods 1 (Observation) and Method 2 (Interviews) in these areas. The designer shall have to determine what the acceptable level of risk to the structure is before choosing which method to apply.

In the case of bridge or other more expensive structures, observation of proposed crossing sites for the duration of one rainy season would be beneficial if possible where doubts as to the characteristics of the water course and its peak flow exist.

6.10 Duration of Peak Flow

The duration of peak flow will not usually affect the design of the structure but will determine how long the crossing may be impassable. It is therefore necessary to collect these data if a drift or vented ford is proposed. The duration of the peak flow depends on the factors which affect the rainfall runoff described above, and may therefore be difficult to calculate. As these data are only required for simple structures it will be acceptable to rely on information gathered from the local population and/or the following rule of thumb.

'For catchment areas less than 10km^2 the designer can assume that the duration of peak flow will last no longer than twice the length of rainfall periods'.

6.11 Flow Velocity

It is important to determine the velocity of the water flow during peak floods because it affects the amount of scour that can be expected around the structure and, hence, the protective measures that may be required. The velocity can be measured in two ways.

6.11.1 Direct observation in flood conditions

An object which floats, such as a stick or piece of fruit, may be thrown into the river upstream of the potential crossing point. The time it takes to float downstream a known distance (about 100m is a suitable distance) should be measured. The velocity can then be calculated by dividing the distance the floating object has travelled by the time taken. This exercise should be repeated at least 3 times, but preferably 5 times, to obtain an accurate result. Tests where the floating object is caught on weed or other debris in the water should be discarded. The opportunities for making such observations during flood conditions are obviously very limited.

6.11.2 Mannings formula

Flow velocity may be calculated using Mannings formula (see Section 6.4.1) also. As stated above the opportunity to make observations for calculating flow velocity during flood conditions will be limited and as such the aforementioned data resulting from cross sectional survey (Section 6.4 and Table 6.1) and upstream surveys (Section 6.5 and Table 6.1) may be used to calculate the flow velocity for a given return period (Section 6.8) using Mannings Formula. The resultant velocity may be used for scour calculations in the proceeding Section 8.1.2.

6.11.3 Flat terrain

In flat terrain where obtaining such a slope may not be possible and where water flow at a culvert outlet may be constrained by downstream flow restrictions, considerably more care is needed to ensure sufficient flow to minimise siltation. Usually it is sufficient to make sure that the slope of the culvert is not less than1% or, if it is greater, equal to the slope of the water course itself. However some engineering work may also be required to ensure the downstream flow is not restricted.

In completely flat terrain that is liable to seasonal flooding, the road will usually be on an embankment and culverts are required to allow cross flow when the floodwater ebbs or flows. Under these circumstances the flow can be relatively slow provided that enough culverts are available, but insufficient culverts can lead to rapid flow along the side of the embankment and consequent scouring. The best method of estimating this is by asking the local people how long the water usually takes to dissipate from peak flood condition after the rain. Calculating the likely volume and required number and size of culverts necessary to prevent the flow velocity exceeding the velocities shown in the proceeding Table 8.20 is then straightforward.

6.12 Normal Flow Rate

The normal flow rate, like the peak flow rate, is linked to the total runoff and dependent on the rainfall in the catchment area. The design of structures is primarily based on the peak flow rate but it is necessary to know the normal flow rate for two reasons:

1. For the design of drifts and vented fords it is necessary to ensure that vehicles can cross the drift during the normal flow or that in the case of a vented ford the water passes through the pipes and the vented ford is not overtopped.
2. To check that there will be no long-term damage to the structure due to erosion. The short period of peak flows may not damage erodible parts of the structure. However it is necessary to ensure that parts of the structure permanently in contact with the water flow are not damaged.

6.13 Perennial / Seasonal Flow

An investigation into the variation in seasonal water flows is required if the proposed structure will be overtopped. It is necessary to determine the proportion of the year that higher flows will be experienced to estimate the number of days the structure may not be passable. It may be necessary to raise the running surface of the structure to ensure that the structure is only overtopped during particularly rainy months. Unless detailed rainfall data is available for the area it is likely that the only suitable methods for collecting seasonal water levels and flows will be from the knowledge of the local population.

6.14 Amount of Debris in Water

Any debris, such as tree branches, carried in the water could cause blockages in the structural openings. A few small branches can quickly block the 600mm opening of a culvert pipe resulting in water backing up in the watercourse and potential damage to the culvert or road. Investigations must therefore be carried out to determine the amount of debris that is typically carried downstream during a flood to determine if protective measures are required and/or determine the frequency of maintenance required to the completed structure to remove trapped vegetation. The funding, resources and likely responsiveness of the maintenance authority responsible for the route should be investigated to assess the risk of debris blockage and subsequent damage.

7 MATERIALS

This chapter aims to provide sufficient information to enable road designers and builders. The aim is to identify potentially suitable materials through examining material properties, determined through testing, and thereafter determine the range of uses appropriate for each material.

The chapter will also discuss potential causes of deterioration and damage and how these might be avoided by good design.

The remainder of this chapter on materials is organised into four sections:

- Stone masonry;
- Brick and block masonry;
- Timber and organic materials;
- Concrete and reinforced concrete.

For all materials meeting the specification requirements, a costing of the various options and consideration of training, maintenance and other factors will enable a rational decision to be made regarding the final choice of materials. National bridges and structures standards, which have often been 'imported' from developed country conditions or are aimed at structures on main roads, often ignore the possibility of using some of the materials covered by this Manual. This may deny the benefits of lower costs, use of local resources, labour, skills and enterprises, and reduce the likelihood of maintenance being carried out in a timely manner.

7.1 Stone and Stone Masonry

The density and durability of natural stone, where it is available, make it an ideal material for road structures. Fortunately, in hilly territory where road-building entails frequent retaining walls and river crossings, stone of building quality can often be found relatively close by, or may even be generated in forming the roadway. Even in lowland terrain, "field" stone of suitable quality may often be found; and because of the inherent durability of most types of stone, relatively simple field tests are appropriate to assess its suitability for building. Suitable stone may be excavated, prepared and incorporated in the works using hand tools and manual methods, or by mechanised means.

For these reasons, where good quality stone is available, it should be the first choice for retaining walls, piers and wingwalls for river crossings, the formation of masonry culverts, and for low-level drifts. Stone can also be used for masonry arches and other simple bridges.

7.1.1 Stone sources and extraction

The well-known classification of types of stone by their geological origin is valuable because each class has recognisable characteristics. Table 7.1 show typical classes and types of stone that could be used for these structures.

Although the classification of a stone is not essential for its successful use, knowing the origin and type of stone does help to know what properties to expect. Stone from an existing quarry will probably already be classified. Unless it is obvious, help in classifying stone from an unknown source should be sought from professional geologists - samples sent to laboratories can usually be very quickly identified.

Methods of quarrying stone vary greatly from one quarry to another, and are developed to suit the character of the particular stone being worked and resources available. There are basically two different approaches. Where the stone is evenly bedded and valuable, a stone-by-stone approach may be used. The stone is cut straight from the bed to the size required, largely with hand tools and hand drills, 'plugs and feathers', chisels, crowbars or explosives may be used to assist the cutting. The operation is labour-intensive, but little waste is produced; in some quarries, the stone is even mined from underground.

Alternatively, large-scale blasting may be used, bringing down many tonnes at a time, including large blocks of various shapes and sizes, which can be further, split down or removed by cranes for cutting. There will be a large amount of waste, which can be crushed for use as concrete aggregate; this may even be the main product of the quarry. This method uses less labour and more mechanical equipment, and in certain circumstances may be more economical.

In some locations suitable stone may be lying on the ground surface and may be collected by local labour. This can even benefit the local land users by clearing fields to improve crop yields.

Cutting and finishing methods also range from very labour-intensive techniques using only hand tools to highly mechanised operations.

Table 7.1: Classes of rocks used for building

Igneous rocks	Granites and basalts are hard, dense, strong and impermeable, and can form excellent building stone, but they require a lot of work to quarry and form to precise dimensions. Pumice and tuff are relatively soft and porous materials formed by depositions of ash materials on the surface or under water. Strength is very variable, but they can often be easily cut and worked, and may be suitable for building road structures where they are protected from water.
Sedimentary rocks	Sandstones, Limestones show natural stratification and separate layers may have different properties, and natural bedding planes. The stratification makes quarrying and working to precise dimensions easier. Limestones and sandstones often have colour and texture varieties, which make them attractive as well as durable building stones.
Metamorphic rocks	Slates, Quartzite, Marble. These are rocks which are often hard and durable, and can have a foliated structure with layers of stratification. Slates are metamorphically altered clay and shale, which quarry easily and are frequently suitable for walling and roofing stones. Marbles are metamorphically altered limestones which are hard and durable, and suitable for sawing and carving and can often take a high polish.
Laterite	This is the end product of the intense tropical weathering of primary rocks, and it consists largely of the oxides of iron and aluminium, but it has the useful property of hardening on exposure to air. When soft it can easily be cut with a hoe, but some varieties can harden and become weather resistant, and may achieve durability comparable with some building stones. It is widely used as a building material in humid tropical areas. However the quality can be very variable and care needs to be taken in selecting suitable material.
Field stone	Stone that is found away from quarries or other formal deposits, usually transported by water or landslides, and may be of any of the geological types described. Fieldstone can be a useful source of stone for small road projects, but should be subjected to tests as described below to determine its suitability.

7.1.2 Properties of stone

Size

The most important prerequisite of a good building stone is that the stone is available in pieces of a size and shape suitable for the type of wall or structure to be built. Stones should also be small enough to be lifted and placed by hand. For use in rubble walling, a range of sizes is needed. The individual stone height may be up to 300 mm, the length should not exceed three times the height and the breadth on base should not be less than 150 mm, or more than three-quarters of the wall thickness. A range of sizes should be used, with larger stones being used for corners (quoins) and for through (bonding) stones.

Durability

Durability is the resistance of the stone to weathering or deterioration from other causes Stone used for building should be uniform in colour and texture, without soft seams or veins or other visible blemishes. The surface of a freshly broken stone should be bright, clean and sharp without loose grains and be free from an earthy appearance. Visual examination may be sufficient to initially assess its durability characteristics but additional field or laboratory tests are recommended (see 7.1.3, below, and Chapter 5 and Appendix B in Volume 1). Other durability issues are shown in Table 7.2.

Table 7.2: Durability Issues

Soluble salts	Soluble salts can disfigure and ultimately cause deterioration of some sedimentary stones. Soluble salts may occur in the sands used for mortar, in the water behind retaining walls, or in road salts. The remedy is not to use a stone which is liable to react poorly to soluble salts in circumstances where it will be exposed to them.
Thermal and moisture movement	Some small variations in the dimensions of stones always occur as a result of changes in temperature and moisture. These are rarely sufficient to cause any cracking problems, but it is a good precaution to insert movement joints in mortared masonry walls at intervals of approximately 15 metres.

Compressive strength

There are significant problems of strength testing of stone in rural areas. The compressive strength of dense stone is generally greatly in excess of that required in any small road structures. A few porous stones, like pumice or tuff, or weak stones like laterite, may require some testing to establish that they have a suitable compressive strength. In other cases, the compressive strength can be assumed to be adequate for the small road structures described in this Manual based on evidence of established local use. However, for stones subject to abrasive conditions or just use in arches, it is advisable to confirm the compression strength is a minimum of 15MPa unless otherwise specified.

Seasoning

Some laterites may increase significantly in strength and durability after quarrying. The appropriate time for seasoning depends on the quarry, and local knowledge is needed to decide on the correct seasoning time.

Porosity

Porosity is not in itself a disadvantage in most cases, but some stones are capable of absorbing substantial amounts of water and this can reduce the strength. A good building stone should not absorb more than 5% of its weight in water.

7.1.3 *Field testing*

In many cases the best test of the suitability of a stone from a local quarry or other source is its previously successful use in structures in the area, which have been subjected to the local climate for a long period of time. Enquiries to local builders and contractors may result in knowledge gained regarding the best sources of building stone and any local characteristics. This information can be supplemented by additional tests as required.

Durability test

The durability of a stone from sedimentary rock sources can be tested by immersing small pieces in clear water in a glass jar for about an hour and then shaking them vigorously. If the water discolours, the stone is not well cemented and should not be used.

Water absorption

The water absorption of a stone is a measure of its porosity and of its liability to frost damage. The water absorption of a stone can be assessed by:

- Weighing it when dry (stored in a dry environment for at least 5 days);
- Immersing it in water for 24 hours at ambient temperature;
- Weighing it again after removing excess surface moisture.

The difference in weight should not exceed 5% of the initial weight.

Soundness test

The soundness (freedom from cracks or weaknesses) of a stone can be tested by means of the hammer test (see Figure 7.1).

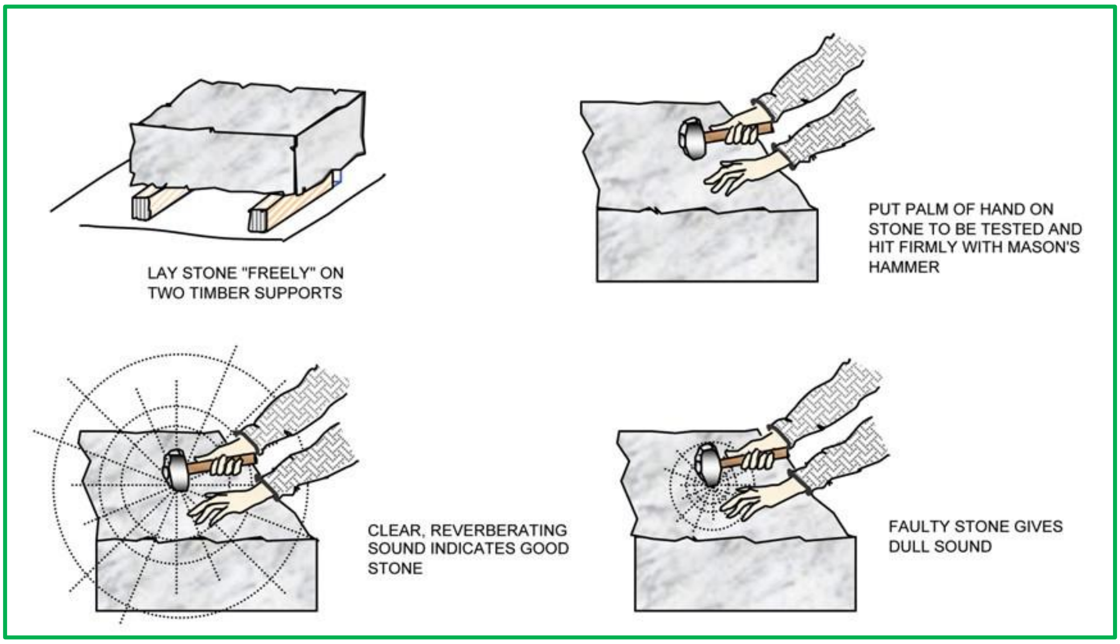


Figure 7.1: Hammer test for stone

Acid test for weathering potential

A small sample is immersed into a 1% solution of hydrochloric acid for seven days, during which time it is frequently agitated. If the sample has retained the sharpness of its edges and corners, it will weather well.

Compressive strength

The simplest field test for compressive strength is the hammer test, above. Other low cost options that may be available are the Point Load Test and the Schmidt Hammer. (see Table B-2, Appendix B, volume 1). This is not normally an important consideration except with blocks made from rather weak stones such as tuff. Where needed, testing should be entrusted to a competent engineer or laboratory.

Hardness

The surface hardness can be tested by scratching with a penknife. All types of stone will be marked by a knife blade under firm pressure; but stone in which a penknife blade can make a groove exceeding 2mm is likely to be moderately weak in compression, and compression testing may be needed.

7.1.4 Mortars

Unless dry stone walling skills are available or can be introduced, stone masonry usually involves mortar jointing. The principal function of mortar in masonry is to provide an even bed to distribute the load over the whole bearing area of the units, and to bond the masonry units together.

Good mortars should:

- Be cohesive, spread easily and retain water so that they remain plastic while the masonry units are positioned and adjusted;
- Set and develop strength rapidly after the units are in place;
- Have a final strength adequate to carry the load without cracking the masonry;
- Be impermeable to moisture movement, and resistant to weathering.

Mortars are composed of clean sand and a binding agent (usually Portland cement) and often some additive (either lime or plasticiser) to improve plasticity and workability. Sand should be soft building sand free of organic particles and clay. Lime should be bagged, dry, hydrated lime or lime putty. A plasticiser is an admixture to the mortar used in small quantities to improve the workability of the mix or to achieve the same workability with less water, thus improving both strength and durability. Plasticisers are proprietary materials and should be used according to manufacturers' instructions.

It is important that the strength should not be greater than that of the units being joined so that movement cracking will be dispersed through the mortar joints and not lead to a few wide cracks which could affect strength and weather resistance.

Table 7.3 below shows typical mortar mixes using cement-sand or cement-lime-sand.

Table 7.3: Mortar proportions by volume

	Type of mortar	
	Cement: lime: sand	**Cement:sand**
Higher strength for structural use or contact with water	1 : 0.5 : 4	1 : 4
Lower strength for general use	1 : 1 : 6	1 : 6

Commonly used mixes are 1:4 cement:sand for structural use or where there is contact with water, and1:6 in other cases. For a good quality mortar, water content should be low (typically 0.4 water/cement ratio). The quantity mixed in any one batch should not be more than can be used in about one hour; during that time unused mix should be covered to protect it from excessive evaporation.

7.1.5 Stone walls

Random stone masonry is constructed from stones as they came from the quarry or source with minimal dressing. The laying skill is in selecting individual stones so that they create a reasonable joint with the adjacent stone without the excessive use of jointing mortar. Stone should be bonded both longitudinally (along the wall) and transversely (across the thickness of the wall). Longitudinal bond is achieved by placing each joint more than one-quarter of a stone's length away from the joint below. Transverse bond is obtained by the use of bonders (at least one per m^2 of wall), extending about two thirds to three quarters across the width of the wall or right through the wall if water penetration is not a problem.

Random stonewalls may be constructed without any courses, or brought to level courses for example every 600 or 900mm.

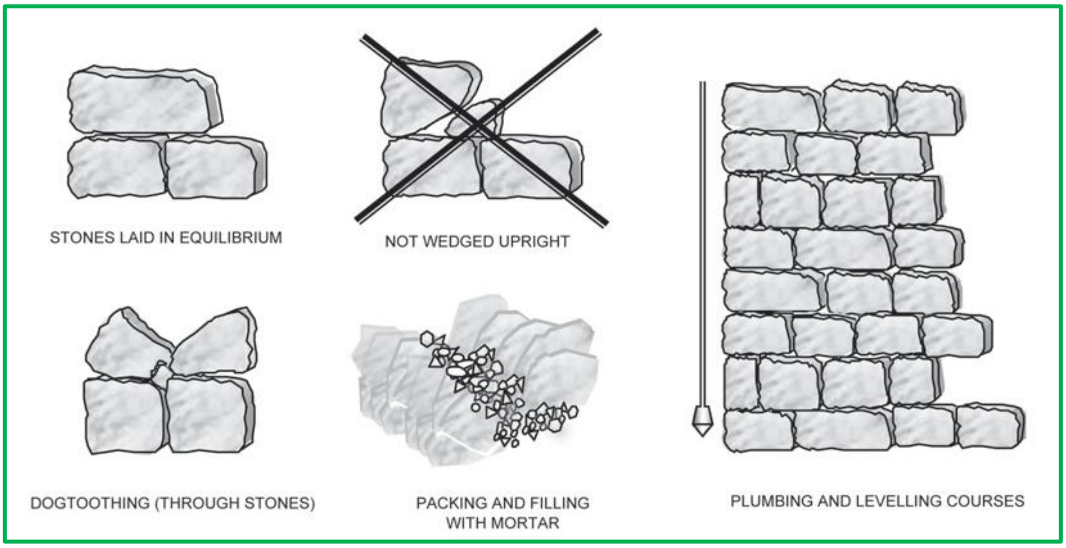


Figure 7.2: Rubble masonry wall

Dressed stone masonry is built with stones which are dressed to approximately rectangular shape, usually before leaving the quarry. It is built in courses, which may vary in height from 100mm to 300mm, often with thicker courses lower in the wall. All stones in any course are squared to roughly the same height. Bond stones are laid in each course at about 1.5m spacing. Examples of rubble masonry walls are shown in Figures 7.2 and 7.3 and Plate 6.

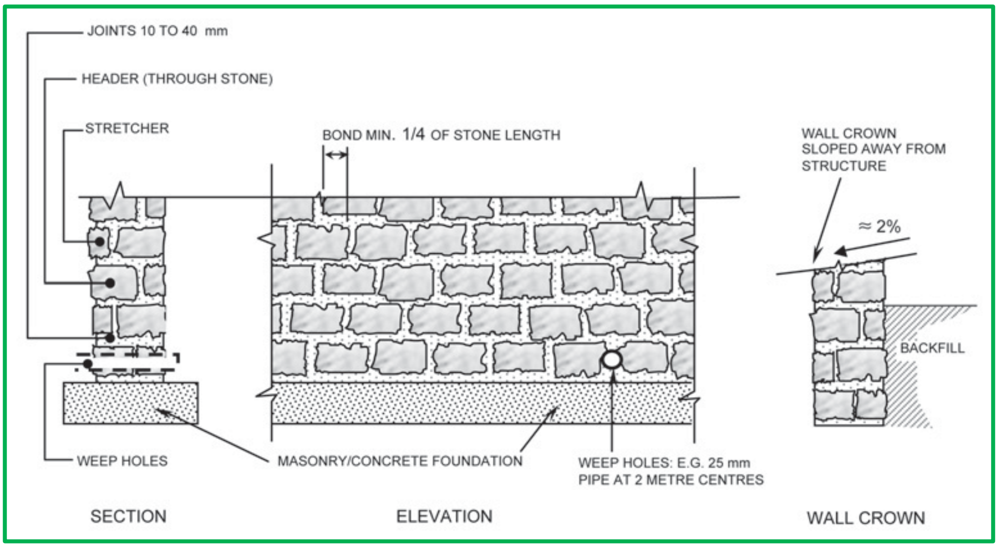


Figure 7.3: Squared masonry walling

Some general requirements for stonewalls are:

- The minimum thickness of a stone masonry wall should be 400mm;
- The height of a free-standing wall should not be more than six times its width at the base, and maybe tapered over its height;
- Mortar joints should be between 10 and 40mm thick, and have a minimum overlap of one quarter of the length of the smaller stone;
- Mortar joints should be pointed on the face of the masonry;
- No stone should touch another, but should be laid into mortar;
- Mortar should be made of cement and sand using volumetric proportions shown in Table 7.3 above. A common mortar is 1:4 cement:sand.

Some additional requirements for retaining walls are:

- The thickness of a gravity retaining wall at any point should be at least one third of the retained height above that point;
- Retaining walls should be provided with regular weep holes just above ground level on the outer face;
- Weep holes should be of 75mm diameter and spaced at 1.5m centres;
- A filter of loose stone or lean concrete should be placed at the back of the weep holes to permit free drainage of water, but not allow material to be washed through.

7.1.6 Dry stone walling

Dry stone walling is a form of stone walling built without mortar (Plate 7). A dry stonewall costs substantially less than a mortared wall, but requires considerable skill in choosing and laying stones if instability and rapid deterioration are to be avoided. The face stones are usually roughly dressed and laid on a firm natural soil bed; the core is formed from earth or smaller stones.

Some guidelines for the construction of dry masonry walls are as follows:

- All front-side inclinations should be in the range of 3:1 to 4:1 (vertical:horizontal);
- All back-side inclinations should be 1:10;

- The top width of the wall should be 1m;
- The tilt of the bottom of the foundation should be at right angle to the front inclination of the wall and hence fixed in the range of 1:3 to 1:4;
- The stones used should be generally of a large size and care must be taken in dressing and placing them;
- The joints between the stones must be arranged in a staggered fashion as in brick masonry (see Figure 7.4);
- All other construction details can be considered analogous to the rules applicable to gabion wall construction.

7.1.7 Hybrid walls

Hybrid walls are walls made of bands of mortared stone masonry reinforcing areas of dry stone masonry. The construction of a hybrid wall is recommended when the height of a dry stonewall is greater than 5m. The construction technique is the same as that of a dry wall, except for providing 0.6m bands of mortared cement masonry at intervals of 2m–3m both horizontally and vertically. This type of wall is recommended for heights between 5m and 12m both in valleys and on hillsides.

7.1.8 Masonry culverts

Masonry arch culverts may be more economical than pipe culverts where stone is locally available. Some general requirements are:

- Culverts are usually up to 2 metres in span;
- Strip foundations of concrete or stone masonry should be laid on firm ground: the foundation walls are brought up to the level of the arch springing;
- Arch formwork may be made from corrugated steel roof sheets, timber or reusable steel formwork. Simple compacted earth fill can also be used and excavated after the masonry has been constructed;
- The arch should have a minimum thickness of 400-500mm with all stones having the same dimensions as the arch thickness;
- The ground seepage cut-off, invert (base) slab, headwalls, wingwalls, drop inlets and aprons may also be constructed of masonry as required.

The masonry is normally mortar jointed using skills available with local building contractors. Dressed stone skills are required for dry stone masonry culverts.

7.1.9 Gabion works

Gabions are wire mesh boxes filled with stones and tied together to form basic structures. Their principal uses are for retaining walls, drifts and erosion protection (Plate 8). Gabion boxes may be made from purpose made gabion cages, welded steel mesh sheets or galvanised chain link fencing.

Gabions are used as an alternative to concrete or masonry, and gabion structures should be built with the same principles of good foundation, stability and quality control. The advantages of gabions are their simplicity of construction (requiring low levels of skill), use of local materials (stones), ability to let moisture pass through, avoiding the build-up of water pressure, and flexibility (should minor settlement occur). Flat gabions are also referred to as gabion mattresses.

The process of gabion construction is as follows:

1. Foundations should be excavated and cleaned as for a conventional structure with any unsuitable material removed and replaced with good soil, stone or gravel, and compacted.
2. The baskets should be erected in their final position.
3. Cages should be woven together using 3mm binding wire securing all edges every 150mm with a double loop. The binding wire should be drawn tight with a pair of heavy duty pliers and secured with multiple twists.
4. The connected baskets should be stretched and staked with wires and pegs to achieve the required shape.
5. Filling should only be carried out by hand using hard durable stones not larger than 250mm and not smaller than the size of the mesh. The best size range is 125 - 200mm. The stones should be tightly packed from the edges inwards with a minimum of voids.
6. Boxes of 1 metre height should be filled to one-third height. Horizontal bracing wires should then be fitted and tensioned with a windlass to keep the vertical faces even and free of bulges.
7. Further bracing should be fixed after filling to two-thirds height. 500mm height boxes should be braced at mid-height only. 250-300mm gabions do not require internal bracing.
8. Where water falls directly onto the top of the gabion, vertical bracing wire should also be fitted to secure the gabion lid when closed;
9. The stones should be carefully packed to about 3-5cms above the top of the box walls to allow for settlement. Smaller material can be used to fill the voids on the top face, but excessive use of small stones should be avoided. Fibre matting can be placed over the stones on the top of the gabion to promote vegetation growth.
10. The lids are then closed and stretched tightly over the stones, (carefully) using crowbars if necessary. The corners should be temporarily secured to ensure that the mesh covers the whole area of the box; the lid should then be securely woven to the tops of the walls, removing stones if necessary to prevent the lid from being overstretched.

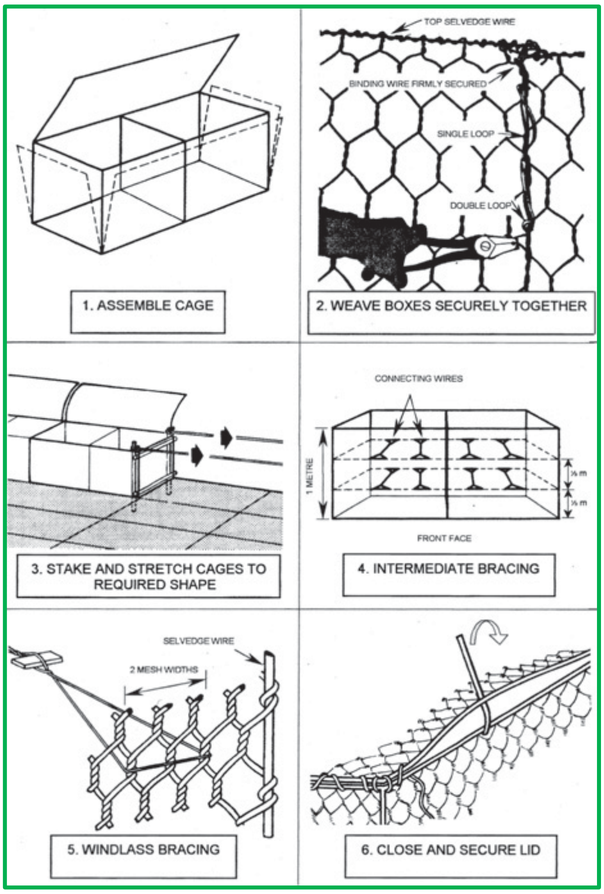


Figure 7.6: Gabion details

7.2 Brick and Block Masonry

Brick and block masonry materials are commonly where suitable materials are readily available and are frequently the standard materials used for walling in building construction.

Fired clay bricks have been used for centuries for bridges and are one of the most adaptable general building materials. Their small and regular size makes them suitable for incorporation in any shape of structure. They are ideal for utilising local building labour and contractor skills. Good quality fired brick is suitable for most types of road structure. The following requirements should be met for its application:

- Material selection and firing methods should ensure a consistent quality of brick;
- Bricks should be laid with a suitable durable mortar (as stone masonry) that is not as strong as the bricks themselves;
- Bricks should be laid bonded, to similar principles as stone masonry;
- Abrasion situations such as drift surfaces should be avoided.

Fired clay bricks are suitable for use in foundations, bridge piers, abutments, wing walls, arches, culverts and retaining walls (Plate 9). Bricks can be a particularly important construction material in regions and locations with shortages of hard stone resources.

Local brick making skills can be developed as a small-scale rural industry where there could be complementary demand in the road, building and infrastructure sectors. In some locations only low grade bricks are produced to meet a relatively undemanding requirement for general building bricks. In these cases some improvements in production such as kiln/clamp design, firing temperature and period may be required to achieve bricks of suitable quality for the more demanding structures applications. Bricks produced in 'one burn clamps' can have variable quality; the bricks near the outside usually being less well burnt. Permanent kilns and industrial production usually ensure more consistent quality products.

Fired clay bricks may be produced using agricultural wastes (such as rice husk) as the kiln fuel as described in the gTKP report on practices established in Vietnam[2]

Concrete blocks are increasingly widely available and can often be cheaper for the same applications as burnt clay bricks. Other masonry materials such as stabilised soil blocks and trass (a naturally occurring binder) lime blocks may be suitable for less demanding applications such as culvert headwalls and low retaining walls. The requirements, properties and testing recommendations described for bricks and blocks need to be adapted for other masonry materials.

A wide range of soils is suitable for brick and block making. To make bricks, a suitable soil (clay or brick-earth) is mixed with water, formed into the desired shape in a mould, dried, and then set in a kiln and fired at a sufficient temperature (usually 850-1000°C) to create permanent ceramic bonds between the soil particles.

Bricks are classified in various ways according to their intended use. A common classification recognises three classes according to their durability: internal quality bricks or blocks (suitable only for protected situations inside buildings); ordinary quality (suitable for external use in normal conditions of exposure (walls protected by damp-proof courses and a coping); and special quality (suitable for unprotected external uses such as parapets and earth retaining structures). Bricks and blocks may also be classified according to strength characteristics or shape (see Figure 7.7).

Concrete blocks are made from aggregates and cement, and mainly manufactured in large fixed or mobile plants using heavy compaction or vibration, and sometimes steam curing. They can also be made on site using individual moulds; a labour intensive process which can result in quality variability without adequate control processes. Solid blocks have no holes, cellular blocks have cavities, which do not pass right through the block, and hollow blocks have cavities passing right through. Manufactured blocks are made to satisfy standards requiring a minimum crushing strength.

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2 *Bach The Dzung & Petts R.C. 2009. Report on Rice Husk Fired Clay Brick Road Paving, Vietnam. gTKP.*

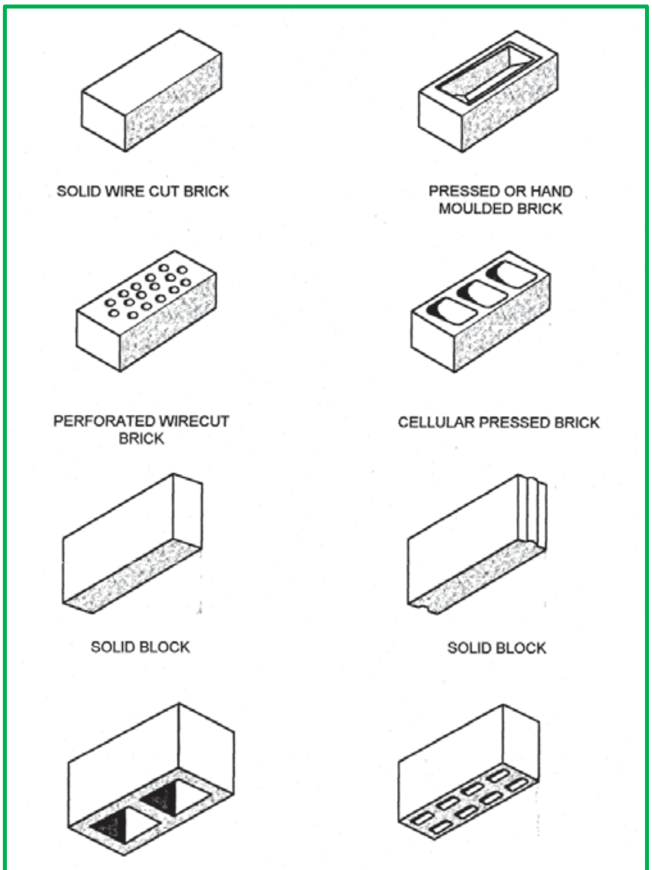


Figure 7.7: Brick types

7.2.1 Properties of bricks and blocks

For all brick and block materials the principal requirements are:

- Acceptable and handle-able size and small variation in dimensions;
- Dimensional stability over time;
- Strength;
- Durability.

Chemical composition and limited water absorption are also important for clay bricks.

Size

The standard size of clay bricks differs to some extent from location to location. In South Sudan the standard brick format is 250 x 120 x 60mm, although the average size of the actual brick is typically 10mm less than this to allow for the mortar joint. For individual bricks some variation is acceptable and must be allowed because of the differences of firing and moulding of individual bricks, but the average over a large number of bricks should stay within about 3 to 4% of the standard size. For walls whose appearance is important, the distortion of individual bricks should be limited, but normal distortions, even of hand- made bricks, can usually be absorbed in the mortar joints.

The standard size for concrete blocks in South Sudan is 400 x 200 x (100, 150 or 200)mm.

Dimensional stability

Burnt clay bricks change in dimension to a small extent over time as a result of moisture movements, and temperature. There is an initial expansion of about 1mm per metre length, most of which occurs within the first week after the bricks leave the kiln. Subsequent moisture movements are small, and thermal expansion (about 0.15 to 0.25mm per metre for a 30°C temperature rise) is small compared with other building materials. Expansion joints are normally allowed every 12m in facing brickwork in order to accommodate these movements without causing cracking. More detail of expansion joint design and construction are given below under “Thermal and moisture movement”.

Blocks shrink after manufacture by about 0.5 to 1mm per m length of wall, which can be sufficient to cause cracking if expansion joints are not used; expansion joints are normally required to be spaced at 8m centres in blockwork to allow for the initial drying shrinkage, and subsequent moisture and thermal movements.

Strength

The compressive strength requirement depends on the loading on the wall. A minimum unit compressive strength of 3.5 MPa may be adequate for walls, which are not carrying large loads, and this is easily achievable in masonry materials made by simple processes; but masonry units of strengths up to 50 MPa or even more can be manufactured for use in special conditions. The stronger masonry units also tend to be less permeable, more resistant to frost and water erosion and thus more durable.

Water absorption

Water absorption is a concern for burnt clay bricks. It is a measure of the porosity of a brick, and should be limited, especially if the bricks are to be used in exposed positions, eg parapets, piers and abutment walls. A water absorption not greater than 8% by weight of the dry brick weight for a 24 hour immersion test is required for acceptable performance.

Chemical composition

For clay bricks, limitations on the content of certain salts are sometimes specified to reduce the problems of efflorescence and sulphate attack. Limiting sulphate content to 0.5% can eliminate the problem of sulphate attack (see below); alternatively sulphate-resisting cement may be needed. Efflorescence is unsightly but does not seriously affect the strength or durability of the masonry. Elimination of nodules of lime (kankar) in the brick earth is essential; their expansion after the bricks have fired can damage the brickwork.

Durability

The durability of a brick or block masonry wall depends as much on the climatic conditions, the extent to which protection of the faces and edges is ensured by copings and damp-proof courses, and the quality of the mortar as it does on the masonry units themselves. No specific requirements for durability can be stated, but units satisfying the requirements for strength and water absorption can usually be expected to perform satisfactorily if properly protected, by design, from extreme exposure.

Resistance to chemical action

Soluble salts in bricks, which may derive from the original clay used or from the kiln reactions, can cause staining and efflorescence or deterioration of the mortar. Efflorescence is the crystallisation of soluble salts at the surface of the brickwork when bricks dry after a prolonged period of wetting. It is usually not damaging and can be tolerated. If the bricks contain soluble sulphates, these may cause an expansive reaction with Portland cement in the brickwork mortars which will damage the integrity of the wall. Sulphate attack may also occur as a result of sulphates in groundwater in contact with earth retaining walls.

Abrasion and impact

Bridge structures, piers and abutments may be subject to abrasion (due to driving rain, wind-borne sand or dust, or flood water). The possibility of vehicle impact from road or water should be considered. Well-made masonry units will have adequate resistance to these actions but they should be considered in deciding the quality of bricks or blocks and mortar to use; and impact loads should be considered in the design of the wall resistance. In some instances the design of the structure needs to be detailed to minimise the risk of, or physically protect vulnerable components from, the impact from road or water born traffic or debris.

Thermal and moisture movement

Thermal and moisture movements can cause expansion and contraction in brickwork which can result in cracking unless it is allowed for. Mortars should normally be designed to be weaker than the bricks or blocks laid up in them to enable high stress concentrations to be relieved. The recommended mortars for various classes of bricks allow for this. Expansion joints should be provided through brickwork (and any supported structure) every 12m; they should be 10mm wide, and filled with compressible material so that they do not become inactive.

7.2.2 Field testing

Where possible, information should be obtained from the brick or block manufacturer regarding the Standard to which the units conform, and details of the results of recent tests on strength, dimensional stability, water absorption and chemical composition as appropriate. Failing such information, field-testing will help ensure that the bricks are of generally sound quality.

Quality of the raw materials used

The brick earth used for making burnt clay bricks should not contain iron pyrites, pebbles, or nodules of lime or tree roots. The content of clay should be 15% to 30%. A small quantity of lime is acceptable as long as it is in a finely divided state. Soils from areas, which are or have been saturated in salt or sea- water, should be avoided. Similarly aggregates for concrete blocks should satisfy the requirements for good concrete, as set out later in this chapter.

General characteristics of clay bricks

A good clay brick should be sound, hard and well burnt with uniform size, shape and colour, homogeneous in texture, and free from flaws and cracks. A broken surface should show a uniform structure free from holes or embedded lumps. Corners should be square, straight and well defined. When struck against another brick or with a small hammer, bricks should give a metallic ring, not a dull thud. When soaked in water for 24 hours there should be no sign of softening or distortion. Before or after immersion, the surface should not be able to be scratched with the fingernail.

Strength: drop test

If no specific compressive strength requirement is required for load-bearing purposes, the strength of a masonry unit may be crudely assessed by dropping it flat from a height of about 1.2 to 1.5m to the ground, or striking one brick against another. In neither case should it break.

Strength: impact test

For a more controlled impact strength assessment, place a brick with its largest face downwards; resting on timber battens 180mm apart. Drop a mason's 2kg hammer from a height of 0.5m so that it strikes the upper face midway between the battens. The brick should not break. If more than 2 in a sample of 20 bricks break in this test, the bricks should not be used. For bricks and blocks of different shapes, a similar test may be used but the height of drop and span will vary.

Dimensions

No dimension should differ by more than 5mm from the standard size. The overall dimensions of a set of 20 or more bricks or blocks, randomly selected, should not deviate by more than +/-4% (length and width) or +/-3% (height) from the standard size.

Water absorption test for clay bricks

Take a sample of 5 bricks at random. Dry and weigh each brick (W1); then submerge in clean water at ambient temperature for 24 hours. Wipe surface and weigh again (W2).

The water absorption (%) is the ratio:

100 x (W2-W1) / W1

For bricks to be used in normal conditions of exposure, water absorption should not exceed 15%. More severe limitations will be required for bricks to be used in conditions exposed to permanent wetting and drying (e.g. at the base of piers or abutments).

Durability

One way to test durability is through the construction of a test panel to be exposed to conditions similar to the proposed work; but a period of some months' exposure in severe weather will normally be needed to assess performance adequately. Alternatively observing the performance of the same masonry units in other building situations of comparable exposure (reference sites) can be a good indication of durability. Some kind of exposure test should be used if the units are to be used in conditions where they will be exposed to heavy frosts.

7.2.3 Mortars for brick and block masonry

The requirements for mortars are the same as those for stone masonry.

7.3 Timber and Organic Materials

In many areas timber, in the form of sawn sections or poles, is a highly cost-effective material to use for load-bearing structures, even where there are concerns about the over-exploitation of tropical forests. The quantities of timber required are relatively small and a good management regime will ensure or arrange for planting of replacement trees for construction and maintenance needs. This can be stipulated in contract documents. With proper selection of species; stress-grading (See Section 7.3.1 following) to ensure efficient utilisation; and attention to seasoning, preservation and subsequent maintenance; structures made from either softwoods or hardwoods can have a design life comparable to that of steel or concrete structures. In addition the appearance of timber structures fits the natural surroundings and its use can provide local employment without the need for highly sophisticated technology in manufacture or preparation with reduced transport costs.

The principal use of timber in low-cost road structures is for bridge decks where its structural advantages can be utilised most fully, and where it is more easily protected from moisture penetration. Use of timber for running surfaces may make sense even when the supporting structure is of steel, masonry or concrete. Trussed or girder bridge decks can be made from cut sections of timber or from timber poles. Timber has also been used for bridge piers and abutments and for retaining structures, though in these uses a relatively shorter lifetime must be expected. In Tanzania, a successful programme to use timber for culvert linings has been in progress for some years.

7.3.1 Characteristics and utilisation of timber

Hardwoods and softwoods and their availability

Softwoods are derived from coniferous evergreen trees grown mainly in temperate forests. They are relatively rapid-growing and the wood is of a generally relatively low density (typically less than500 kg/m^3), moderate strength and easy to work. However, the wood is not normally very durable unless protected by preservatives. Globally, coniferous forests are very extensive and are managed to produce a sustained yield of timber. In areas of temperate climate, softwoods are therefore relatively cheap, making timber structures highly cost-efficient.

Hardwoods are derived from broad-leaved (deciduous) trees which lose their leaves in winter; they are found in both temperate and humid tropical climates. Compared with softwoods they are relatively slow-growing and this results in wood which is denser (typically > 650 kg/m^3), and of higher strength, though sometimes difficult to work with normal hand-tools. Often hardwoods are highly durable even without the use of preservatives. However, some hardwoods, such as balsa, are extremely light and have a low strength (hardwood is a botanical rather than a mechanical classification of timber). Hardwoods of a number of species from the tropical forests have been seriously over-exploited and are, or will soon become, scarce. Nevertheless in most tropical regions there is a sufficient supply of less well-known species which are available locally at reasonable prices and these may prove to be ideal for use in road structures in these regions. Efforts are being made to introduce sustainable hardwood management practices.

The principal species suitable for road structures are shown in Tables 7.4, 7.5 and 7.6 (with their scientific and common name) divided into heavier and lighter hardwoods and softwoods.

Table 7.4: Heavy hardwoods

Density >650kg/m^3 when dried to 18% moisture content	
Afrormosia	(Pericopsiselata)
Ekki	(Lophiraelata)
Greenheart	(Ocotearodiaei)
Iroko	(Chlorophoraexcelsa, regia)
Jarrah	(Eucalyptus marginata)
Karri	(Eucalyptus diversicolor)
Keruing (gurjun)	(Dipterocarpusspp)
Opepe	(Naucleadiderrichii)
Sapele	(Entandrophragimacylindricum)
Teak	(Tectonagrandis)

Table 7.5: Lighter hardwoods

Density <650kg/m^3 when dried to 18% moisture content	
African Mahogany	(Khayaivorensis, anthotheca)
Afzelia	(Afzelia spp.)
Dahoma	(Piptadeniastrumafricanum)
Gum	(Eucalyptus saligna)
Jacareuba	(Calophyllumbrasiliense)
Meranti	(Shorea spp.)
Muminga	(Pterocarpusanyolensis)

Table 7.6: Softwoods

Softwoods for bridge construction should generally have a density >420kg/m^3 when dried to 18% moisture content	
Cedar	(Cedrus spp.)
Cypress	(Cuppressus spp.)
Douglas fir	(Psewdotsugataxifora)
Kauri, East African	(Agathis alba)
Parana Pine	(Araucaria angustifolia)
Pine, Caribbean Pitch	(PinusCaribaea)
Pine, Scots or Redwood	(Pinussylvestries)

Forms of timber and timber products

Timber is most commonly utilised structurally in the form of sawn sections. Timber is generally sawn at sawmills, in or close to the forests from which the trees are extracted, and then supplied to timber wholesalers or importers who sort, grade and treat the timber for supply to the users. There are, however, many local variations and hand sawing is still practiced in some areas. Whether machine or hand-sawn, logs are usually sawn by means of a series of parallel cuts through the log, which is referred to as flat-sawn. The resulting sections have a tendency to some distortion because of different shrinkage rates on the upper and lower surfaces. The alternative quarter-sawn logs will have less distortion, but waste more of the log (see Figure 7.8). In sawing timber into rectangular sections some of the log is inevitably wasted, and a more economical way to use timber, which eliminates sawing and also preserves more of its natural strength.

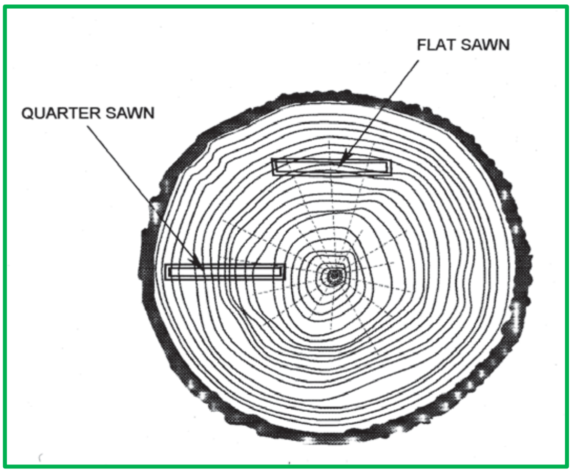


Figure 7.8: Saw cuts

The poles can be used for piling or as part of a timber lattice structure. Larger logs can be used as abutment, pier or deck members. Use of pole structures enables younger trees or thinnings from immature forests to be used, and thus the timber is cheaper.

Bamboo, though botanically closer to grass than timber, can often be of very high strength and strong enough to be used structurally. Bamboo bridges have been built for road traffic but it is very difficult to achieve good durability in bamboo structures and its use is not recommended in this manual without further local research evidence.

Seasoning

Freshly cut timber contains a substantial proportion of water (up to 100% of its dry weight) and, if used in the green state, it is subject to substantial shrinkage movement as well as being prone to fungal attack. Thus, for effective structural use, timber must be dried so that its moisture content is close to the equilibrium moisture content (between 10% and 20%, depending both on the type of timber and the climatic conditions). This process, which has to be carried out with care to avoid distortion, is referred to as seasoning. Seasoning also increases the strength and stiffness of the timber.

Timber preservation

Preservative treatment is needed to protect timber from fungal attack, insects and marine borers. There are a number of chemical treatments available. The success of the treatment depends on effective choice of both the chemical substance used and the treatment process.

Chemical preservatives include:

- Oil-based preservatives such as creosote;
- Water-based preservatives such as copper/chrome/arsenite;
- Organic solvent preservatives such as pentachlorophenol.

Stress grading

Because of the natural variability of timber, even of pieces from the same source, careful grading, piece by piece, is essential to ensure safe and efficient use. Stress grading can be done either visually or mechanically. Visual grading involves making a visual assessment of the extent of the principal factors affecting strength - knots, fissures, grain slope, wane, distortion, and perhaps worm holes and fungal decay, and classifying the timber according to predetermined measures of each which are acceptable in the various grades. Some aspects of visual stress grading are described below. In machine grading, each piece is subjected to a bending test under load in an automated process, and is graded according to its deformation; a visual assessment is carried out at the same time.

Natural defects

Natural defects shown in Figure 7.9 are features which develop in the living tree which may affect its structural usefulness. Some can be accommodated within limits.

The most important are:

- Knots - parts of branches which have become enclosed in the main tree; they can reduce strength in tension and can be difficult to work;
- Fissures- splitting separation of the fibres due to a variety of causes including: stresses in the standing tree (shakes), slits from rapid drying, resin pockets (in resin-bearing softwoods);
- Wane - inclusion in the sawn timber of part of the original round surface of the log;
- Insect holes;
- Grain slope - the small angle between the direction of the grain and the length of the cut timber.

Several other types of natural defect are unacceptable and should be eliminated from any timber used structurally:

- Brittleheart - this material is found in the centre of some tropical trees and should be avoided because it is of low strength and breaks with a brittle fracture;
- Fungal decay - this is discussed below.

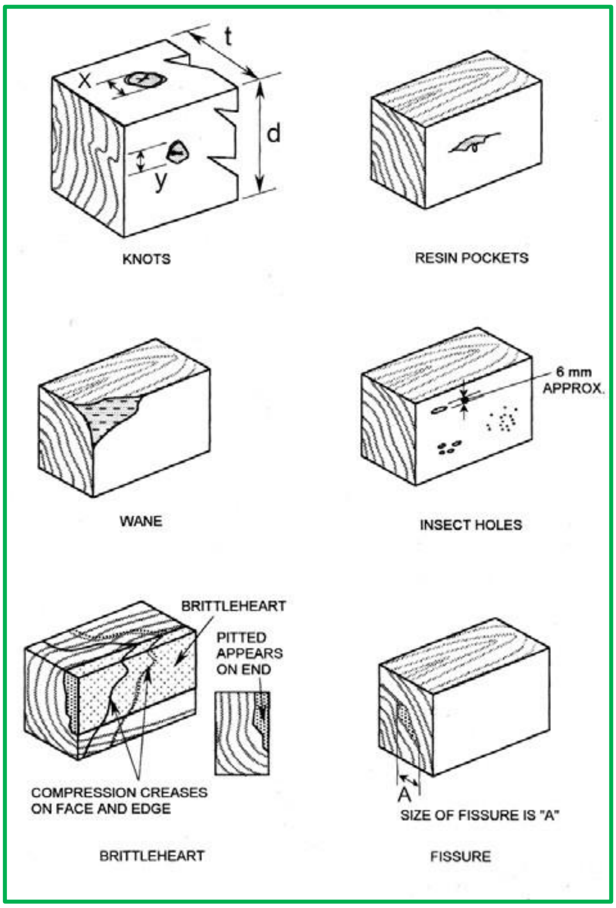


Figure 7.9: Natural defects in timber

Shape

The processes of sawing and seasoning timber create distortions which must be limited for satisfactory use. The four principal types of distortion encountered are bow, spring, twist and cup. Some suggested limits are given in Table 7.7 below.

Moisture content

Moisture content needs to be limited to achieve the best structural properties and reduce shrinkage as well as reduce susceptibility to fungal attack. Seasoning should reduce the moisture content to within 5% of the equilibrium moisture content, which is in the range 10 - 12% for hot-dry regions but may be 14 - 18% for tropical rainforest regions.

Density

The density of timber depends on its type. Softwoods typically have densities in the range 350-480 kg/m^3 but, for bridge construction, those suitable have densities above 420 kg/m^3 at 18% moisture content. Tropical hardwoods typically have densities in the range 500 to 800 kg/m^3(or even higher) but there are many hardwoods with much lower densities. The foregoing tables divide the common species of hardwoods into two classes: heavy hardwoods with densities above 650 kg/m^3 when dried to a moisture content of 18%; and lighter hardwoods with densities less than 650 kg/m^3.

Strength and elasticity

Strength and stiffness are the most important properties from the point of view of structural utilisation and they are closely related; timbers with higher strengths generally also have a higher modulus of elasticity.

For structural design, maximum allowable stresses in bending, tension, compression (both parallel to and perpendicular to the grain) and in shear must not be exceeded. These are normally derived from guidelines or codes of practice in which timbers are grouped into strength groups; values of the strength and stiffness parameters are given for each group depending on the moisture content and extent of defects in the timber. Design stresses for the three principal timber groups are shown in Table 7.7.

Table 7.7: Design stresses for the three principal timber groups

	Heavy Hardwoods (MPa)	**Lighter Hardwoods (Mpa)**	**Softwoods (MPa)**
Bending	15.1	8.6	5.4
Tension	9.0	5.0	3.2
Compression parallel to the grain	11.3	6.8	5.0
Compression perpendicular to the grain	2.2	1.8	1.5
Shear	2.2	1.1	0.9

Durability

The durability of timber relates primarily to its resistance to fungal attack and attack by insects or marine borers. Durability is enhanced by good timber selection, effective seasoning, preservative treatment, and maintenance after construction. It is also enhanced by good design, particularly measures to ensure that timber is protected from water. The end grain and joints are particularly susceptible.

Fungal attack can cause both staining and decay. Some fungi attack cell contents only rather than the cell wall substance and, as a result, no structural degradation of the timber occurs. Decay is not an inherent property of the material itself but depends on the availability of food (the wood itself), moisture, air and favourable temperature conditions. Some species have more durable heartwood than others and this is related to the toxic chemicals present in the cells and cell walls of the more durable species.

Ensuring that its moisture content is below 18% (based on the oven-dry weight of the wood) can increase the natural resistance of wood to decay. In addition to using seasoned timber, the wood should be protected from dampness by moisture barriers or flashing. If timber is in contact with the ground, only the more durable heartwood or preservative-treated timber should be used.

In tropical climates great damage is done to wood by subterranean termites. Termites must have access to the soil or to some other constant source of moisture. They can severely damage timbers in contact with the ground and may even extend attack to the roof timbers of high buildings.

Ensuring that all means of access are eliminated may prevent damage above ground. Metal shields or stump caps, or poisoned soil barriers are effective in preventing the passage of termites from the foundations to other parts of the structure. Where shields are used, adequate clearance below deck level should be provided to allow easy, and regular, inspection. In areas of severe infestation the only practical methods of control are, however, the use of termite-resistant or preservative-treated timbers.

Apart from termites, there are a number of other insects, which attack timber. Moisture is an essential element for some insects' development and hence drying is an obvious protective treatment. However, preservation is generally regarded as being a broad and more positive measure particularly where the timber is to be used in structural applications.

Protection of timber submerged in salt water against attack by waterborne organisms is usually based on the use of mechanical sheathing with resistant timbers, concrete or non-ferrous metal, or the use of preservatives which are resistant to leaching, such as creosote. Some tropical woods possess a natural resistance to such attack.

Shrinkage and thermal movement

Some shrinkage and expansion as a result in changes in the moisture content of the timber must be allowed for in design. The important shrinkage movements are tangential and radial, that is, across the width of the timber; in these directions the movement can exceed 3% as a result of a change in relative humidity from 90% to 60%. In the longitudinal direction the shrinkage movement is very small, less than 0.1%. The coefficient of thermal expansion is 30-60 x 10^{-6} per °C across the fibres, but less than one tenth of this parallel to the fibres. Thermal expansion, even of large structures, is therefore not a problem.

Fire resistance

Timber is a combustible material and will ignite at temperatures of around 220 to 300°C. It also produces toxic carbon monoxide and large quantities of smoke when ignited. When used in external conditions on road structures the risks are from fire caused by fuel spillage in overturned vehicles and wildfires. However, timber chars as it burns, at about 0.5-0.7mm per minute, which helps to insulate the interior. There is no instant loss of strength in fire, nor a rapid expansion, and timber structures can safely carry their loads for some time in a fire, enabling people to escape and the fire to be extinguished. Fire retardant and fire-protection chemical treatments are available either as paints or for pressure impregnation, but they are expensive, and the paints require maintenance. Fire protection is therefore not usually applied to external structures for low volume roads.

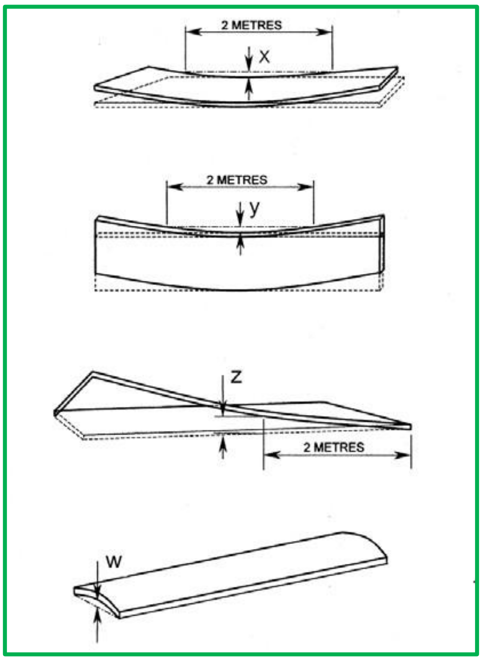
7.3.2 Field testing

Some visual indicators for a good quality timber are:

- The cellular tissue should be hard and compact;
- The fibrous tissues should adhere firmly together and should not clog the teeth of the saw;
- Depth of colour indicates strength and durability;
- A freshly cut surface should be firm, shining and somewhat translucent, whereas a dull chalky appearance is a sign of bad timber;
- In resinous timbers those with least resin in the pores are the strongest and most durable; in non-resinous timbers those with least sap are best;
- A good timber is uniform in colour, with straight grains, free from dead knots, cracks and shakes, and has regular annual growth rings.

Shape

The bow, spring, cup and twist of a piece of timber can be measured directly if the timber is placed on a flat surface. An average of at least 10 measurements should be taken. Some limits to distortion appropriate for tropical hardwoods and softwoods to be used structurally are shown in Figure 7.10.



Bow: X should not exceed 15mm per 2m length (in a piece of 75mm and greater in thickness)
Spring: Y should not exceed 7mm per 2m length (in a piece of 250mm or more in width)
Twist: Z should not exceed 10mm per 2m length
Cup: W should not exceed 1mm per 25mm of width

Figure 7.10: Timber shape criteria

Visual stress grading

Visual stress grading involves making measurements or inspections of natural defects: slope of grain, knots, fissures and resin pockets, wane and insect holes.

Minimum acceptable limits for all these characteristics are shown in Table 7.8. Other visible defects including bark pockets, compression failures, fungal decay, and brittleheart should not be permitted in any structural timber.

Table 7.8: Limits of visible defects for structural timber from tropical hardwoods

Property	**Acceptable limit for structural timber**
Slope of the grain	1 in 11
Knots: size	25% of the thickness, up to 75mm
Knots: frequency	One sizeable knot per metre of length
Fissures and resin pockets	Moderate fissures (of greater than 1/3 the thickness but less than the thickness): not to exceed in length 20% of the length or 1.5 times the width.
Wane	Not to exceed 25% the sum of the width and thickness
Insect holes	In a square of 100mm sides not more than 32 pinholes (<1mm), nor more than 4 shot holes (<3mm) nor more than 2 holes of 6mm diameter

Determination of moisture content

The moisture content of wood can be measured by the oven test method. Small samples are cut from the wood to be tested, the samples are weighed and then dried in the oven at 100 ^{0}C until their weight becomes constant. They are then weighed again. The moisture content, m, is calculated, as a percentage.

$$m\ \% = 100 \times \frac{\text{weight of water}}{\text{dry weight}} = 100 \times \frac{\text{initial weight} - \text{final weight}}{\text{final weight}}$$

Typical equilibrium moisture contents for different regions are shown in the foregoing text. The equilibrium moisture content of the timber should be determined by a laboratory; the oven test can then be used as a check on the effectiveness of seasoning of timber delivered to site. Moisture content should be kept within 5% of the equilibrium moisture content.

Strength and elasticity: load testing

The suitability of the structural properties of a timber are normally determined by the use of standard tables of properties for the species to be used, coupled with stress grading to determine the classification of the sections available. However, in certain circumstances, the structural properties of timber can be checked by a direct load test. This is easiest to carry out when the timber is to be used in bending.

A pair of joists is set up between solid supports using the span length which will be used in the actual structure. The joists are connected to each other by cross-bracing, and a deck is placed over them. The deck is loaded uniformly, using heavy materials such as bricks or stone, until it reaches the design load. The deformation at mid-span is then measured. Under the design load it should not exceed about 1/300 of the span. The load should then be increased to 50% above the design load under which load the timber should show no sign of failure.

7.4 Plain and Reinforced Concrete

Plain and reinforced concrete are widely used in road construction. Concrete technology is now established almost universally, even if it is not always well understood. Suitable raw materials to use as aggregates, forming the bulk of the material, are found almost everywhere. Cement and reinforcing bars are widely manufactured to standards that are internationally recognised. Concrete is sometimes the cheapest available option. However, high importation, production or transport costs and the high carbon footprint of both cement and steel can make locally produced materials more attractive. When it is well made, concrete is also a strong and durable material leading to a low maintenance requirement, important for rural structures. Concrete also has the particularly important property of being highly resistant to the action of water.

Reinforced concrete is suitable for bridge decks, piers and abutment, as well as for box culverts and culvert rings Plain concrete may be used for drifts and causeways, culvert rings up to 900mm diameter and for the foundations of walls, piers and abutments made of masonry and timber.

Because concrete, unlike other structural materials, is generally made on site from its raw materials, an important requirement for the use of concrete in structures is that both designers and builders, as well as those responsible for long-term maintenance, understand its essential properties and characteristics.

7.4.1 Materials for concrete

There are three essential constituents of concrete as illustrated in Figure 7.11:

1. Cement is the active ingredient. It constitutes about 10%-15% of the concrete by weight. The cement, in combination with water, forms a strong matrix which surrounds and binds the aggregate together. As the concrete mix sets and hardens it gains strength and durability.
2. Water constitutes about 5% of the concrete by weight. Initially, it gives the concrete workability, allowing it to flow and take up the shape in which it is molded. Over time, the water combines chemically with the cement in a process called hydration which causes the concrete to set and develop strength.

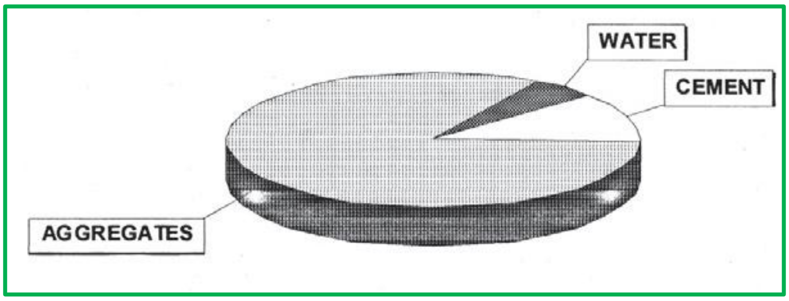


Figure 7.11: The constituents of concrete

3. Aggregates are inert materials, usually of mineral origin, which constitute the bulk of the concrete (about 75%-85%). They are usually chosen from local sources for low cost but their size range, shape, density, hardness and surface properties have important effects on the resulting concrete.

In making concrete, these three constituents are mixed together in appropriate proportions to make a fluid mass which is then placed in formwork, compacted to remove air, and finally allowed to set and harden.

Plain concrete is relatively weak in tension therefore steel reinforcement is used where tensile stresses are expected. When reinforced concrete is being made, the reinforcement is formed into a cage or grid which is placed in the formwork before the concrete is placed. The following sections describe the materials requirements.

Cement

The cement most commonly used for concrete is Ordinary Portland Cement (OPC). This is made in factories in which a mixture of limestone (or other calcium-rich minerals) together with clay or shale is fired at a high temperature and the resulting cement clinker is ground to a fine powder. The operation is highly controlled and the resulting cement is produced to a specification which defines the essential properties including strength, setting rate and chemical composition.

Cement is normally delivered to site in 25 - 50kg bags. The cement must be kept totally dry until it is used otherwise it will begin to react with the water and be rendered useless. Cement should therefore be stored off the ground in a shaded, dry and well-ventilated place (Figure 7.12). If any lumps of hardened cement are found in a bag, the cement in that bag should not be used for structural work. Cement should typically be used within 6 months and therefore stored in a 'first in – first out' system.

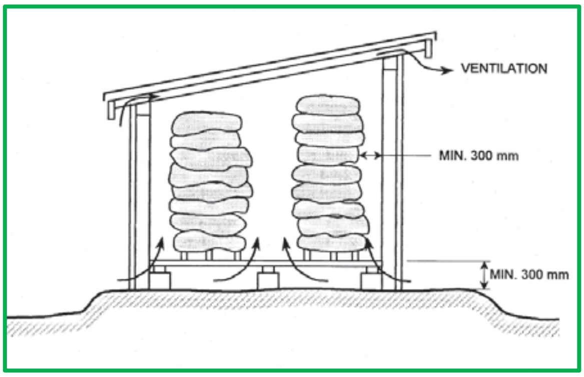


Figure 7.12: Cement stored in dry conditions

Water

The mixing water used should be clean and free from salts. It can be taken from rivers, lakes or wells or from a treated water supply. Saline water may be used for plain concrete, though it will affect the rate of setting, but should not be used for reinforced concrete. River water containing sediments can be used if the sediments are first allowed to settle out in a tank or drum until the water is clear.

Aggregates

The aggregate is divided into two parts: coarse aggregate and fine aggregate. The fine aggregate is normally naturally occurring sand with particles up to about 2mm in size. The coarse aggregate is normally stone with a range of sizes from about 5mm to 20mm (or sometimes larger); it may be naturally occurring gravel or, more commonly, crushed or hand-broken quarry stone. In areas without hard stone resources and with an established fired clay brick industry, burnt bricks can be machine or hand crushed to be used in concrete.

Aggregates must be entirely free from soil or organic materials such as grass and leaves as well as fine particles such as silt and clay, otherwise the resulting concrete will be of poor quality. Some aggregates, particularly those from salty environments, may need to be washed to make them suitable for use. Tests for aggregate quality are described in Section 7.4.4.

Both the coarse and fine aggregates need to contain a range of particle sizes that are mixed together in such a way that the fine aggregates fill the space between the coarse aggregate particles. A ratio by volume of one part fine aggregate to two parts coarse aggregate is generally used. Aggregates can be crushed and screened by hand or by machine.

Aggregates should be stored in such a way that they do not become contaminated by soil and so that rainwater can drain easily.

Reinforcement

Reinforcement is normally in the form of steel bars. Three characteristics are of primary importance:

- Enough strength that a small amount of reinforcement can be used to carry the tensile and shear forces;
- Enough ductility that the rods can be bent without breaking and, if a member is overloaded, that the structure will deform without failing;
- Sufficient bond between the reinforcing and the concrete that forces can be transferred between them.

Two types of steel reinforcement are in common use: mild steel and hot rolled high-yield steel. Mild steel bars are round whereas high yield bars have a deformed surface to improve the bond with the concrete. Typical reinforcement sizes range from 6mm to 30mm in diameter. Reinforcing steel is usually available both in rod and mesh forms. Reinforcement bars are cut to the required length and bent to the required shape. They are then tied together in the arrangements shown on the drawings using binding wire and spacer blocks.

On site reinforcement should be kept straight until needed and should be stored clear of the ground to prevent contamination with soil.

Concrete mixes

The proportions of the constituents may be varied to obtain the required properties. As a rule, the larger the amount of water added to the mix the more fluid and easy to cast in place it will be but the lower will be the final strength and durability. The ratio of water to cement should therefore be as low as possible for the necessary workability of the concrete. Given this requirement, mixes with a larger proportion of cement to aggregates will tend to be stronger and more durable.

Three principal types of concrete are required for use in low volume roads as shown in Table 7.9.

With good quality graded aggregates and water content just sufficient to give adequate workability, the nominal mixes shown in Table 7.10 should achieve the strengths indicated. It is crucial that the mix does not contain excess water as this will result in increased porosity in the final concrete and considerably reduced strength and durability.

Table 7.9: Concrete types

Structural concrete	Grades 20 and 25 This is concrete intended for use in reinforced structures and load-bearing applications such as bridge decks and culvert rings. The grade indicates the target crushing strength of cubes (N/mm^2) at 28 days after casting. Maximum aggregate size is normally 20 mm to allow the concrete to pass round the reinforcement and give good compaction. Typical mix proportions for Grades 20 and 25 are given in the Table below.
Mass concrete	This is appropriate for gravity structures where reinforcing steel is not used. A large sized stone (up to 50mm) is permitted. For the construction of drifts and causeways, larger pieces of stone (referred to as plums) may be set in place before the concrete is poured to act as fill. These should be of the same quality as the aggregate and have a maximum size not greater than three- quarters of the depth of the concrete. The cement content for mass concrete is higher than for lean concrete but lower than for structural concrete. Mix proportions are 1:3:6.
Lean concrete	This is a meager mix with low cement content. It is used for blinding the foundation excavations for structures where it acts as a clean working surface prior to placing structural concrete. It is also used as a porous backing to structures and behind weep holes to allow water to migrate through without washing soil particles through the structure. The mix proportions are 1:4:8 by volume.

Table 7.10: Concrete grades, strengths and batching strengths

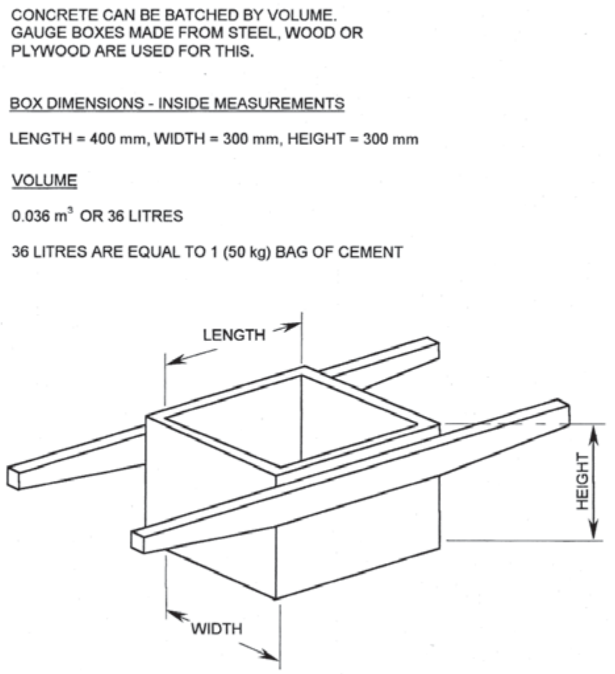
Class of concrete	Expected 28 day strength N/mm^2	Cement/ fine aggregate./ coarse agg. (guidance)	Material required for 1m^3 finished concrete (guidance)		
			50kg Cement bags (kg)	Fine (m^3)	Coarse (m^3)
Lean	-	1:4:8	3.3 (166)	0.47	0.94
Mass	15	1:3:6	4.3 (215)	0.46	0.92
Grade 20	20	1:2:4	6.0 (300)	0.42	0.84
Grade 25	25	1:1.5:3	7.3 (365)	0.38	0.76

7.4.2 Production and placement

Mixing

Concrete may be mixed (or batched) by hand or by a mechanical mixer. When batching by volume is to be used, the mix proportions should be measured using a gauge box with dimensions as shown in Figure 7.13. The gauge box has a volume of 0.036 m^3, equivalent to one 50kg bag of cement.

Aggregates and cement are thoroughly mixed together in the dry state, and then the water added gradually while mixing until a uniform mass of the right workability is achieved. Concrete should be mixed on a clean, hard, level and impermeable platform, or in a mixer.



Class of Concrete	Batchwith1bag		
	Number of boxes of aggregates		Yield per batch
	Fine	Coarse	(m^3)
Lean	4	4	0.30
Mass	3	6	0.24
Grade 20	2	4	0.16
Grade 25	1.5	3	0.14

Figure 7.13: Concrete mixes (guidance)

Transporting

Concrete should be mixed as near as possible to the site of placement and may be transported using trucks, wheelbarrows, or even using head pans for sites with difficult access. The wet mix should be transported within 30 minutes to allow placing before setting commences.

Placing

When the concrete is poured, the formwork or shuttering for the concrete must be clean, smooth faced, and secure from movement or leakage. Formwork is normally constructed from timber and plywood, especially where shapes are complex. Where the same shape is repeated (e.g. for culvert barrels or headwalls) then steel formwork can be economical and efficient to use. The dimensions and widths of the space to be filled must be carefully checked. Formwork construction should be planned to enable later removal. Formwork must be strong and well secured so that it does not move or distort under the pressures exerted by the wet concrete or the vibration operation. It must be complete without gaps for the wet concrete to escape through. Any reinforcement must be well secured and positioned away from the formwork with set mortar or plastic spacers to ensure that the correct cover is achieved. Purpose-made mould oil can be used to aid later removal of the formwork without damage to the concrete; used engine oil may be used for this function.

The wet concrete should be placed in layers and rammed or vibrated immediately to form a dense well-graded mass with no air pockets. The layers should be built up and compacted into each other without allowing joints of set concrete to form (except at predetermined construction joints). The concrete should be placed in layers of thickness less than 300mm when hand ramming. This may be increased to 600mm when a vibrating poker is used. Care must be taken not to disturb the formwork or any reinforcement during placing and compaction. Over-vibration must be avoided because it can lead to segregation of the concrete paste from the aggregates.

The top of the placed concrete should be finished smooth with a mason's trowel or float. However, any day work joints (e.g. in a wall lift) should be left rough to ensure a good bond for the next layer of concrete. Concrete should not be mixed or placed in ambient temperatures of less than 3˚C or above 38˚C.

Curing

Concrete hardens as a result of hydration of the cement with water. Fresh concrete contains more than enough water to hydrate the cement completely but if the concrete is not protected against drying out, the water content, especially near the surface, will be insufficient for complete hydration. This causes cracking. Direct sunlight will speed up evaporation so temporary shading should be provided where needed. Curing should start as soon as the concrete begins to harden (3-4 hours after placing). Suitable methods include: sprinkling or flooding; covering with empty cement bags, hessian bags or other fabric, sand, sawdust (50mm thick), grass or leaves, all of which should be kept wet. For faces cast against formwork, the formwork may be loosened after one day and left in place, dampening from time to time. All concrete should be cured for at least 7 days. During this time it should be protected from frost if necessary.

Detailed local specifications for concreting procedures should be followed because these can take account of local raw materials, site practices and climate.

Table 7.11 provides guidelines for the placing, compacting and curing of concrete to assist in the attainment of a quality material.

Table 7.11: Recommendations for good quality concrete

Activity	**Recommendations of good practice**
Placing concrete	• Forms and the shutters should be cleaned before placing the concrete; • Concrete should be placed in layers of 300mm depth; • Concrete should not be placed in heaps because this causes separation of the stones from the sand and cement; • Concrete should not be dropped from a height of more than 1.5m because this also causes separation of the stone from the sand and cement; • Reinforcement bars are to be placed inside the shuttering before placing the concrete.
Compacting concrete	• Compacting is undertaken by tamping with a steel or wooden rod or vibrating poker; • It is important to remove all the air in the concrete because entrained air reduces the strength of the concrete;.
Curing concrete	• Curing means keeping the outside of the concrete moist (wet)during the setting (hardening) of the concrete by: ▪ Wetting the concrete surface frequently; ▪ Covering the surface with wet material (cloth, paper bags, sand etc.); • Hardening of concrete requires at least 7 days. Curing prevents cracks in the surface layer of the concrete;. • As cement is normally one of the most expensive items in the construction process, it should not be wasted.
Too much cement = costly Too little cement = low strength	

7.4.3 Properties of concrete

Workability of fresh concrete

In its freshly mixed state concrete needs sufficient workability to enable it to be placed into the formwork and compacted. The workability needed depends on the shape of the formwork to be filled, the amount of reinforcement in it, and sometimes on the method of transportation. Workability is measured on site by the slump test, which is described below. Table 7.12 indicates the maximum workability suitable for different situations.

Table 7.12: Maximum slump values for particular uses

Concrete use	Maximum slump
Lean concrete	100mm
Reinforced foundations	80mm
Other reinforced areas	50mm

Strength and stiffness

Concrete mixes are designed to achieve a given 28-day strength in compression, as measured by crushing tests on cubes or cylinders. The strength of a concrete develops slowly as the cement hydration reaction continues. After 28 days the concrete will have attained most of its final strength, which is why at this age strength is specified. Typical structural concretes have strengths in the range 25- 40 MPa. For good quality control of the concrete, crushing test samples are made regularly on site and sent to a testing laboratory for testing at 28 days.

Tensile strength and stiffness also develop as the compressive strength develops. The tensile strength of concrete is normally about one-tenth of its compressive strength. A quality control test, which could be used to assess the strength based on the tensile strength, is suggested in field testing below.

Moisture movement

Wet cured concrete exposed to air will shrink over time. It will also expand and contract subsequently as a result of changes in ambient humidity or exposure to rain or moisture. The extent of shrinkage depends on the properties of the concrete and ambient conditions but, typically, about 0.8 to 1.0mm per m of drying shrinkage can be expected (in all dimensions) with subsequent variations of about one-third of these values. This can cause unsightly cracking in concrete structures unless joints are provided at intervals to allow it to occur. Additional (creep) moisture movements occur as a result of the load. Creep continues over a long period of time (some months). Both creep and shrinkage can be restrained (though not prevented) by the presence of reinforcement.

Durability

The durability of concrete depends on its resistance to the major causes of deterioration: corrosion of the reinforcement, frost attack, sulphate attack, chemical attack, and deterioration of the aggregate-cement bond. There are four principal agents of deterioration shown in Table 7.13. Protection of the concrete from these agencies of deterioration can be achieved by:

- Good compaction - permeability of concrete is increased if compaction is poor or cracking occurs as a result of poor curing;

- Adequate cover to reinforcement - minimum cover is specified according to the environmental conditions; greater for external surfaces, and surfaces which are to be tooled etc.;
- Use of low permeability concrete - by using well-compacted concrete with low water cement ratio, which reduces the ability of water to move through the concrete;
- Providing a minimum cement content - to create a sufficiently alkaline environment to inhibit reinforcement corrosion, a minimum quantity of cement is needed. Nominal mixes provide an adequate amount;
- Minimise the risk of alkali silica reaction - by limiting the alkali content of the concrete or by using non-reactive aggregates.

Table 7.13: Agents of concrete deterioration

Corrosion (rusting) of the reinforcement	Corrosion is caused by an electro-chemical reaction occurring in the presence of water and air. It occurs when water gains access to the reinforcement; through inadequate concrete cover to the reinforcement; because of poorly mixed or poorly compacted concrete; or as a result of cracking.
Sulphate attack	Sulphates in soil and some aggregates will react with the hydrated cement resulting in expansion and damage of the concrete.
Alkali-silica reaction	So-called “concrete cancer” is a deterioration of the concrete as a result of a reaction between alkaline fluids and reactive minerals in certain types of aggregates.

Thermal movements

The coefficient of thermal expansion of concrete is about 10 to 14 x 10^{-6} mm/mm, i.e. about 3mm per m for a 30°C temperature rise, about the same as for structural steels (12 x 10^{-6}). Thus, for long concrete structures such as multi-span bridges, expansion joints are needed to allow for seasonal temperature changes.

8 STRUCTURE DESIGN

There is a large amount of energy stored in flowing water. A fast flowing river 0.5m deep can wash away a car or pickup truck. Even at lower volumes and velocities, water can wash away road structures. A high priority task in designing a road structure is therefore to minimise the disturbance to the water flow in the channel, which then minimises the potential damage to the structure and scouring of the watercourse.

The vast majority of structural failures occur during flood periods and over 50% of these failures can be attributed to scour. The initial section of this chapter deals with scour and how to design and construct a structure to withstand scour effects.

There are often a number of elements, which form a road structure. In some cases these are common to a range of structures. After the section dealing with scour this chapter is broken down into sections which each cover an individual structural element. Table 8.1 shows the aspects which must be consulted for the design of different structural elements for water crossing structures.

Table 8.1: Guidance on design aspects

Structural Item	Drift	Culvert	Vented Drift	Large-bore Culvert	Bridge
Foundations	✓	✓	✓	✓	✓
Structural slabs	✓		✓	✓	
Cut-off walls	✓	✓	✓	✓	✓
Pipes		✓	✓		
Headwalls &wingwalls		✓	✓	✓	✓
Apron	✓	✓	✓		
Approach ramps			✓	✓	✓
Downstream protection	✓	✓	✓	✓	✓
Arches				✓	
Bridge design • General • Deck • Abutments • Piers • Bearings & joints				✓ (arch bridges)	

8.1 Scour

Scour is the erosion of material from the river sides and bed due to water flow (Plate 10) Damage due to scour is the most likely cause of structural failure. Minimising or eliminating the effects of scour should therefore receive the most attention when designing any structure. Scour can occur during any flow but the risk is generally greater during floods.

There are three major types of scour to be considered:

1. **River morphology:** these are long-term changes in the river due to bends and constrictions in the channel affecting the shape and course of the channel.
2. **Construction scour:** this is the scour experienced around road structures where the natural channel flow is restricted by the opening in the structure. The speed of the water increases through the restriction and results in more erosive power, removing material from the banks and bed.
3. **Local scour:** occurs around abutments and piers due to the increased velocity of the water and vortices around these obstructions.

The latter two scour types are the most important to consider when designing a structure. The amount of scour at a structure will be affected by the following factors:

- **Slope, alignment and bed material of the stream**: the amount of scour is dependent on the speed of the water flow and the erodability of the bed material;
- **Vegetation in the stream**: any vegetation growing permanently in the stream can improve the strength of the riverbed, reduce the flow velocity, and reduce scour ;
- **Depth, velocity and alignment of the flow through the bridge**: the faster the flow, the more scour will occur;
- **Alignment, size, shape and orientation of piers, abutments and other obstructions**: water is accelerated around these obstructions, creating vortices with high velocities at abrupt edges on the obstruction, increasing the scour depth;
- **Trapped debris**: debris can restrict the flow of water and cause an increase in water velocity - it is important that structures are designed to minimise the chances of debris being trapped and to ensure that inspections and maintenance are carried out after flood periods to remove any lodged debris;
- **Amount of bed material in the water**: if the water is already carrying a large amount of material eroded from further upstream, a greater amount of scour will occur at the structure.

The proposed site of the structure and the watercourse upstream and downstream must be inspected for evidence of existing scour, erosion or deposition in the watercourse and banks.

It is difficult to accurately predict the level of scour that may be experienced for a particular design. There are many formulae for predicting the amount of scour around a structure but these formulae, in general, require detailed knowledge of the river and bed characteristics. They are also based on empirical data and will often give different design scour depths. Engineering judgement will be required. This Manual proposes a number of ‘rules’ for designing to resist scour. It must be stressed that these rules are not infallible and local knowledge should also be taken into account when designing a structure.

8.1.1 Rule 1 - Provide sufficient foundation or cut-off wall depths

Regardless of the required depth for foundations determined by the ground conditions and predicted scour, the minimum foundation depths shown in Table 8.2 should be provided. The depth is measured from the lowest point in the bed of the watercourse at the crossing point. These depths can only be reduced where firm rock is encountered at a shallower depth and the foundations are firmly keyed into the rock.

Table 8.2: Foundation depths

Structure	Foundation Depth	Cut-off wall depth
Drift	Not applicable	1.5m
Relief culvert	Not applicable	1.0m
Watercourse culvert	Not applicable	1.5m (headwalls and wingwalls)

Vented drift	Not applicable	2m
Large bore culverts	3m	3m
Bridges	3m	3m

8.1.2 Rule 2 - Create a minimal constriction to the water flow

The amount of scour experienced at a structure is proportional to the restriction in the normal water flow. If the flow is considered unconstrained then scour will not exist. If the site conditions permit, the opening widths in Table 8.3 should be provided to eliminate the effects of scour.

Table 8.3: Opening widths

Peak flood flow rate	0.5	1	2	4	6	8	10	15	20	25	30	**m^3/s**
Minimum width (W)	3.5	5	7	10	12	14	15	19	21	24	26	**m**

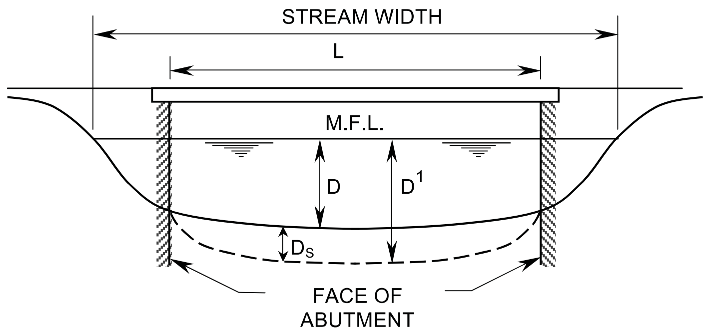
In some cases, particularly for bridges and larger flows, it will not be possible to provide the opening widths shown in Table 8.3 above. The design, particularly the level of foundations, should allow for a lowering of the riverbed level due to scour. The amount/depth of scour (as shown in Figure 8.1) that will occur depends on the following 3 factors:

- Constricted flow width;
- Maximum flow rate;
- The type of material forming the sides and bottom of the watercourse.

The depth of scour is therefore:

Depth of scour = flood water depth at structure – original unconstrained watercourse depth

Ds = D1 – D



W = THE ORIGINAL WIDTH OF THE STREAM

L = THE DESIGNED WATERWAY. WHEN THE BRIDGE IS ASSUMED TO CAUSE CONTRACTION, L IS LESS THAN W

D = THE ORIGINAL DEPTH OF STREAM

D^1 = THE EXPECTED SCOUR DEPTH UNDER THE BRIDGE DUE TO ITS CONSTRICTION

D_S = ADDITIONAL DEPTH OF SCOUR DUE TO CONSTRICTION OF BRIDGE

Figure: 8.1: Scour allowances

The three following graphs (Figures 8.2, 8.3 and 8.4) allow the prediction of the water depth in the channel which will allow the depth of scour to be calculated.

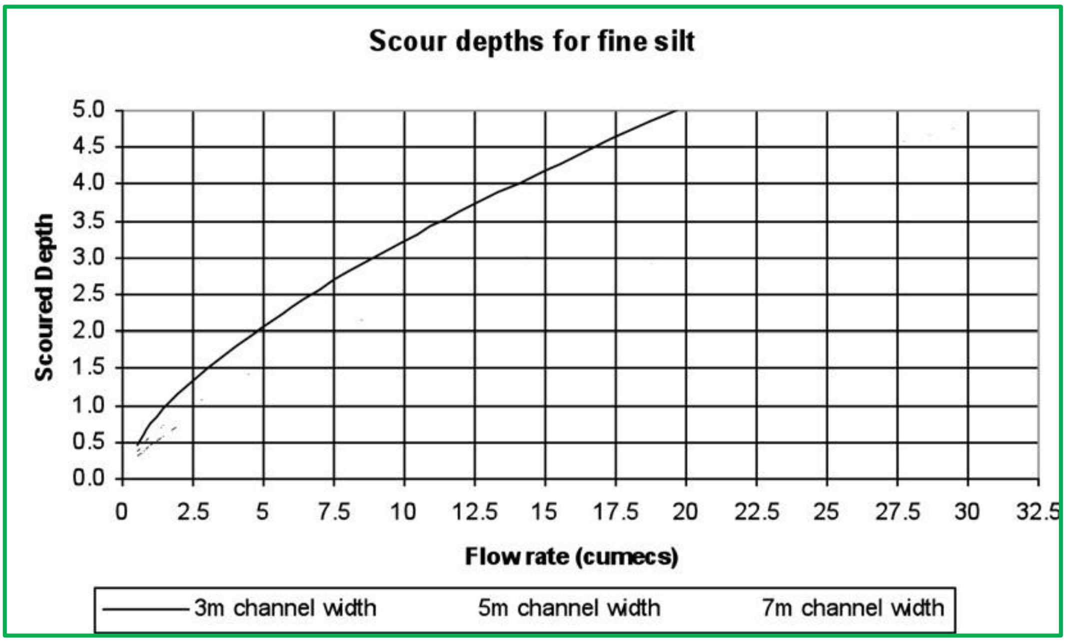


Figure 8.2: Scour – fine silt

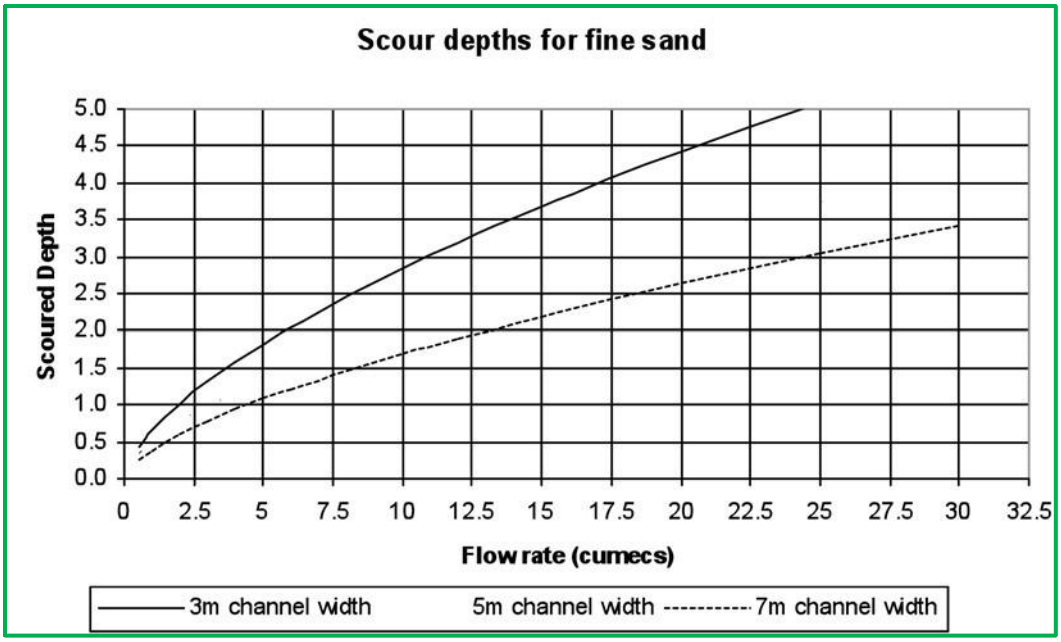


Figure 8.3: Scour - fine sand

(as above)

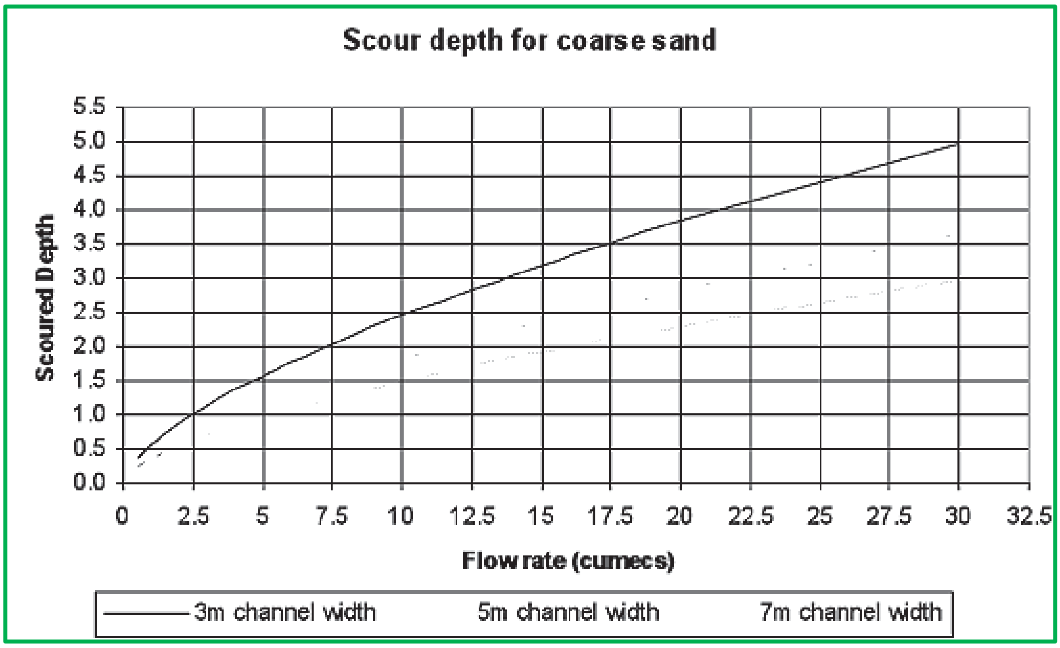


Figure 8.4: Scour – coarse sand

The depth of scour indicates the general level of erosion that will occur in the riverbed. Additional local scour will occur near bridge abutments and wing walls and also at the edges of aprons. Table 8.4 shows the factor that the general scour should be multiplied by to calculate the depth of scour that may be encountered near structural elements.

All foundations should be constructed below the predicted depth of scour.

Predicted maximum depth of scour = depth of general scour x local scour multiplier

Table 8.4: Scour depth adjustment

Local scour at structural elements	**Local scour multiplier**
Long abutments parallel to water flow in straight channels	1.5
Abutments in curving channels and/or Part of structures with multiple openings	2.0
Abutments and wingwalls where flow reaches structure at an angle greater than 20 degrees	2.25
Ends of protective aprons or drift slabs	2.5

8.1.3 Rule 3 - avoid the use of piers

If piers are absolutely necessary they should be aligned exactly in the direction of water flow.

Figure 8.5 shows the likely depth of scour that may be encountered around piers that are aligned in the direction of water flow. Scour around piers will be doubled for piers that are aligned 10-15^{o} away from the direction of water flow.

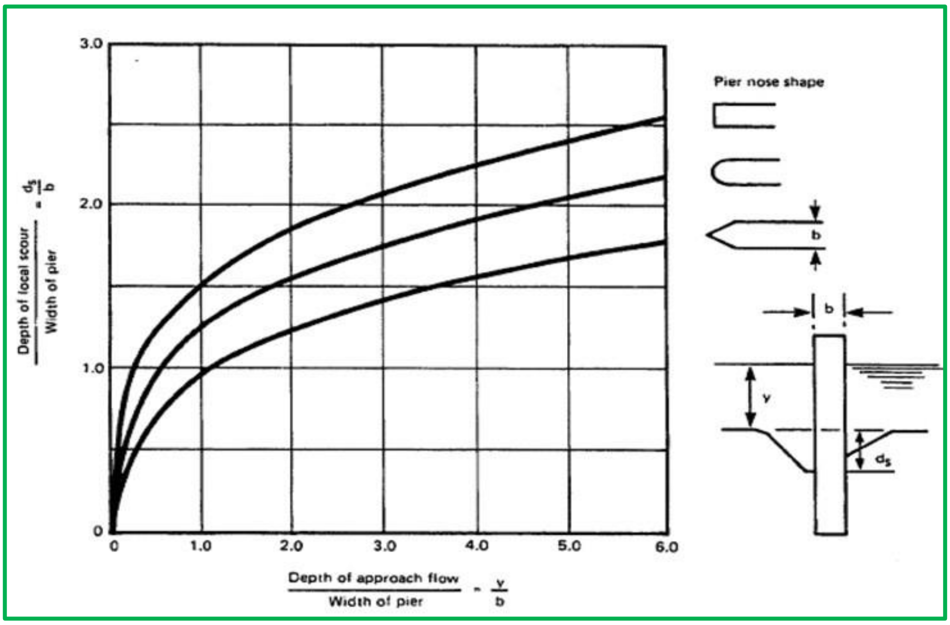


Figure 8.5: Depth of scour around piers (from TRL ORN9)

8.2 Foundations

The strength and durability of any structure will be determined by the quality of its foundation and the bearing capacity of the soil (refer to Chapter 2).

For small, simple structures such as drifts, culverts and vented fords it will be sufficient to construct the structure on well drained, firm soil. Referring to the soil bearing capacity tables in Chapter 5, these conditions include any rock, clays and silts that are at least “firm” or sands and gravels that are at least “loose”. These conditions can be determined on site by checking for footprints when walking over the proposed location. If more than a faint footprint is left it will be necessary to improve the ground before construction commences.

If the ground conditions are poor at the proposed level of the structure’s foundation it will be necessary to continue excavation to firm material that can provide sufficient bearing capacity. The engineer will then have three options for the construction of the structure:

- Alter the design to lower the level of the foundations;
- Replace the poor excavated material with new material that has a better bearing capacity (e.g. a well graded sand and gravel) that is compacted into the excavation in 300mm layers;
- Provide a piled foundation (not covered by this Manual).

For all structures it is necessary to start the construction on a well-drained, level base. The excavations for all structures, apart from those built on rock, should be dug an additional 300 mm below the proposed foundation level. A 300mm layer of sand and fine gravel should then be placed and levelled in the bottom of the excavation to provide a good base for the structure. Alternatively at least 100mm of lean concrete blinding should be laid to provide a firm clean working platform.

A method for calculating the approximate load exerted by the foundations of a vented ford or large bore culvert on the ground is to calculate the load of the structural fill material and multiply by a safety factor shown in Table 8.5.

Table 8.5: Bearing safety factor

Material	Load per metre of fill	Safety factor
Concrete/gravel	25kN	1.5
Earth	20kN	1.5

Where a foundation is to be built on rock which may be sloping down to the watercourse (see Figure 8.6), it will be necessary to form a level platform for the foundation. This may be achieved by either breaking out the rock to give a level foundation or building up the foundation to level by placing concrete around drilled and grouted mild steel bars. The preferred option, which should be adopted unless the rock is too hard to break out, is to break out a level platform. Sloping firm rock abutments are, of course, suitable for arch bridge springings. In these circumstances the rock should be excavated approximately to a plane roughly at right angles to the slope of invert of the arch at the springing (See Figure 8.17 detailing masonry arch culvert construction). The face may be cut in steps to increase bond between the structure and rock foundation.

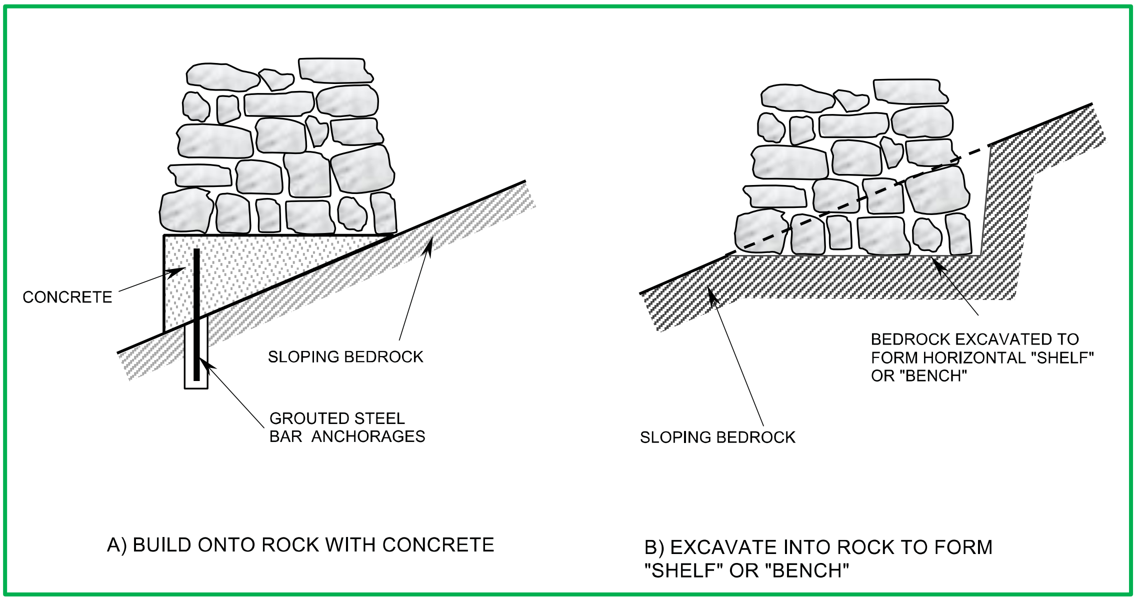


Figure 8.6: Construction on sloping bedrock

8.3 Structural Slabs

8.3.1 Drifts

The primary objective in the design of a drift is to provide a suitable surface for vehicles to drive across while creating minimal disturbance to the water flow. Drift slabs should therefore follow, as closely as possible, the bed of the watercourse. The drift slab surface should be no more than 200mm above the existing bed level. However, it is desirable to construct the drift with a finished level at the same level as the riverbed. Slabs which are constructed more than 200mm above the existing bed level are likely to cause severe erosion downstream of the drift, requiring frequent maintenance.

NOTE: There is one situation where it may be permissible to raise the finished level of the drift above the riverbed. If the site selected for the drift appears to suffer from silting the final level of the drift could be raised 200-300mm above the natural riverbed. This raising of the level will cause water to flow slightly faster over the drift and reduce the potential for the drift to silt up.

If the river is flowing in a channel with banks on each side, it will be necessary to ensure that there is a suitable approach slope from the road on each side to the drift in the bottom of the riverbed. These approach slopes should not be so steep that vehicles get stuck at the bottom of the drift. A maximum gradient between 5 and 10% will be determined by the vehicles that are using the road. A gradient of10% may be used if the only vehicles using the road are cars and light trucks. A gradient of 7.5% may be used for medium size trucks and small minibuses and a gradient of 5% used if buses and large trucks (>10tonnes) are expected to travel along the road. Allowance should be made for the fact that heavier vehicles may use the road following improvement of the route.

Although vehicles may not be able to cross the drift during periods of high water, it is essential that the drift slab extends beyond the highest flood level to ensure that scour and erosion will not take place at each end of the drift. It may, therefore, be necessary to construct the drift slab to the top of the riverbanks at the end of the approach slope.

To reduce the cost of construction it may be possible to reduce the width of the drift slab so that it is narrower than the normal road width. Vehicles would not be able to pass each other on the drift so the designer must ensure that there is sufficient passing space on each side of the drift to allow vehicles to wait and pass each other. To prevent vehicles driving off the drift and possibly getting stuck in the soft or loose river bed, or vehicles attempting to pass each other on the drift, guide stones should be placed along the edges of the approaches and across the drift.

The width of the central or flat middle section of the drift should minimise disturbance to the water flow. The construction of the road will cause a larger amount of water to flow across the drift due to water flowing off the road along the side drains.

Drift slab construction

There are four possible solutions for constructing the drift slab. In descending cost they are:

- Concrete slab;
- Cement bonded stone paving;
- Dry pitched stone paving;
- Gabions with gravel or broken stone.

The main factors affecting the choice of construction method are:

- The nature of the river bed;
- The expected volume and flow rates of the water;
- The availability of different construction materials;
- The cost of labour.

If large volumes of fast flowing water are expected it will be necessary to use a concrete slab or cement bound stone paving because the water will erode gravel and dislodge hand pitched stones. In the cases of slower flowing water or small streams hand pitched stone or gabions are likely to be acceptable and a cheaper option.

8.3.2 Concrete slab

Although concrete slabs are the most expensive they are a long lasting, low maintenance solution. The concrete slab should extend the full width of the drift between the cut-off walls with a minimum thickness of 250mm. In areas where stone is locally available 'plums' may be put in the slab to reduce the amount of cement required and hence reduce the overall cost.

Where plums are used they should not have a dimension greater than 75mm (100mm where the slab is 300mm or thicker) and should be placed as far as possible in the middle of the slab.

8.3.3 Cement mortar bonded stone paving

Stone paving will offer a cheaper alternative to a concrete slab in areas where masonry or locally manufactured blocks of sufficient strength are available. The slab should be a minimum of 300mm thick and may require more than one course of paving to be laid. The blocks should be laid in an arrangement to ensure that the different courses interlock with each other.

8.3.4 Hand packed stone

In areas where masonry stone is widely available this option is likely to be cheaper than constructing a concrete slab. However, it is only suitable for low velocity flows and can take a considerable length of time to construct for larger crossings. It is essential that the stones are well placed to ensure that they are interlocked to prevent them being washed out by the water. The whole structure can be washed away if the water can wash out one stone because this weakens the remaining structure. Larger stones are better than smaller ones because they are less likely to be washed away. The best stones to use are angular and flat faced and should be placed on their edge to give the greatest interlock between stones.

8.3.5 Gabions and gravel

This is likely to be the cheapest and quickest option for constructing a drift slab. Smaller stones may be used in the gabion than for hand pitched stone and maintenance does not require specialist skills. However, gabion baskets and gravel will be unable to withstand large flows of water. The drift basically consists of a gabion basket on the downstream side which acts as a dam to prevent the gravel being washed away.

Where gravel may be washed away but there is a reasonable amount of gravel in the riverbed, it may be possible to protect the riverbed and trap gravel and sand in the top of a gabion mattress to create a vehicle running surface. Gabion mattresses are similar to gabion baskets except that they are a flatter section, usually 250-300mm deep, and cover a wider plan area. Sand and gravel will tend to be trapped on the top of the gabions which will prevent wear of the wire by traffic.

An additional measure to stabilise the face of the gabion and the retained material is to insert natural fibre matting in the top and face of the gabion. This also encourages vegetation growth for improved stabilisation.

8.3.6 Slab construction (vented fords and large bore culverts)

The number of options available for the type of slab will depend on its ultimate use. If the slab is to be used on the top of a fill layer, as in the case of vented fords or causeways, it is likely that only a concrete slab or cement bonded stone paving will be suitable. The slab should also have a 2-3% crossfall in the direction of water flow to ensure that the deck drains quickly when overtopped and sand or silt is not deposited on the running surface.

8.4 Cut-off Walls

Cut-off walls, also called curtain walls, should be provided at the edge of a structure. They prevent water eroding the material adjacent to the structure which would eventually cause the structure to collapse. The location of cut-off walls for the various structures is shown in Table 8.6.

Table 8.6: Cut-off wall locations

Structure	Locations
Drift	Upstream and downstream sides of drift slab
Culvert	Edges of inlet and outlet apron
Vented ford	Upstream and downstream sides of main structure and approach ramps
Large bore culvert	Upstream and downstream sides of approach ramps The foundations of the main structure should be built at a greater depth than standard cut-off walls, below the possible scour depth
Bridge	The foundations of the main structure should be built at a greater depth than standard cut-off walls, below the possible scour depth

The absence of cut-off walls at the inlet of the structure could allow water to seep under the apron and structure causing settlement and eventually collapse of the structure. At the downstream end of the structure the flowing water could erode the material next to the apron, eventually eroding under the apron and causing it to collapse. The benefits of a cut-off wall are illustrated in Figure 8.7.

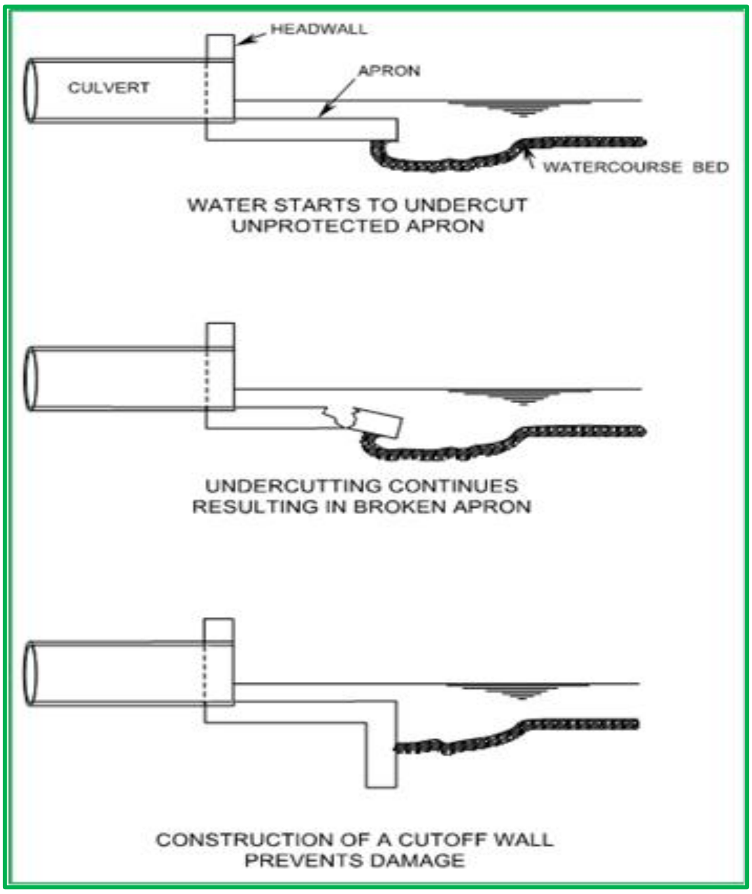


Figure 8.7: Cut-off wall

The depth of the cut-off walls will depend on the ground conditions. Where a rock layer is close to the ground surface the cut-off walls should be built down to this level. If there is no firm stratum near the surface the cut- off walls should extend the minimum dimensions listed in the previous section on scour. The method of construction of the cut-off wall should be similar to the construction method and material used for the remaining parts of the structure to facilitate the construction and reduce cost.

8.5 Pipes

Pipes will be required for culverts and vented fords. This section initially covers the vertical positioning of culverts followed by the sizing of pipes and then other design issues including types of culvert and construction options.

8.5.1 Vertical positioning of pipes

The vertical positioning of culverts requires particular attention. The consideration of the natural vertical alignment of the watercourse must take precedence over the vertical alignment of the road. Neglect of this factor has led to many culverts being installed incorrectly leading to excessive silting, erosion and, in some cases, failure. It should be remembered that the water forces during peak flow will be actively promoting the return to the natural watercourse alignment.

There are three basic culvert installation situations. The most appropriate culvert type will depend on the outfall gradient.

T**ype A:** Flat outfall (less than 5%). This culvert type should be used in flat areas and for watercourses with shallow gradients. In these cases the road should be built up over the culvert with ramps 20-50m long or to comply with national road vertical alignment standards. A culvert will silt up if it is positioned too low to avoid the requirements of building up the road alignment.

Type B: Intermediate outfall (approx. 5 - 10 %).This arrangement requires the culvert to be excavated slightly into the existing ground although the invert of the culvert at the inlet should be at the same level as the bed of the watercourse. The inlet of the culvert will be below the existing ground level and will require an ditch to be dug leading to the inlet with a gradient of approximately 4% or a drop inlet will be required to be provided. The road will still have to be built up with ramps or alignment adjustment over the culvert to provide the minimum required cover.

Type C: Steep outfall (more than 10%). The culvert can be installed without building up the road level. The culvert should be buried to provide adequate cover over the pipe. A drop inlet will be required at the entrance to the pipe and a short outfall ditch at the exit. On steeply sloping ground careful attention should be given to preventing erosion downstream of the culvert. Further information on erosion protection is given in a later section in this chapter.

8.5.2 Pipe sizing

Because of changing climatic conditions, debris and bed load in channels, changing land use patterns, and uncertainties in hydrologic estimates, culvert size and capacity should be conservative and should be oversized rather than undersized. Ideally, a culvert will be of a size as wide as the natural channel to avoid channel constriction. Channel protection, riprap, headwalls, and trash racks can all help mitigate culvert problems, but none are as good as an adequately sized and well placed pipe. An oversized culvert, designed to avoid pipe repairs or failure as well as prevent environmental damage, can be very cost-effective in the long run. Also, the addition of concrete or masonry headwalls helps reduce the likelihood of pipe plugging and failure.

A number of methods are available to assess the required culvert pipe size(s). These are described in the following sub-sections.

The most appropriate method for sizing pipes is to carry out a design based on one of the three cases shown. However, this design process requires data on the culvert catchment area and predicted rainfall intensity. In the absence of other data Figure 8.8 suggests the size and number of pipes that are required to give a suitable culvert capacity for the recommended storm return period. Figure 8.8 is based on gentle/rolling ground with medium soil permeability.

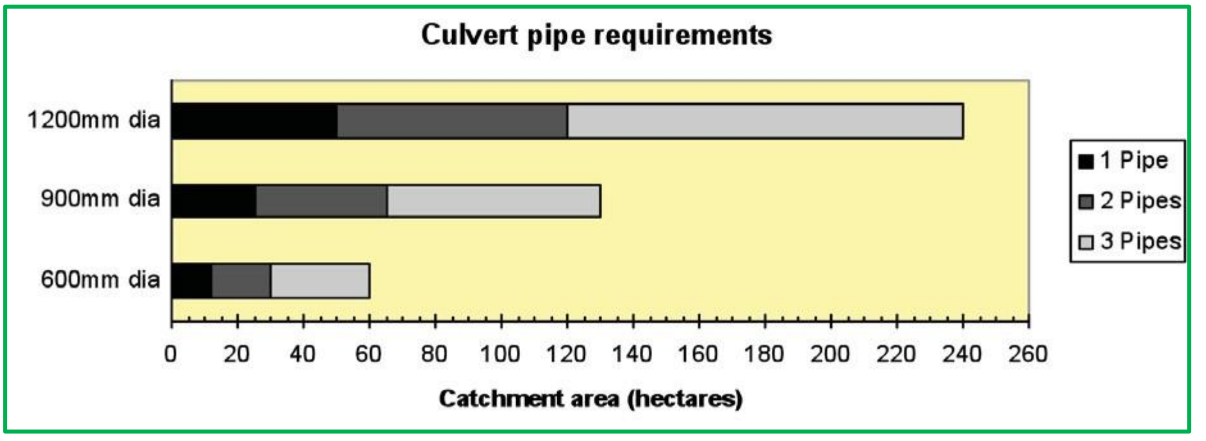


Figure 8.8: Culvert pipe requirements

The design process for sizing pipes will depend on the particular flow characteristics of the water through the pipes. There are three cases, which must be considered as shown in Figure 8.9.

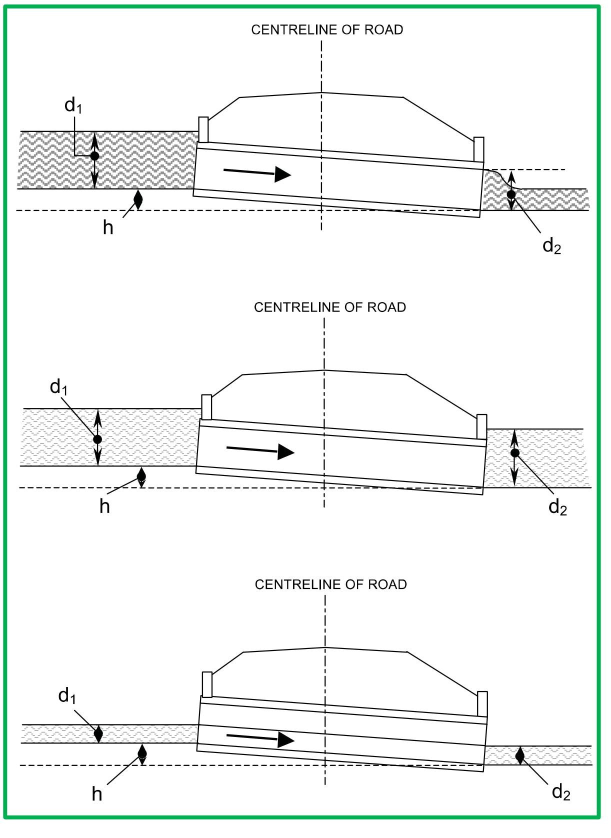


Figure 8.9 Pipe design cases

Proceed with the following steps for the design of the pipe.

Step 1: Peak flood flow

The first stage in culvert pipe design is to estimate the maximum expected peak flood flow which was discussed in Chapter 6, Section 6.1.

Step 2: Check for case 3

If case 3 exists it will not be necessary to carry out any further work because the culvert size is determined by the requirements of minimum diameter for cleaning. Table 8.7 shows the maximum flow rates for assuming case 3 flow exists for a 600mm diameter culvert with an invert on different gradients. For case 3 to exist the flow at the downstream end of the culvert must be uninhibited. This will require the outfall from the culvert to have the same or greater slope than the invert of the culvert.

Table 8.7: Maximum flow rates

Maximum flow rates for 600mm diameter case 3 culverts	
Invert slope	Max flow rate
1%	20 l/s
2%	40 l/s
3%	50 l/s
4%	60 l/s

Case 1
Case 1 has water backed up on the upstream side of the culvert but the water is able to flow freely away from the downstream side of the culvert. This situation is likely to occur on sloping ground where the outfall continues down the hillside.

Case 2
Case 2 has water backed up on both the upstream and downstream sides of the culvert. The flow of water through the culvert is less than in case 1 (for the same size culvert) because the water backed up downstream reduces the flow. This situation will exist in flat areas where the water in the culvert outfall slows or ponds in the channel.

Case 3
Case 3, with no water backed up at either end of the culvert, will only occur for low flow rates and where the water can flow away from the culvert in the downstream channel. If flow rates are low but the outfall slope is shallow the culvert is likely to operate under case 2.

Step 3: Pipe dimensions

In order to design the pipe it will be necessary to guess a pipe size and invert level and gradient. These dimensions will be used for the flow calculations and then compared with the predicted peak flood flow. Through experience the designer will be able to make a good initial guess at the size and/or number of culvert pipes required. For designing a culvert a first guess should be taken as one 600mm pipe. A fall of 3-5% should be placed in the invert to ensure that water flows through the culvert without depositing silt and other debris.

Regardless of the design water flow, all pipes should have a minimum diameter of 600mm to ensure that they can be manually cleaned when clogged

Step 4: Maximum upstream depth

During flood periods, storm water will back up in the upstream channel of the culvert. The amount of back up will depend on the culvert characteristics. The amount of back up permitted should be chosen to ensure that the water does not flood cultivated land and property or overtop the road embankment and culvert headwall. The depth of water due to backing up is measured for the streambed and is shown as d1 in the Figure 8.12.

Step 5: Determine downstream characteristics

It will also be necessary to determine if the water is likely to pond and back up at the downstream end of the pipe. Ponding will depend on the slope of the channel.

Step 6: Driving head

The driving head (the difference between water levels each side of the culvert) is the potential energy, which causes the water to flow through the pipe.

Driving Head = H **H = d1 + h – d2**	Where: H is the driving head d1 is the upstream depth d2 is the downstream water depth h is the drop in invert level as shown in Figure 8.9 above

Step 7: Friction factor

The length and roughness of the pipe will affect the flow rate. The friction factor determined from the graph (in Figure 8.10) is an indication of the resistance to flow due to the pipe's characteristics and is required to calculate the maximum flow in the pipe.

Step 8: Check maximum flow rate

Once the friction factor and head are known the maximum flow rate through the pipe can be obtained from the graphs in Figure 8.11.

Step 9: Check inlet restriction

For higher flow rates the rate of water flow through the culvert will be restricted by the entrance diameter of the culvert. Check the maximum flow rate for the culverts obtained from Figure 8.12 and compare it with the flow rate obtained from step 8.

Step 10: Check acceptable flow rate

The maximum flow rate obtained in either step 8 or 9 should be compared with the maximum predicted flow rate.

Where the maximum flow rate is larger than the predicted flow rate, the culvert design is acceptable. The next design stages for the culvert should be carried out namely selecting appropriate inlet and outlet arrangements and confirming the type of pipe based on the assumptions made in the design steps.

If the maximum flow rate is less than the predicted flow rate the design is unacceptable. If the culvert were to be constructed in this design the floodwater would overtop the road causing it to be washed out, or it would flood adjacent fields and properties. The design process must be carried out again from step 3 making one of the following changes:

- Adding another pipe of the same diameter;
- Increasing the size of the pipe.

Nomogram method

Pipe size as a function of anticipated design flow (capacity) and headwater depth can be determined using the Nomograms shown in Figures 8.13, 8.14 and 8.15. These figures apply to commonly used culverts of round corrugated metal pipe, round concrete pipe, and concrete boxes. Each of these figures applies to pipes with inlet control where there is no constraint on the downstream elevation of the water exiting the structure. In these circumstances the culvert acts as an orifice and the capacity can be determined in a relatively simple manner on the basis of headwater height and inlet geometry (barrel shape, cross- sectional area and the inlet edge). Barrel slope affects the inlet control performance to a small degree but may be neglected. Ideally, the inlet water elevation (headwater depth) should not greatly exceed the height or diameter of the structure in order to prevent saturation of the fill and minimise the likelihood of the pipe plugging from floating debris.

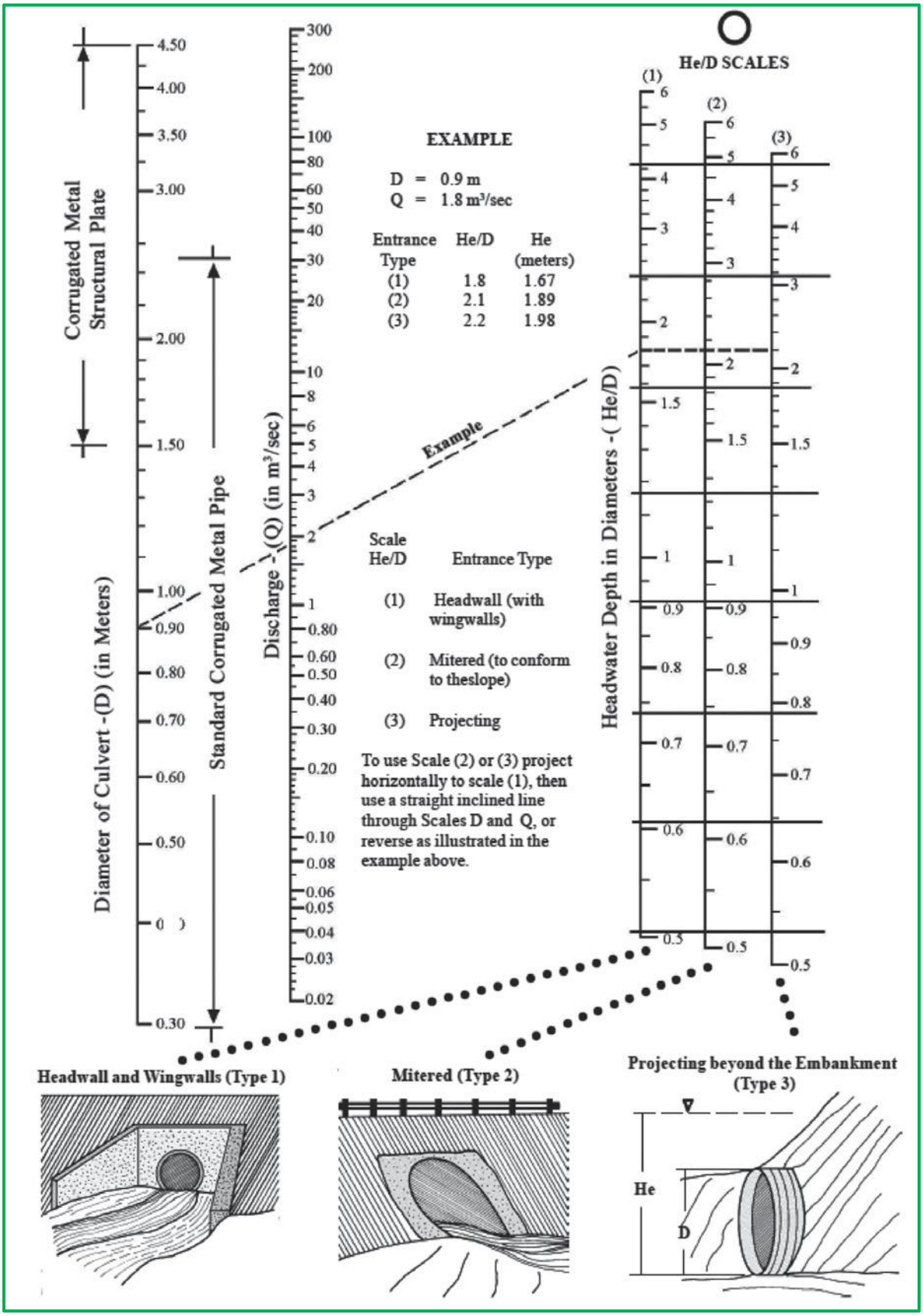


Figure 8.13: Headwater depth and capacity for corrugated metal pipe culverts with inlet control (Adapted from FHWA 1998)

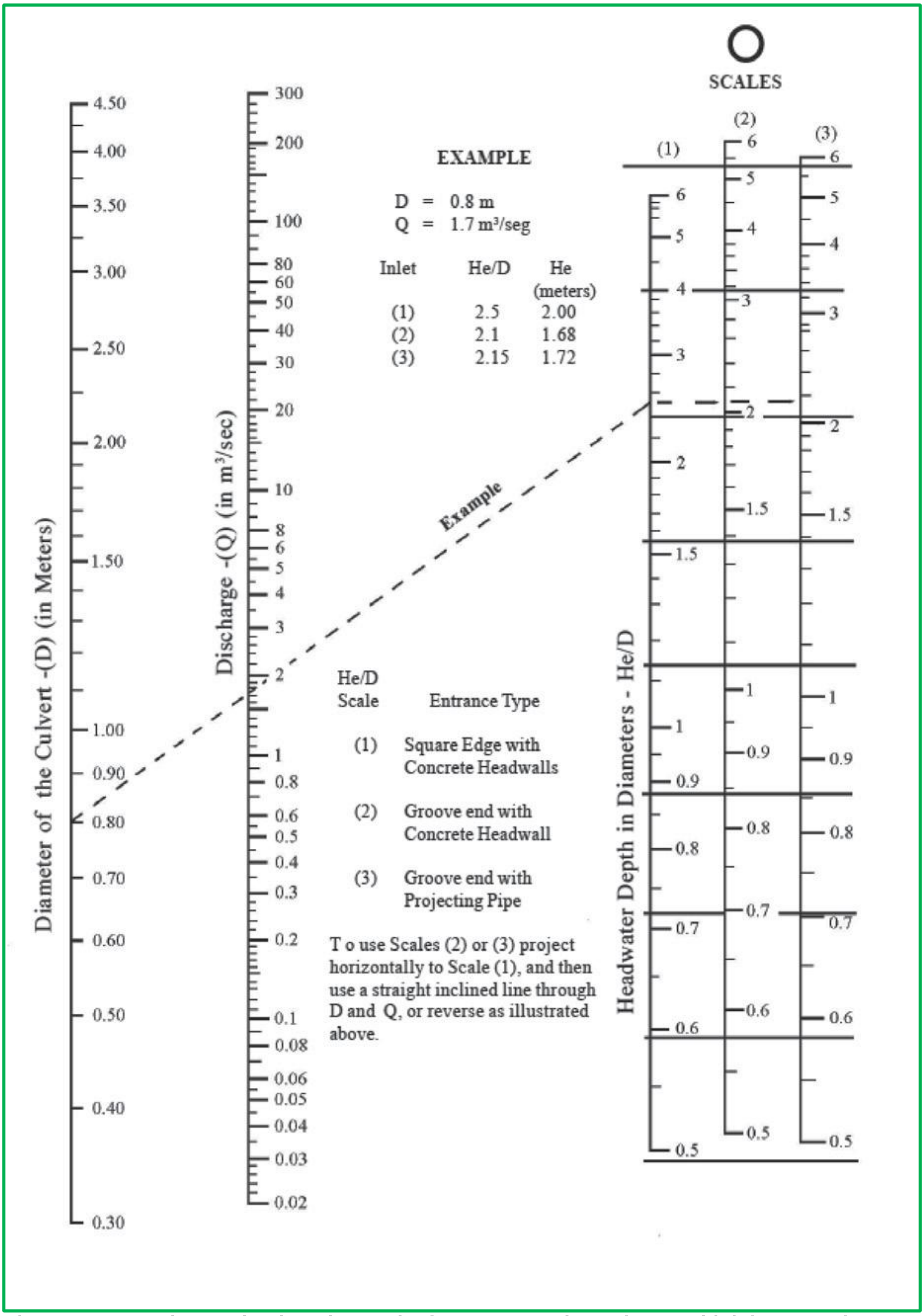


Figure 8.14: Headwater depth and capacity for concrete pipe culverts with inlet control. (Adapted from FHWA, 1998)

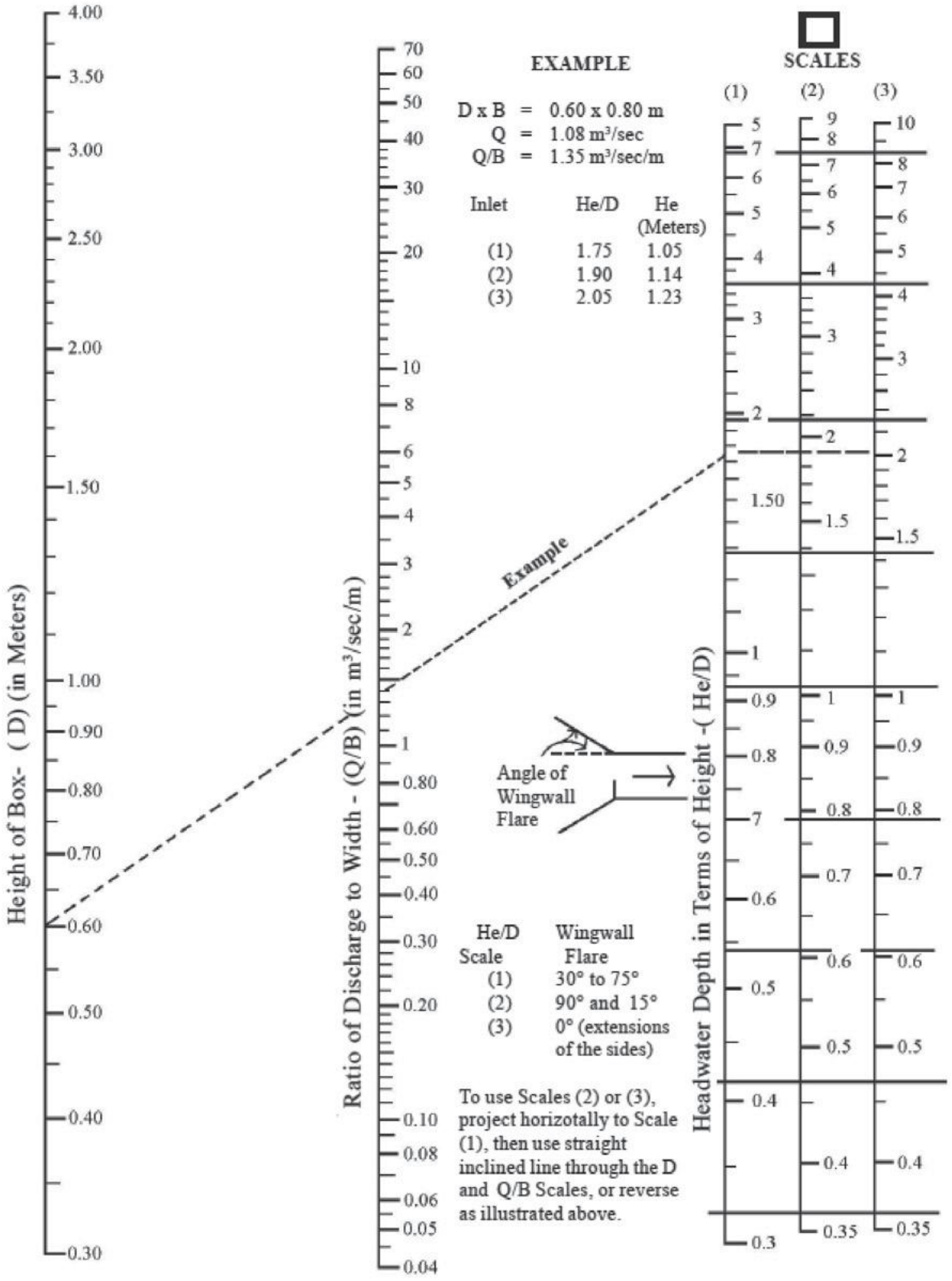


Figure 8.15: Headwater depth and capacity for concrete box culverts with inlet control. (Adapted from FHWA, 1998)

Simplified formulae method

The use of formulae (Table 8.8) is preferred by some designers to the use of the Nomograms shown above. The formulae are based on the following assumptions:

- Inlet Control;
- Wingwall Angle = 45^0;
- Vertical Headwall.

Table 8.8: Simplified Formulae for calculation of discharge capacity

Type	Discharge Capacity Q (m^3/s) (with inlet control)		
	Hw/D=1.00	**Hw/D=1.25**	**Hw/D=1.50**
Concrete Pipe	1.3 x D2.5	1.9 x D2.5	2.2 x D2.5
Corrugated Metal Pipe	1.1 x D2.5	1.6 x D2.5	1.8 x D2.5
Arch Culvert (semi-circular)	2.3 x H2.5	3.4 x H2.5	4.0 x H2.5
Box Culvert	1.5 x B x H1.5	2.1 x B x H1.5	2.5 x B x H1.5
D: diameter of a pipe culvert (m)		B: width of a box culvert (m)	
Hw: headwater height (m)		H: height of a box/arch culvert (m)	

Tables for the hydraulic design of pipes sewers and channels Volumes I & II, 7th edition, published by HR Wallingford (UK), may also be used where different conditions exist, or greater accuracy is needed. More detailed information can also be found in FHWA Manual HDS-5, Hydraulic Design of Highway Culverts, 1998.

8.5.3 Pipe options

There are many different options available to the designer for constructing culvert pipes.

Precast pipes

Precast pipes are usually manufactured in a central yard and are then transported to site. This method of construction has the advantage that the quality control for the construction of the pipe is likely to be improved, but the two main disadvantages are the increased transportation costs (as illustrated in Figure 8.16) in bringing the pipes to site and the careful transportation and handling required to ensure the pipes are not damaged.

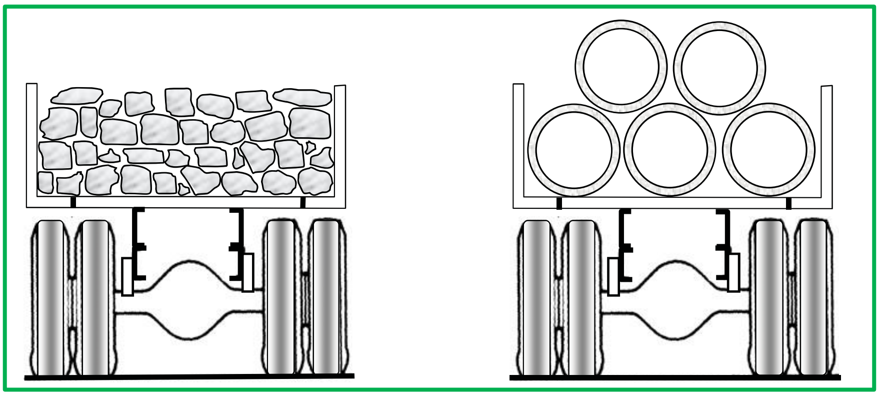


Figure 8.16: Transportation issues

Concrete pipes should preferably be transported on end on a bed of sand, to minimise the risk of damage. Particular care is required in laying and jointing the pipes to ensure good support to the lower third of the pipe circumference.

In situ construction

Pipes constructed in situ can be made from a variety of materials. Careful supervision will be required on site to ensure that the pipes are manufactured to sufficient quality but the transportation costs may be reduced when compared with precast pipes if their transport distances are substantial.

Masonry culverts (arch and box)

Masonry culverts are generally constructed as box culverts for small sizes and arch culverts for larger sizes (Figure 8.17). There are three stages to constructing a wall and slab box culvert:

- Excavation and construction of the base;
- Construction of the walls;
- Laying the roof slab and backfilling the culvert.

The culverts can be constructed with different top slabs depending on the size of the culvert. These slabs may be masonry, timber or precast concrete. The advantages and disadvantages of masonry culverts are shown in Table 8.9.

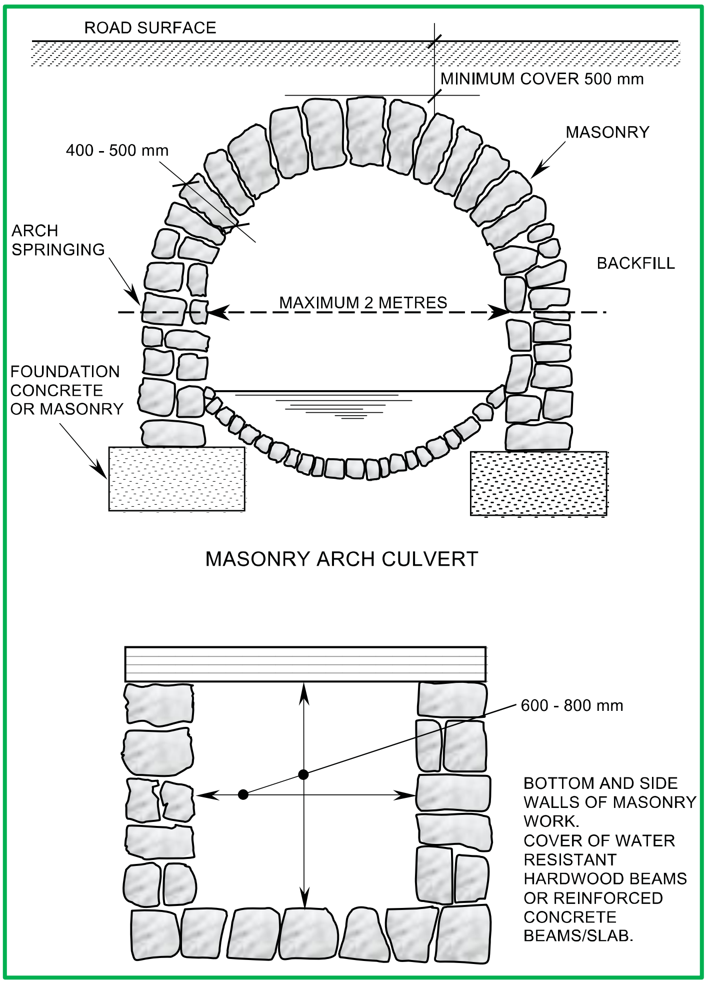


Figure 8.17: Masonry culverts

Table 8.9: Masonry culverts

Advantages	Disadvantages
• The use of locally available material reduces the cost of construction • Simplicity of construction • Low level of maintenance required • Range of options available for the top slab on box culverts	• Arched culverts require dressed stone bricks, blocks or mortared jointing

Concrete arch or box culverts

These can be constructed using the same principles as masonry culverts. Spans larger than 800mm will require reinforcement design and detailing.

Timber Culverts

Option 1: Timber barrel

Timber barrel culverts are typically manufactured from shaped, treated wooden planks with tongue and groove joints held in position by steel bands or wire. Once the culvert is in place and backfilled, the steel bands are no longer required because the ground material holds the pieces of the culvert in position. The bands can therefore rust away after the culvert has been placed without the culvert collapsing. The advantages and disadvantages of these types of culverts are shown in Table 8.10.

Table 8.10: Timber barrel culverts

Advantages	Disadvantages
• Can provide cheap culvert if timber widely available; • Culverts can be assembled at site allowing larger numbers to be transported on a lorry; • Design life is over 25 years with treated wood; • They are light and easy to handle; • Culverts can withstand small ground movements and settlement without losing their structural integrity; • Short working life if wood is badly treated.	• Professional wood treatment facilities required.

Option 2: Timber log culverts

A simple and quick method for constructing small relief culverts can be to use timber logs (see Figure 8.18). These culverts will usually be unlined, bare earth and will only accommodate slow flows (up to 1 m/s). Figure 8.15 shows the key dimensional requirements for these types of culvert. This type of construction should only be viewed as a temporary culvert unless the timber is properly treated. It can be a useful construction method for emergency maintenance during the rainy season.

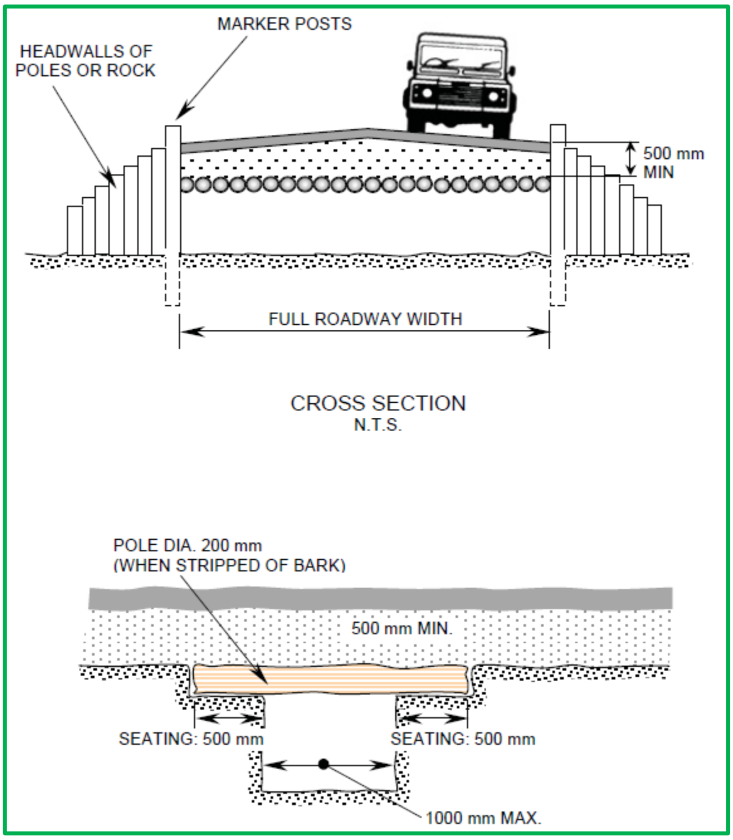


Figure 8.18. Timber log culvert details

Table 8.11: Timber log culverts

Advantages	Disadvantages
• Very quick and cheap to construct; • Minimal skills required for construction.	• Very short life, especially if timber is untreated; • Unlined ditch very susceptible to scour during heavy rains.

Cast in-situ concrete culverts

These culverts use a timber or steel mould to form the pipe of the culvert. A rubble concrete mixture is used to form the foundation of the pipe. The mould is then placed in position and lean mix concrete poured around the culvert mould. Once the concrete has set the mould is collapsed and removed. The advantages and disadvantages of a in-situ cast culvert are given in Table 8.12.

Table 8.12: Cast in-situ concrete culverts

Advantages	Disadvantages
• Low cost as mould can be reused many times; • Quick construction methods; • Low cement requirements due to use of rubble concrete.	• Poor life expectancy if rubble concrete is not well placed or compacted.

Precast unreinforced concrete culverts

These culverts are usually manufactured in a casting yard and brought to site in units. They need to be manufactured under conditions of good quality control to ensure that they have sufficient strength. This option is only worth considering for high production numbers where a large number of culverts will be constructed in the same area. The advantages and disadvantages are shown in Table 8.13.

Table 8.13: Precast unreinforced concrete culverts

Advantages	Disadvantages
• The quality of the pipe can be ensured; • Do not require steel reinforcement; • Very good performance when bedding and back filling has been carried out well; • Pipes up to 900mm dia. can be man handled by labour alone; • Economic where a large number of identical pipes are required.	• High cost for small batches; • Careful transportation required to ensure they are not damaged or broken; • Not suitable if site access route is in bad condition; • High transport costs due to their shape • Diameters greater than 900mm dia. cannot be made due to strength and handling problems; • Pipe lengths are restricted to 1m to ensure that they can be handled by labour alone.

Steel culverts

Steel culverts will usually be constructed from pre-bent corrugated sheets, which are bolted together on site. They can be very expensive if a steel manufacturing capability is not available locally in country. Imported steel culverts consume scarce foreign exchange resources. Their advantages and disadvantages are shown in Table 8.14.

Table 8.14: Steel culverts

Advantages	Disadvantages
• The steel culverts can withstand small ground movements; • Light sections are easy to handle and install; • The components for a number of culverts can be transported on one truck.	• Requires the transport and possible import of expensive steel sheets; • Secure storage of the sheets required to prevent theft; • Particularly susceptible to early failure on unpaved roads without a rigorous maintenance regime that will ensure minimum cover to the steel pipe is maintained.

8.5.4 Pipe inlets

The general design of headwalls and wingwalls is discussed elsewhere in this Chapter. However, there are two design cases of pipe inlets that require special attention:

- Pipes on steep slopes;

- Pipes, which are transferring large volumes of storm water from a side drain to the other side of the road.

Pipes on steep slopes

If the culvert is located on steeply sloping ground the overall height drop across the culvert may need to be much steeper than 5%. If this case occurs the culvert should be designed for the maximum desirable invert slope (5%) and a drop inlet used to achieve this. This will reduce the energy of the water leaving the culvert thereby preventing extensive scour. Drop inlets can also be used for relief culverts on long downhill lengths of side drain (see Figure 8.19).

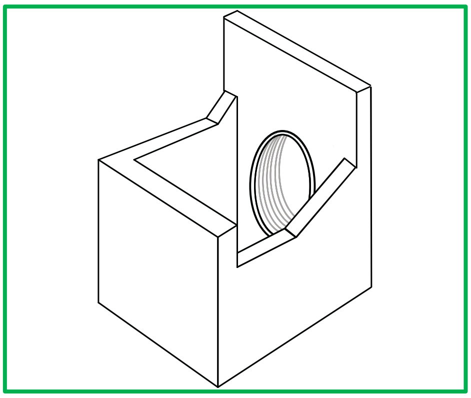


Figure 8.19: Drop inlet on relief culvert

Pipes transferring large water volumes

One of the most important design rules when constructing a road water structure is to disrupt the flow as little as possible. Unfortunately this will usually not be possible for a culvert that is transferring water from a side drain to the opposite side of the road. The water must make an abrupt right angle change in direction to enter the culvert. For large flows there will therefore be a large amount of turbulence in the water and the potential for scour will be high. Figure 8.20 indicates the following key features in the inlet design for large flows:

- Rounded wingwalls to 'guide' water into pipe;
- Sloping wingwall on inside radius;
- Lined channel sides and base which extend 5m up the channel;
- Cut-off wall provided at the edge of the inlet;

Consider a box culvert option because this will cause less restriction and turbulence.

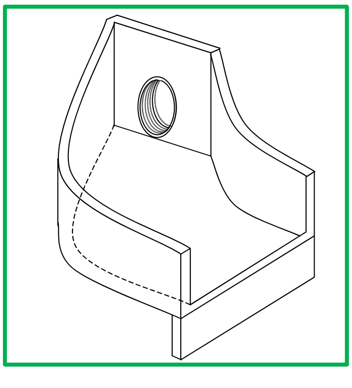


Figure 8.20: L-shaped inlet

8.5.5 Pipe bedding and cover arrangements

If the culvert is constructed from precast units it will be necessary to place a bedding material, such as sand, on the foundation to remove any irregularities and ensure an even support to the base of the precast units. The support for the pipe should be either 250mm of compacted crushed stone, granular material (with a maximum stone size of 30mm) or 150mm concrete slab (see Figure 8.21). If the preferred design option is a masonry culvert the foundation for the walls can be extended to form the base of the culvert.

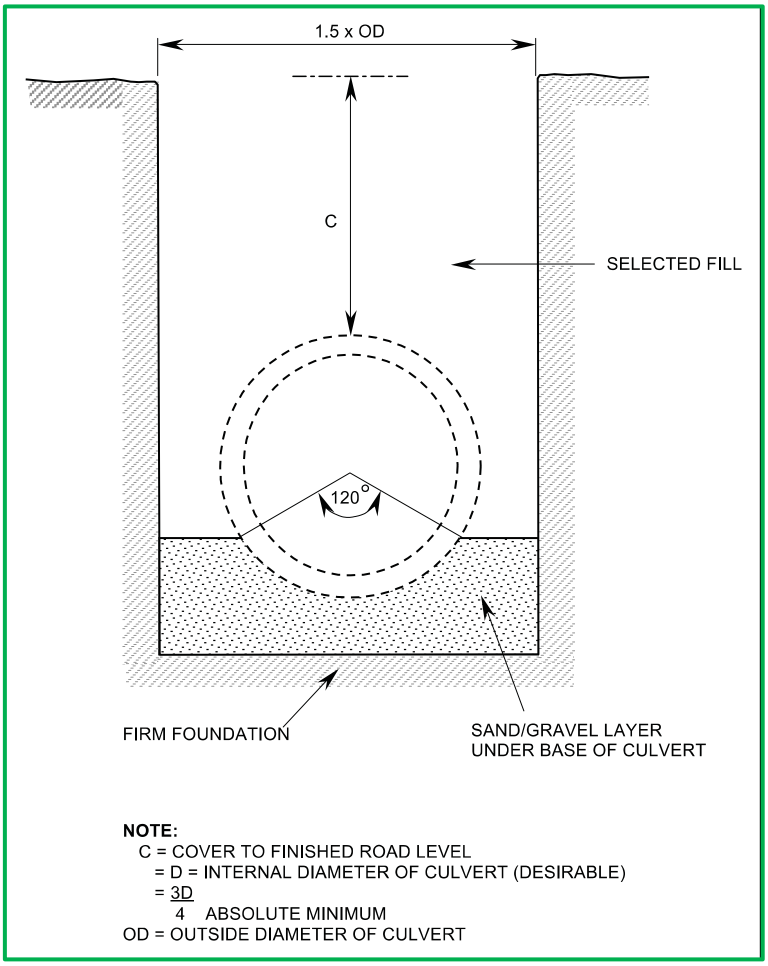


Figure 8.21: Pipe, granular bedding and cover

Backfilling around the culvert is one of the most important stages in the construction (Plate 11). The quality of the backfilling will determine the strength of a culvert to resist vehicle loads above it. The designer should specify the material to be used to backfill around the culvert which should be easy to compact and well graded to promote drainage. Stones larger than 30mm should not be included in the backfill as they may damage the culvert. The excavated material from the culvert construction may be used for backfilling if it meets these criteria.

As material is backfilled around the culvert it should be well compacted in layers of 150mm. Particular care should be taken for the lower half of the pipe to ensure:

- The material under the pipe is compacted with hand rammers;
- Hand rammers do not damage the culvert;
- The pipe is held at the correct level and does not ‘rise’;
- Each side of the culvert is backfilled at the same rate to ensure that the culvert is not pushed out of line.

The minimum desirable cover from the top of a culvert to the road surface should be the same as the diameter of the culvert. If the conditions do not permit this depth of cover it may be reduced to 75% of the pipe diameter.

The cover can be reduced to half the culvert's diameter if the concrete bed, haunch and surround are cast as shown in Figure 8.22. The remaining cover should be good quality standard fill material and the road should be surfaced with gravel or other material as appropriate.

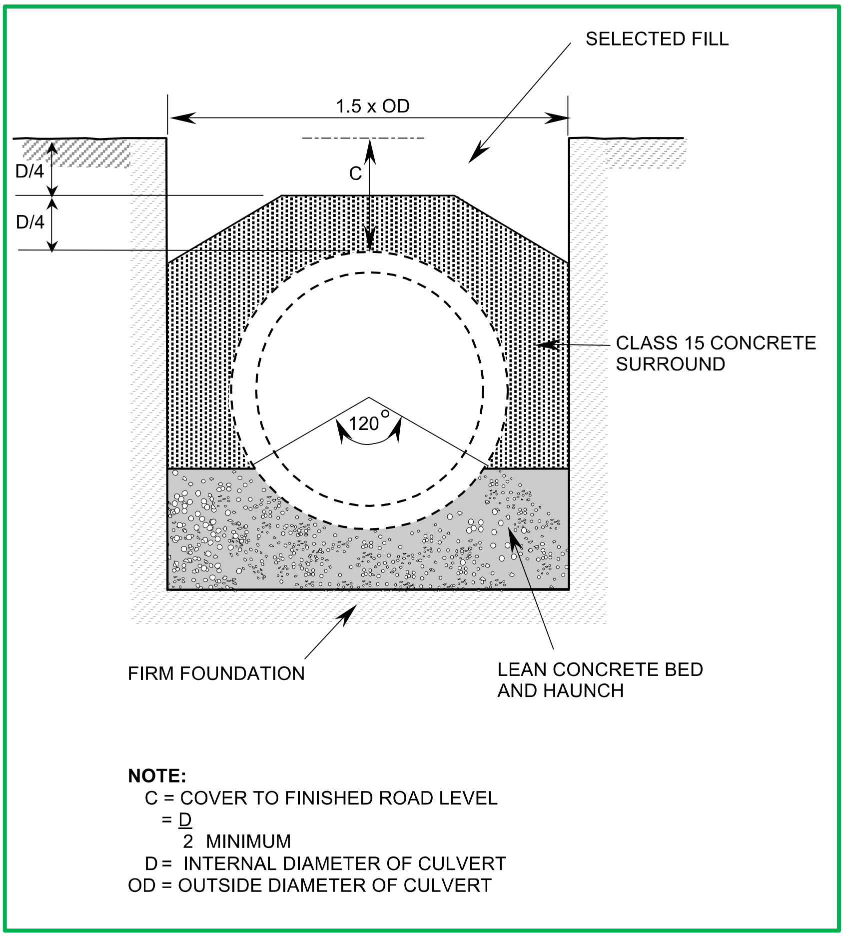


Figure 8.22: Pipe arrangement with minimum cover

8.5.6 Multiple culverts and vented fords

The design principles for multiple culverts and vented fords are the same as single bore culverts. Where more than one pipe is to be installed the minimum space between the centreline of adjacent pipes should be at least 2 pipe diameters. Where space restrictions require the installation of pipes at closer spacing, the factors in Table 8.15 should be used to reduce the flow rates through the pipes derived previously in this chapter.

Table 8.15: Pipe spacing and flow reduction factors

Spacing between pipe centres	Flow reduction factor
More than 2.0 pipe diameters	1.0
1.5 - 2.0 pipe diameters	0.9
Less than 1.5 pipe diameters	Due to difficulties in ensuring adequate compaction under and between pipes, bedding of lean concrete should be used in these circumstances.

The flow capacity of different culvert shapes and diameters should be checked according to the characteristics of the site. The number and size of pipes should then be chosen to ensure that the sum of all the individual pipe flows is greater than the design flow.

The design flow for a multi-bore culvert should be taken to be the maximum flood flow. As vented fords are designed to be overtopped during peak flows the pipes should be designed to pass the normal flow and small floods. Overtopping will only occur for the higher flow rates and the designer will have to decide what level of flow the pipes will pass before overtopping occurs. The overtopping flow will depend on the duration, size and regularity of high flows and the total number of pipes that can be fitted into the structure.

This Manual does not cover the design of box culvert options. For these refer to the current MRB Bridge Design Manual and publications such as TRL Overseas Road Note 9.

8.6 Headwalls and Wingwalls

8.6.1 Culverts

Headwalls and small wingwalls are required at each end of a culvert and serve a number of different purposes:

- They direct the water in or out of the culvert;
- They retain the soil around the culvert openings;
- They prevent erosion near the culvert and seepage around the pipe, which causes settlement.

The headwall can be positioned at different places in the road verge or embankment as shown in Figure 8.23.

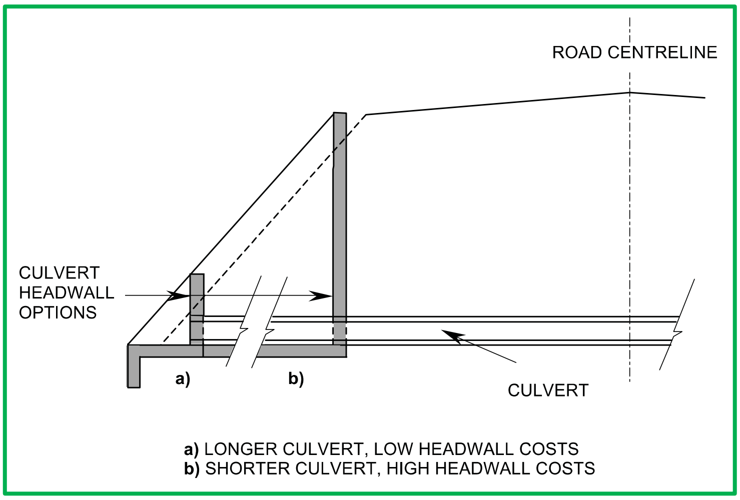


Figure 8.23: Possible culvert headwall positions

The closer the headwall is placed to the road on an embankment the larger and more expensive it will be. The most economical solution for headwall design will be to make it as small as possible. Although a small headwall will require a longer culvert, the overall cost of the structure will normally be smaller. If, due to special circumstances at a proposed culvert site, a large headwall with wingwalls is required, it should be designed as a bridge wingwall.

Where a road is not on an embankment the size of the headwall will be small regardless of position. In this case the position of the headwalls will be determined by the road width and any requirements of national standards. The headwalls should be positioned at least 1 metre beyond the edge of the carriageway width to prevent a restriction in the road and reduce the possibility of vehicle collisions (see Figure 8.24).

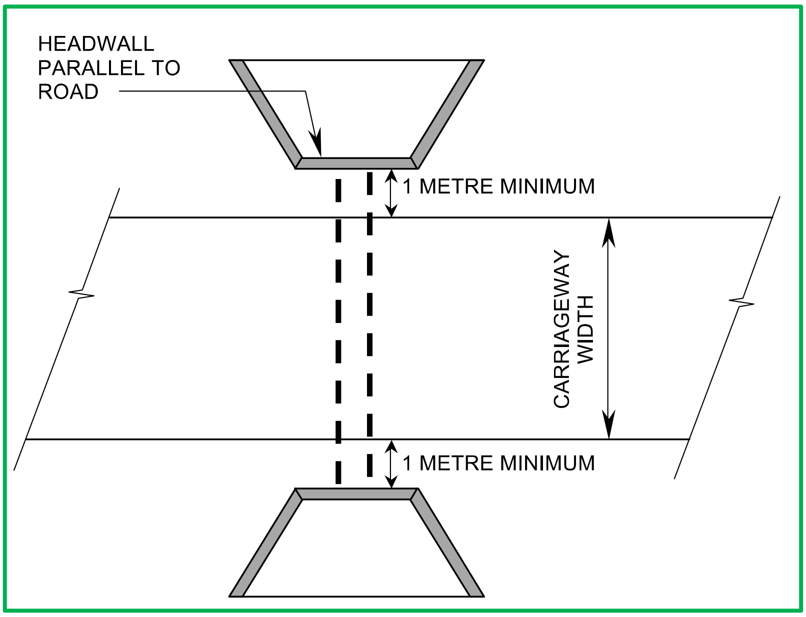
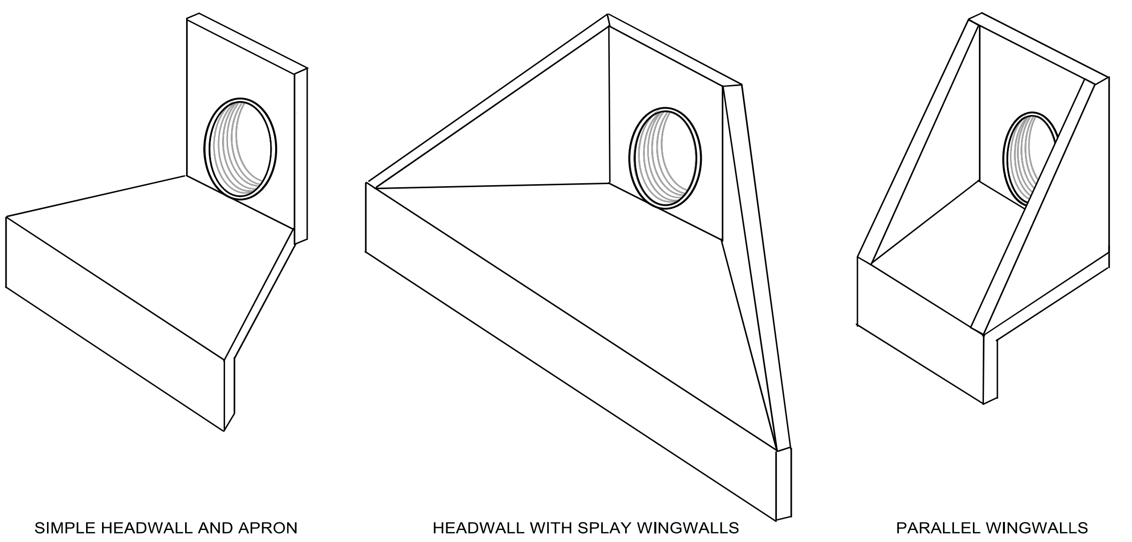


Figure 8.24: Position of culvert headwalls

Headwalls should project above the road surface by 300mm and be painted white so that they are visible to drivers. There are a number of different layout options for culvert headwalls which are shown in Figure 8.25.



This arrangement can be used for simple low flow relief culverts. It is the cheapest option but prone to erosion for larger flows.	This arrangement should be used for larger flows instead of the simple arrangement. The wingwalls increase the protection from erosion.	Where the road is on an embankment it is essential that wingwalls be provided to prevent the risk of water seepage and subsidence of the embankment. This arrangement is likely to be the most economical.

Figure 8.25: Headwall and wingwall arrangements

Headwall with drop inlet: This arrangement should be used when the road is on a steep side slope to reduce the invert slope of the culvert (see Section 8.5.4).

Headwall with L inlet: This arrangement should be used where the road is on a gradient and water is to be transferred from the carriageway side drain on the high side of the road (see previous pipe inlets section 8.16.4).

Headwall and adjacent works must be designed so that the culverts can be de-silted manually under maintenance arrangements. This can be difficult with a drop inlet arrangement.

8.6.2 Wingwalls - Larger structures

Wingwalls are used to retain the soil behind the abutments of bridges, to help guide flows through the structure in flood conditions, and to safely retain the backfill material without risk of erosion. There are two basic reference layouts for wingwalls, either parallel to the road or parallel to the watercourse (see Table 8.16). However, wingwalls are usually constructed at an angle between these two arrangements. Wingwalls should always be constructed to the toe (bottom) of the slope and not part way down. Wingwalls that do not extend to the bottom of the slope are likely to suffer from erosion around the ends.

Table 8.16: Wingwalls

Wingwalls parallel to water course	Wingwalls parallel to road
Foundations on same level.	Foundations can be stepped but are harder to construct.
Wall more susceptible to erosion from watercourse.	Wall mostly away from watercourse.
Wall size smaller than wall parallel to road.	Wall size longer than wall parallel to watercourse.
Larger amount of fill to be moved, placed and compacted.	Reduced amount of fill required to be moved, placed and compacted

The relative availability and cost of fill material and raw materials to construct the wingwalls will determine the most appropriate arrangement. In general, to ensure the cheapest option, the design should ensure the smallest wingwalls are chosen for the structure and its particular location. Where wingwalls are chosen that run parallel to the road it is necessary to take suitable measures to prevent water in the carriageway side drains causing erosion around the wall at their outfall. This usually requires a lined channel or cascade at the base of the wingwall. The two main factors affecting the overall design of a wingwall are the construction material and the bearing capacity of the soil.

8.6.3 Stone, brick and blockwork walls

Stone, brick and blockwork walls should be built with a tapering back face to withstand the pressure exerted by the fill material (see Figure 8.26). The size of the wall will depend on its height, the bearing capacity of the soil, and if there is any surcharge (additional fill material above the wall). Any material used in the wall should meet the requirements of Chapter 7.

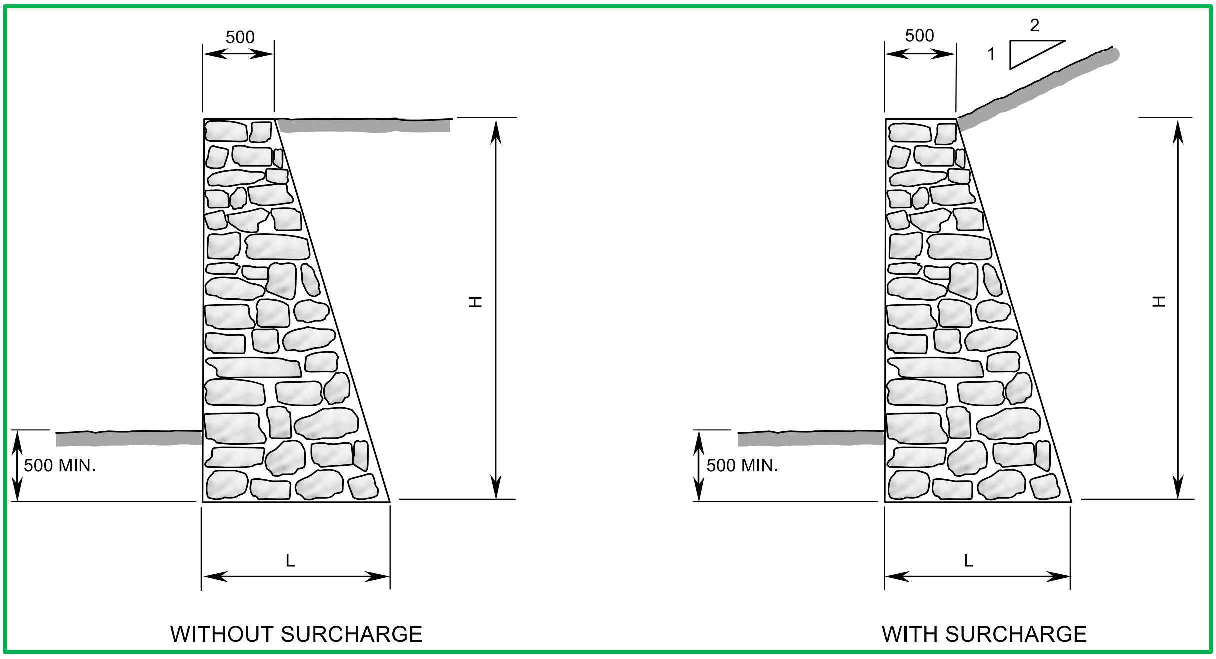


Figure 8.26: Stone, brick or blockwork wall with and without sloping backfill (surcharge*)*

Tables 8.17 and 8.18 provide a guide to the height of the wingwall with and without surcharge related to the bearing capacity of the soil and the width of the base.

Table 8.17: Height of wingwall without surcharge

H- Height of wingwall (without surcharge)	Bearing capacity of the soil		
	Low (75-125kPa)	Medium (125-250kPa)	High (>250kPa)
	L - Width of the base (mm)		
1000	500	500	500
1500	900	800	800
2000	1700	1150	1150
2500	*Construction not possible without ground improvement	1450	1450
3000		1750	1750
3500		2400	2000
4000		3200	2300
4500		4200	2600

Notes:

* Ground improvement increases the bearing capacity of the soil through the addition of other materials to the ground eg gravel or cement – this is outside the scope of this Manual.

Where wingwalls are constructed on medium or high bearing capacity soil, parallel to the road, and are only used to retain road fill material to a height of up to 3 metres the wall may be constructed as follows:

1. Top of the wall to be 500mm wide

2. Vertical front face and 1:4 sloping back face (1 horizontal: 4 vertical)

Table 8.18: Height of wingwall with surcharge

H- Height of wingwall (with surcharge)	Bearing capacity of the soil		
	Low (75-125kPa)	Medium (125-250kPa)	High (>250kPa)
	L- Width of the base (mm)		
1000	1000	950	950
1500	1500	1200	1200
2000	2000	1450	1450
2500	*Construction not possible without ground improvement	1750	1750
3000		2350	2000
3500		3200	2250
4000		4200	2550

Notes:

* Ground improvement increases the bearing capacity of the soil through the addition of other materials to the ground e.g. gravel or cement – this is outside the scope of this Manual.

Where wingwalls are constructed on medium or high bearing capacity soil parallel to the road and are only used to retain road fill material to a height of up to 3 metres, the wall may be constructed as follows:

1. Top of the wall to be 500mm wide
2. Vertical front face and 1:4 sloping back face (1 horizontal: 4 vertical)

8.6.4 Gabion baskets

Gabion baskets may be used in areas where stones are available (Figure 8.27).

In some areas there may be a problem of persons removing wire from the gabion baskets for other construction purposes. If consultations through community groups cannot resolve this problem then more robust steel mesh gabions may need to be considered.

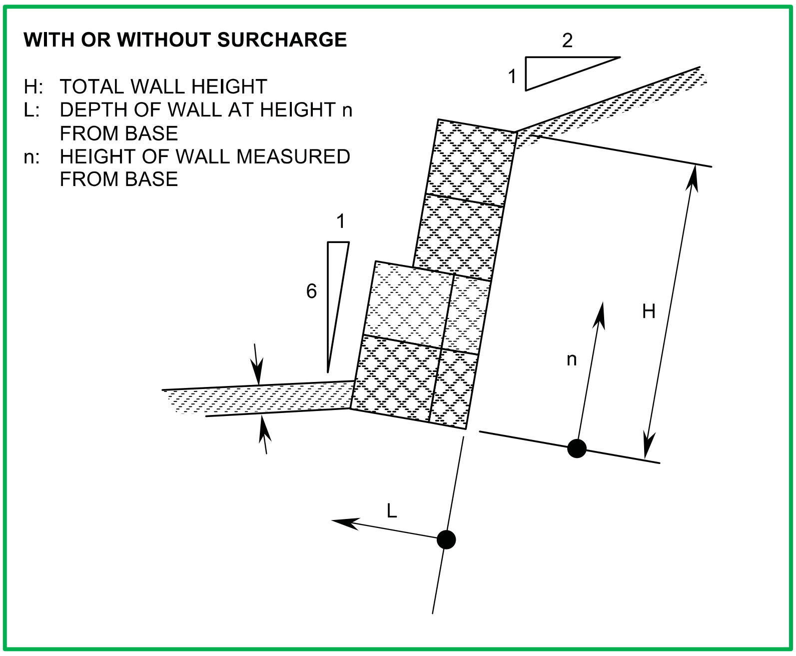


Figure 8.27: Gabion baskets for walls

Table 8.19 assumes that the gabion baskets have been filled according to the criteria outlined in Chapter 7 and have a height and width of 1 metre.

Table 8.19: Height and width of gabion walls

Bearing capacity of soil	**Height of wall (m)**	**Width of gabion wall at height 'n' above base**								
		0	0.5	1	1.5	2	2.5	3	3.5	4
50 - 125 kPa	1.5	1	1	1	1					
	2	1	1	1	1	1				
	2.5	1.5	1.5	1.5	1	1	1			
	3	1.5	1.5	1.5	1.5	1	1	1		
	3.5	2	2	2	1.5	1.5	1	1	1	
>125 kPa	1.5	1	1	1	1					
	2	1	1	1	1	1				
	2.5	1	1	1	1	1	1			
	3	1.5	1.5	1	1	1	1	1		
	3.5	1.5	1.5	1.5	1	1	1	1	1	
	4	2	2	1.5	1.5	1.5	1.5	1	1	1

8.6.5 Timber walls

Felled timber tree trunks as described in Section 7.3 can be used to form a wingwall.

8.7 Aprons

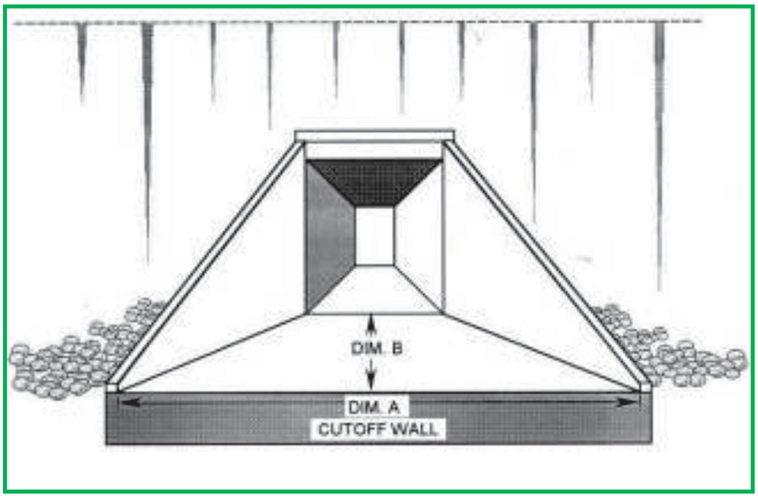
An apron is required at the inlet and outlet of culverts and downstream of drifts and vented fords to prevent erosion. As the water flows out of or off a structure it will tend to erode the watercourse downstream causing undercutting of the structure. Refer to the section on cut-off walls earlier in this Chapter. Aprons should be constructed from a material which is less susceptible to erosion than the natural material in the streambed.

8.7.1 Drift aprons

Where the discharge velocity across the drift is less than 1.2m/s, which may be experienced for relief drifts, a coarse gravel layer (10mm) will provide sufficient protection downstream of the drift. For discharge velocities greater than 1.2m/s more substantial protection will be required using larger stones. This is discussed in the section on downstream protection. The width of the apron should be at least half the width of the drift and extend across the watercourse for the whole length of the drift.

8.7.2 Culvert aprons

Aprons should be provided at both the inlet and outlet of culverts (see Figure 8.28). They should extend the full width between the headwall and any wingwalls. If the culvert does not have wingwalls the apron should be twice the width of the culvert pipe diameter. The apron should also extend a minimum of 1.5 times the culvert diameter beyond the end of the pipe. Cut-off walls should also be provided at the edge of all apron slabs. The choice of apron construction is likely to depend on the type of material used for construction of the culvert. It may be constructed from gabion baskets, cemented masonry or concrete.



Dim A – Distance between wingwalls or 2 x culvert dia. for culvert without wingwalls,

Dim B – 2x culvert dia.

Figure 8.28: Culvert apron

8.7.3 Vented ford aprons

The apron for vented fords should extend the whole length of the structure including downstream of the approach ramps to the maximum design level flood. The other design requirements for vented ford aprons are the same as culvert aprons.

8.8 Approach Ramps

Ideally crossings should not have approaches steeper than 10% (See Section 4.3.1).However, steeper approaches can be provided if governed by the local terrain. Approaches steeper than 10% will require the running surface to have a thin concrete or cement bound masonry slab to allow vehicles to maintain traction particularly during wet periods. The slab should be at least 150mm thick and be constructed on a sand or compacted masonry/aggregate base.

The approach way is subjected to similar erosion characteristics as the main structure. It is therefore necessary to surface the approach ways with the same material as the main structure, at least to the height of the maximum flood level, to ensure damage does not occur. If the structure is designed to be overtopped the approach ways must be constructed higher than the maximum flood level to ensure that the water does not erode around the ends of the structure leaving it inaccessible.

It is also necessary to provide cut-off walls (Section 8.4) along the sides of the approach ways to protect against scour. The sides of the approach ways should be faced to ensure erosion does not occur. They may be constructed from:

- Masonry walls (most appropriate for higher walls);
- Gabion baskets;
- Concrete walls (for low walls up to 0.5 metre);
- Timber logs (high maintenance required).

The design of these walls will be similar to the design of wingwalls described in Section 8.6. The fill material in the approach way should be chosen from one of the three options shown in Table 8.20.

Table 8.20: Fill material in the approach way

Well compacted sand and gravel	Rubble masonry	Lean concrete mix with plums
Sand and gravel may be readily available in the watercourse around the crossing site. These may be stockpiled during the initial stages of construction by labour. The material to be used as a fill should be well graded and placed in 100mm layers which are well compacted before subsequent layers are placed.	If a well-graded mix of sand and gravel is not available it may be more economic to use rubble masonry rather than breaking rocks to create a well graded material. Broken man-made bricks can be used in addition to, or instead of, natural stone provided they meet the requirements outlined in chapter 7. Rubble masonry should be bound together with a 1:8 cement-sand mortar.	A concrete mix of 1:4:8 (cement, sand and aggregate) can be used with large plums up to 200mm in size. This option will have the highest cement requirement, and hence cost. However, it may be the most beneficial fill option if there are small quantities of sand, aggregate and large stone near the bridge site.

The running surface of the approach way should be designed as a structural slab of either concrete or cement bonded stone paving. The slab should also have a 2-3% crossfall in the direction of water flow to ensure that the deck drains quickly after rainfall.

Approach ways will be susceptible to scour from water flowing from the carriageway side drains into the watercourse due to the increased slope. A lined channel should therefore be provided at the edge of the approach way to ensure that erosion does not occur. The approach ways (see Figure 8.29) should be constructed separately from the main structure to allow for thermal expansion of the structure and slight ground movements, particularly for the structural slab. If they were constructed integrally with the main structure, any slight settlement or thermal effects could cause cracks in the structure which would weaken it against damage from water. The approach ways therefore require an end wall and cut-off wall next to the main structure. The gap between the two structures should be very small (no greater than 10mm). The edges of the approach ways should be marked.

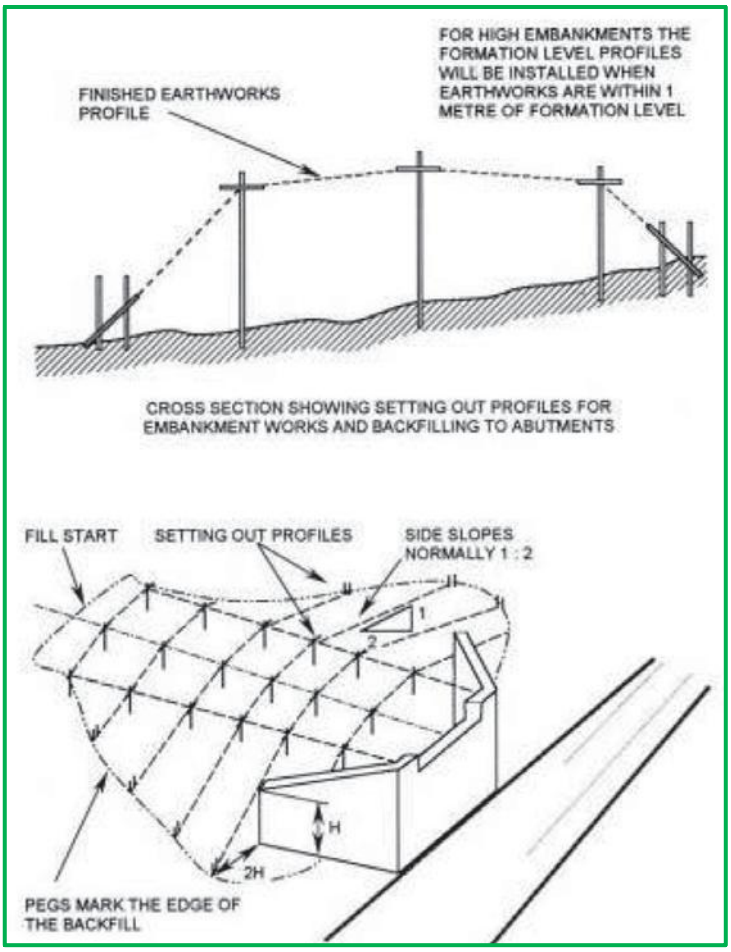


Figure 8.29: Construction of approach ways

Figure 8.30 shows an example of an approach way cross-section with guide/kerb stones to show drivers the location of the edge of the carriageway.

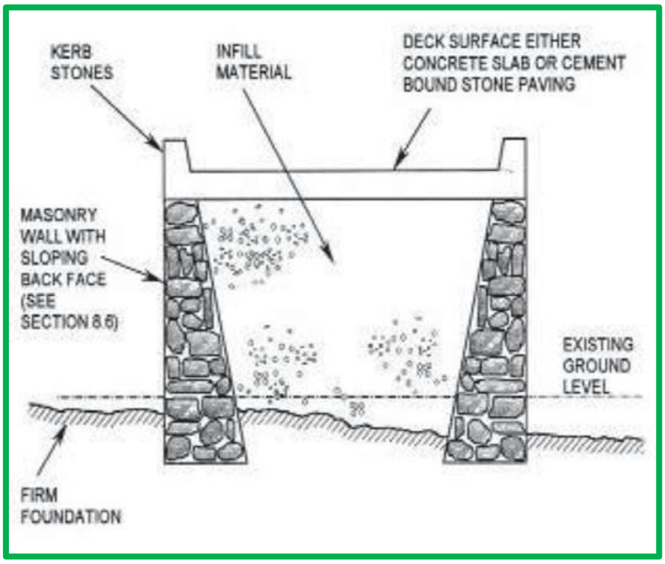


Figure 8.30: Approach way cross section

8.9 Downstream Protection

Previous sections on scour indicated that it is likely that erosion of the watercourse will occur around the structure due to a constriction of the water flow. The constriction causes the water velocity to increase as it passes through/ over the structure and this high velocity can be maintained well downstream of the structure. A previous section also discussed the use of aprons downstream of a structure to prevent erosion and undercutting of the structure itself. However, in small-constrained channels severe erosion may still occur after the apron, particularly where the watercourse is on a gradient. It is therefore often necessary to provide additional protection to the watercourse to reduce the velocity of the water and prevent erosion.

For slow flowing water it is unlikely that any protection will be needed but for faster flowing water the maximum allowable velocity will depend on the bed material and the amount of silt or other material already being carried in the water.

Erosion can occur in any channel regardless of the presence of any structure. It is therefore not possible to state how far downstream of a structure channel protection should extend. However, the following issues should be taken into account:

- The general erodability of the bed, this will depend upon the type of channel material and the gradient;
- The likelihood of damage to the structure if erosion occurs downstream;
- The potential effects of erosion on downstream areas (eg. damage to buildings or farming land).

Maximum water flow velocities that can be tolerated without channel protection related to the type of bed material are shown in Table 8.21.

There are many methods for providing protection to the watercourse. The choice of method will depend on the availability or cost of different materials, the size of the watercourse and level of protection required.

Table 8.21: Maximum water velocities

Bed material	Maximum water velocities without channel protection	
	Clear water	Water carrying silt
Stiff clay	1	1.5
Volcanic ash	0.7	1
Silty soil / sandy clay	0.6	0.9
Fine sand / coarse silt	0.4	0.7
Sandy soil	0.5	0.7
Firm soil / coarse sand	0.7	1
Graded sand and gravel	1.2	1.5
Firm soil with silt and gravel	1	1.5
Gravel (5mm)	1.1	1.2
Gravel (10mm)	1.2	1.5
Course gravel (25mm)	1.5	1.9
Cobbles (50mm)	2	2.4
Cobbles (100mm)	3	3.5
Well established grass in good soil	1.8	2.4
Grass with exposed soil	1	1.8

8.9.1 Rip-rap

Rip-rap is the name given to stones placed in the river bed to resist erosion. In order to be effective the stones used should be large or heavy enough that they will not be washed away during floods. Although rip-rap may appear to consist of random rocks it should be well graded and placed as tightly as possible to improve its resistance to erosion. The rocks used should also be strong and not likely to crumble. Angular rocks, in general, have the best performance due to the interlock that is formed between rocks. Round rocks can be used if they are not to be placed on the sides of a watercourse which has a gradient steeper than 1:4. Flat slab stones should also be avoided as they can be easily dislodged by the water flow. Table 8.22 shows the sizes of stone that should be used for rip-rap. It should be possible for one or two labourers to place the majority of the stones with the few remaining larger stones being placed by a small labour gang.

Table 8.22: Stone sizes for rip-rap bed protection

Water velocity (m/s)	Rock size dia. (m)	Rock mass (kg)	Minimum % of rock meeting specified dimensions	Thickness of rip-rap (m)
Less than 2.5	0.40 0.30 0.15	100 35 3	0 % 50 % 90 %	0.5
2.5 - 3	0.55 0.40 0.20	250 100 10	0 % 50 % 90 %	0.75
3 - 4	0.90 0.70 0.40	500 250 35	0 % 50 % 90 %	1.0

8.9.2 Masonry slabs

In areas where outlets from culverts are on a steep slope it may not be possible to place rip-rap because it will be washed down the slope. Masonry slabs, cascades or channels may be constructed on the steep section of the outfall to control erosion (Figure 8.31). As the water velocity will be high it will be necessary to use mortar in the slab because hand pitched stones are likely to be washed out. It will not be necessary to make the slab smooth: a rough slab will help to reduce the energy in the water. Large stones which project above the standard level may be fixed in the slab to create more turbulence to slow the water speed. Masonry cascades or step structures can incorporate a series of ‘ponds’ or sumps to help dissipate energy.

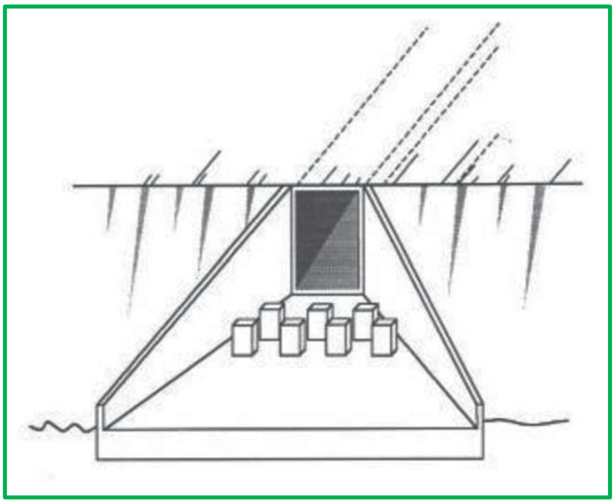


Figure 8.31: Energy dissipating apron

In flatter areas, up to a 5% gradient, it should be possible for small watercourses to use hand pitched masonry providing it is well placed with any large flat stones bedded on their edges.

8.9.3 Gabions

Gabion construction methods are discussed in some detail in Section 7.1.9. Gabions can be used to protect the bottom or banks of a watercourse (see Figure 8.31). As the stones are confined by the wire cages, much smaller stones than those used for rip-rap can be used. The disadvantage of gabions is that they have the additional cost of the wire for the cages when compared with rip-rap. However, the ability of single labourers to move and place the stones may outweigh the cost of the wire. As gabions can be made in different sizes they can be used for a wide range of different shaped watercourses. They can also withstand limited ground movements and therefore accommodate any small changes in the riverbed. If the bottom of the watercourse requires protection it will be possible to make a gabion that is only 200 or 500mm thick to form a mattress over the watercourse bed. Figure 8.32 shows two methods for using gabions and mattresses for protecting the watercourse.

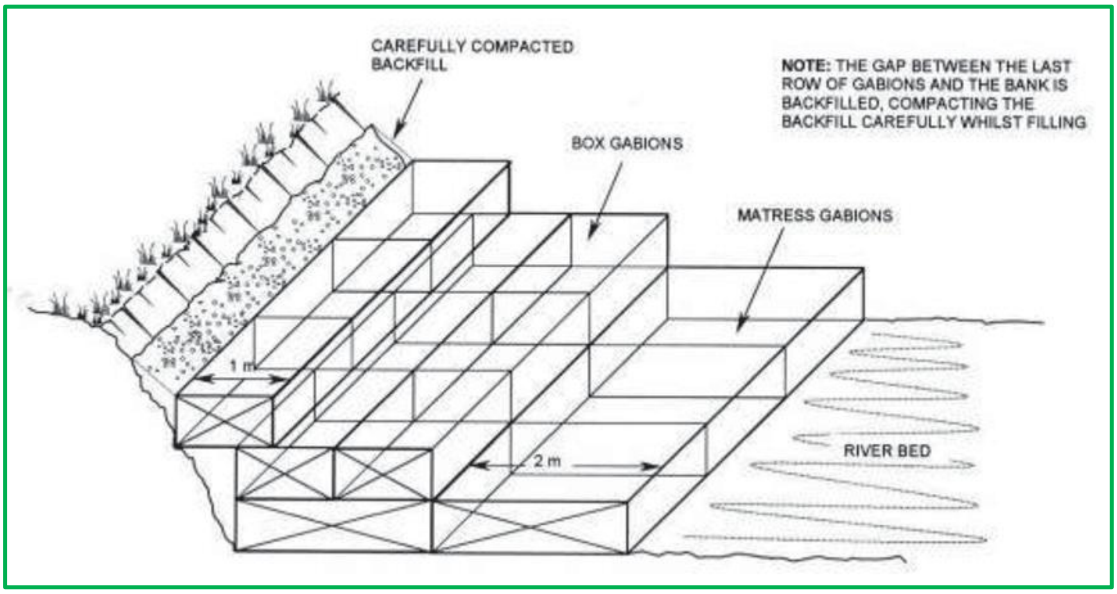


Figure 8.32: Gabion protection on steep banks

Figure 8.33 Illustrates how gabion can be tied together to form a protective mattress on slopes less than 1:2. The size of the gabions will depend on the velocity of the water flow. For all flow velocities the smallest gabion used is 0.5 x 0.5 x 1m.

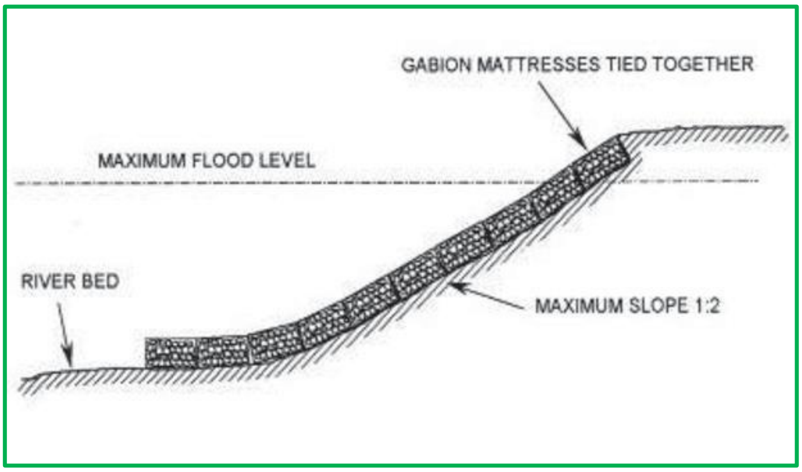


Figure 8.33: Gabion protection on shallow banks

Any mattresses in the bottom of the watercourse should be 200-300mm thick for water velocities up to3m/s and 500mm thick for velocities over 3m/s. It is very important that they are securely wired together to ensure that they do not slide down the bank and cause the water to erode the watercourse banks behind them. The minimum size of the gabion baskets makes this option suitable only for larger watercourses.

8.9.4 Vegetation

Vegetation is likely to be the best option for small watercourses because, once established, it slows down the speed of the water flow and holds erodible soil together. It can also be a cost effective protection method where suitable local plants are available. The use of vegetation to control erosion is sometimes called bio-engineering. Bio-engineering covers a wide range of techniques that use vegetation, which include the control of erosion and stabilisation of engineering structures. This Manual discusses the use of bio- engineering to control erosion downstream of water crossings. It is not sufficient to randomly plant any vegetation because the conditions must be correct for the plants to grow and they must produce the desired anti-erosion effect.

The most basic form of vegetation erosion control will be to allow the region’s natural grasses to grow in the water channel. They may grow naturally without any assistance if they are already well established in the channel. However, if some erosion has occurred in the channel it may not be possible for the grass to establish itself without assistance. In these cases it will be necessary to cultivate the grass in a nursery or near the site at the roadside (provided vehicles or cattle will not damage it). Once the grass is established it can then be transplanted into the water channel. The replanting may be by individual plants or by turfing techniques.

Natural fibre matting may also help to establish plant growth. The timing of the planting will be dependent on the rainy season. Plants need to get established in the watercourse while there is moisture in the soil. It may be necessary to regularly water the plants until they are established in their final situation. However, they are not able to grow during periods when the channel is full of water. It is unlikely that the grass will grow in the base of the watercourse if water is flowing throughout the year. In these cases it may be possible to plant the grass on the edges of the channel and an aquatic plant in the base of the channel. The choice of plant will, again, be based on local knowledge but it is likely that plants found in other watercourses with similar conditions nearby will be the most appropriate. The local agricultural or botanical institutions should be able to provide guidance on plant selection.

In areas where hand pitched stone is proposed to protect the channel downstream from a culvert it may be reinforced with plants, rather than cement or mortar, to bind the stones together.

Stones should be placed in the riverbed in the same manner as for standard hand pitched stone slabs. Any small gaps that remain between the stones should then be filled with soil and grass planted approximately 150mm apart. The exact distance will depend on the shapes and gaps between the stones. When the grass is planted the workers should ensure that the roots are deep enough to enter the soil beneath the stone pitching. In channels with permanent water flow the grass should only be planted towards the sides of the channel because it will be unable to grow under water in the centre of the channel.

Vetiver grass in the appropriate environment can be useful for soil stabilisation because it can grow in a wide variety of soil conditions including those of very poor quality. It also develops a fibrous and deep root system which is ideal for holding weak soil together and preventing erosion. Vetiver grass has successfully been used to prevent erosion on steep roadside banks and at the edges of engineering structures. The cultivated grass shoots are planted out in the area prone to erosion. The spacing of each shoot will depend on the perceived erosion risk and will vary between 100mm for high erosion areas and 200mm for lower risk areas.

8.9.5 Steep channels

In areas where water is flowing down steep hillsides and crossing a road through a culvert, it is necessary to provide protection to the slope above and below the road. This is particularly important when a road is winding up a hill and a watercourse crosses the road a number of times where it is not possible to channel all the water down steep inclines at the hairpins. Water flowing downhill has a large amount of energy which must be 'lost' if erosion is to be prevented. The most appropriate method in these cases is to construct a step waterfall or cascade to dissipate the energy (see Figure 8.34).

The photograph and diagram show a step waterfall made from gabion baskets, but it would also be possible to construct the structure from masonry if available. Regardless of the material chosen the structure should be built into the hillside by excavating the necessary material. Care must be taken to ensure that the sides of the channel extend outwards far enough to ensure that the water is contained in the channel.

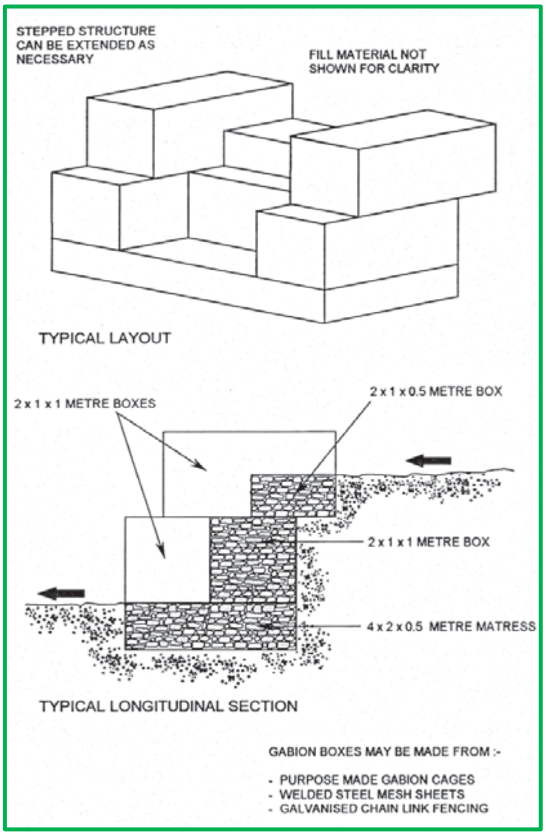


Figure 8.34: Gabion basket step waterfall

8.10 Drain Protection

Along each side of a road there should be a drain to assist in removing water from the carriageway and transferring it into the nearest watercourse. In flat terrain these drains can be earth or gravel lined however, where gradients are greater than 2% they will require protection to prevent fast flowing water eroding the ditch. The most effective method of preventing erosion is to use scour checks which are mini dams constructed in the drain. These scour checks form barriers to the water flow causing silt to be collected behind each scour check and hence forming a series of steps in the drain which help to dissipate the water energy. Further guidance is provided in Chapter 9 of Volume 1 of this Manual.

8.11 Arches

It is often difficult to define the difference between large bore culverts and arch bridges. Regardless of the name given to the structure, it will normally only be required where a road crosses a well-defined watercourse and/or large flows are expected. This Manual defines a large bore culvert as a structure with arches up to 2.5 metre diameter. There are two design issues to be resolved if this type of structure is to be constructed.

- Some form of permanent wall will be required on the upstream and downstream sides of the structure and on the base of the archway to retain the enclosed fill;
- A large amount of fill material will be required to complete the construction.

8.11.1 Arch shape

An arch resists the dead weight and traffic loads by compressive forces in the arch ring. This results in very large forces at each end of the arch which must be resisted by the foundations. If the arch is not semi-circular these forces will have a horizontal component which is harder for the foundations to resist than vertical forces alone. It is therefore recommended that only semi-circular arches are used unless specialist engineering support is available for the design.

The magnitude of the forces at the end of the semi-circular arch shown in Figure 8.35 will be equal to half the total weight of the arch and fill material plus the weight of any traffic. The design of semi-circular arches should allow for an element of horizontal loading particularly during construction and placing of fill material. As the arch load will be concentrated in the foundations at each end of the arch, these structures should only be built on ground which has an adequate bearing capacity.

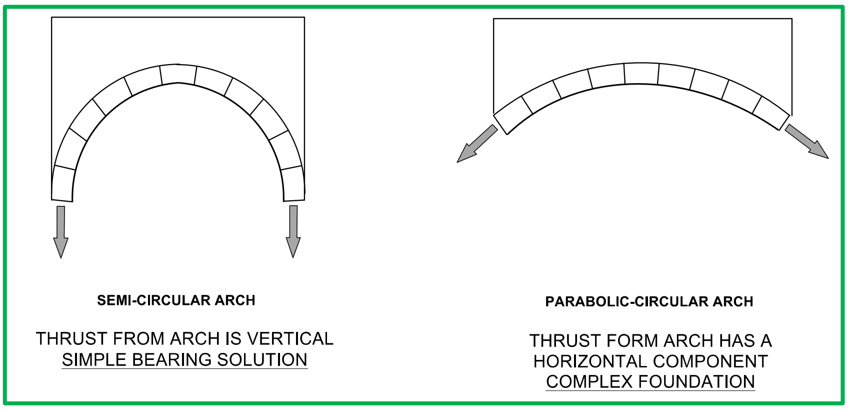


Figure 8.35: Arch forces

8.11.2 Bridge/culvert layout

Once the designer has chosen to construct an arch bridge/culvert he will have to decide on the size of the arch or arches for the structure. The choice will depend on the particular characteristics of each potential site but Table 8.23 highlights the different options. If the designer wishes to use piers then reference should be made to a later section in this chapter, which discusses the design of piers.

Table 8.23: Small versus large arches

Small arches	Large arches
Easier to construct using labour based techniques.	Formwork may require cranes to manoeuvre components into place.
Piers will be required to be constructed in the water course in wider rivers as multiple spans may be required.	It may be possible to span the whole watercourse with one arch and avoid the need for piers in the watercourse (reducing scour problems).
The bearing pressures exerted by the piers will be lower than for large arches.	The load exerted by a large arch will require ground conditions that can withstand very high bearing pressures.

8.11.3 Construction sequence

The first stage of building an arch structure is to construct the foundations and any piers that may be required. The arch formwork can then be put in place and the arch constructed. The sidewall construction should only commence once the ring is fully completed. The placing of fill material above the arch can proceed as the sidewalls are built. The placing of fill in layers about 1m below the constructed fill height will serve as a platform for the artisans who are laying the stonework for the sidewalls. Guide stones should be included on each side of the deck to mark the edge of the carriageway. These could be integral with the sidewalls or be formed with the deck surface. The options for the design of the deck surface will be the same as for the approach ways discussed previously.

8.11.4 Arch materials

There are a number of different material options available for the construction of walls and temporary or permanent shutters for an arched bridge. Some of these options can be used in both the walls and arch while others are only suitable for forming the arch (see Figure 8.36).

Stone, bricks and blockwork can be used to form the walls of the structure. The choice of material should be made based on the cost and availability of each material. Any material that is used should conform to the specifications given in Chapter 7. If part of the wall is in the water flow, the material should be hard enough to resist erosion. The walls should be constructed with a tapered back face, similar to the characteristics of wingwalls discussed in Section 8.17.

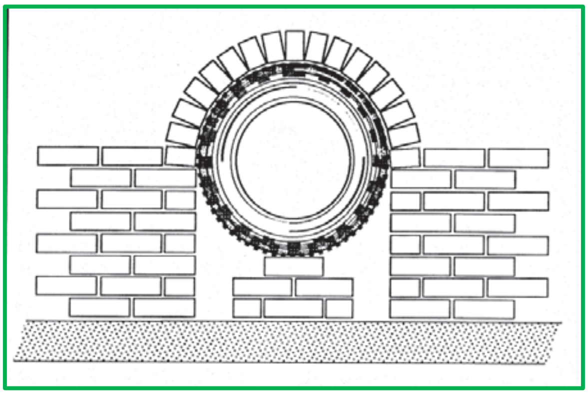


Figure 8.36: Use of tyre in formwork

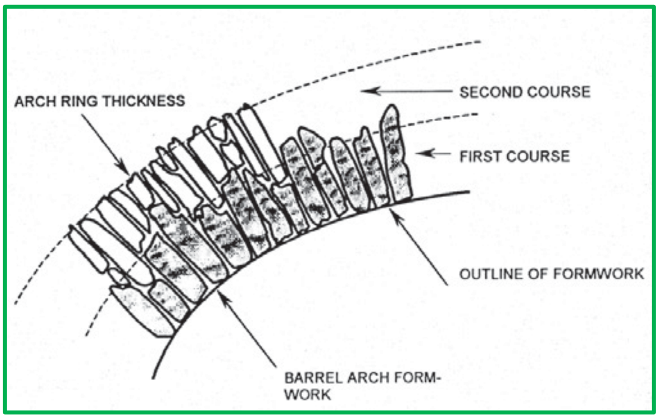


Figure 8.37: Two course arch

Stone, bricks or blocks can also be used to construct the arch of the structure. Some form of temporary framework will be required during construction. This temporary formwork is likely to cost as much as the stonework used in the bridge itself. This option is therefore only likely to be viable if the formwork will be reused for additional spans or on other structures. The most appropriate formwork will usually be a wooden frame covered in wooden planks or sheets, although large truck tyres may be used to hold timber sheets in place for smaller arches. Reusable steel formwork may also be used, especially if a large number of culverts of the same diameter are to be constructed. Because the arch gets its strength from its uniform shape with all components in compression on the arch face it is therefore important that the formwork used is good quality and rigid to ensure that the arch does not deform during construction.

All stonework used in an arch should be placed as shown in Figure 8.37. The arch should consist of a minimum of two courses of masonry which should be interlocking where possible. The minimum thickness of a semi-circular arch ring is shown in Table 8.24 below.

It is not possible to get the level of interleave shown in Figure 8.34 if using bricks. The strength of brick arches can only be ensured if a good bond is achieved between the brick and mortar. As the arch will be very strong and rigid once it has been completed there should be a simple method for releasing the formwork without damage in order that it can be used again.

Table 8.24: Minimum arch ring thickness

Arch span (m)	1	2	3	4	5	6
Ring thickness (m)	0.2	0.3	0.35	0.40	0.45	0.5

An alternative to stone or brickwork for the construction of the arch is to use corrugated metal sheets (Figure 8.38). The advantage of these sheets is that they act as permanent formwork to be left in place, becoming part of the finished structure and preventing the need to use expensive temporary formwork. Although corrugated metal sheets are likely to have a higher purchase and transport cost than stonework this additional cost may be offset by the elimination of the temporary formwork and the possibility of using lower grade fill, lean concrete or stonework and skills in the construction of the arch over the corrugated sheets.

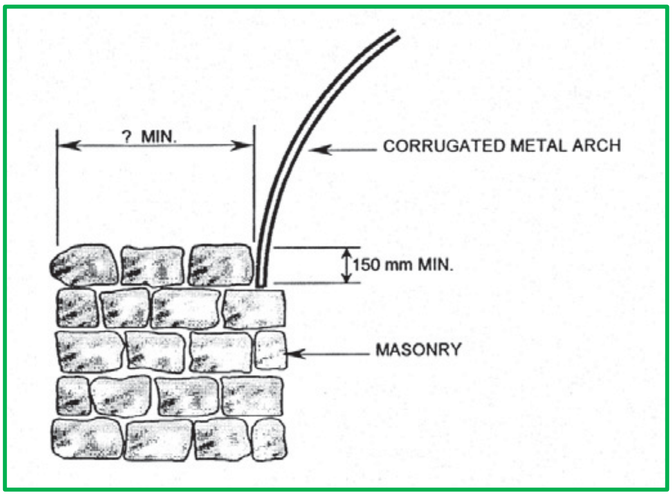


Figure 8.38: Corrugated metal sheet arch

Corrugated metal sheets will need to be pre-bent to the correct radius for the arch by the supplier. They can then be bolted together at the bridge site to form the arch. To ensure that the arch does not distort when the fill is placed and compacted, the foundations or piers should restrain the corrugated metal, preventing it from flattening out. This requires a ledge to be constructed to hold the sheets in place.

8.11.5 Fill options

There are three fill options that can be used in arch bridges which were discussed in the fills for approach ways in the section shown in Table 8.19:

- Well compacted gravel;
- Weak concrete mix with plums;
- Rubble masonry.

8.12 Bridge Design

This section covers the design of bridge decks appropriate for use on low-volume (traffic) roads in rural, often remote, and urban areas. It includes guidelines for the design and construction of support abutments and piers. A bridge is basically an extension of a road, albeit a more sophisticated and expensive part. At a cost of up to 100 times or more than that of an equivalent length of road, however, it is important that careful attention be paid to its design and construction. Bridges are critical elements of the road system. A bridge collapse not only disrupts the serviceability of the whole of the road network but it can also endanger life to a much greater extent than other components of the road.

In this section, as in the rest of this Manual, emphasis is placed on relatively low-technology, labour based solutions because these tend to be the most economic and socially beneficial in rural areas of South Sudan. The previous text in this Manual is generally applicable to small structures both for single and two-lane traffic. The following pages generally cover bridges spanning less than 10m and carrying a single lane of low volume traffic.

For single lane bridges, an appropriate deck width between kerbs or width limiting obstacles is 4m which is sufficient for most commercial farm and public transport vehicles. This can be reduced where certain vehicles are physically prevented from using the bridge and use is confined to motorcycles, bicycles, pedestrians and animals. Extrapolation of the contents of this Manual to larger bridge spans or for heavier traffic is not advisable. In these situations, a full-engineered solution is required and reference should be made to the current MRB Bridge Design Manual, Overseas Road Note 9 (TRL 2000) or other appropriate documents.

8.12.1 Choice of bridge site

An appropriate choice of location is important if an effective bridge solution is to be obtained in terms of cost of construction, maintenance and service life. The ideal site would have low flood levels, high solid banks (preferably rock), a non-skewed crossing and straight approach roads. Normally, however, some compromise is required.

8.12.2 Loading

Consideration must be given to the type, volume and weight of vehicles which will use the road. It is often stated “if a heavy truck can physically use the road, then at some stage it will”. Generally, bridges must also be designed to carry the heaviest load expected. This is particularly important for decks, less so for abutments and piers. Modern bridge loading specifications are generally applicable to structures which experience high volumes of traffic (>10,000 vehicles per day). The economics are such that bridges built to these specifications cannot be justified for the majority of low cost roads used to service rural areas. Note that many low-volume rural roads in South Sudan rarely experience vehicles greater than 6 tonnes. This limit covers cars, light buses, pick-up trucks, cattle wagons, etc. In particular circumstances this may not be sufficient, for example, near stone or gravel sources or factories which produce heavy goods. Where heavier traffic (>6 tonnes gross vehicle weight) is likely to be a regular occurrence, proper engineering design by suitably qualified engineers is required. This is beyond the scope of this Manual and reference should be made to the MRB Bridge Design Manual and documents such as Overseas Road Note 9 (TRL 2000).

8.12.3 Scour

The site of bridges must be carefully chosen to take local conditions into account to ensure durability and functionality, including alignment. Chapter 5 gives details of the general principles involved in site selection and appraisal. For bridges this is crucial if future problems and maintenance costs are to be minimised. Peak Flow (or design flow) and peak flow velocity calculations are detailed in Chapter 5 of this Manual. Design for scour prevention is detailed in Section 8.1 of Chapter 8. The detrimental effects of scour on bridges and support systems must be recognised; in fact this is the most likely cause of structural failure in bridges around the world.

In most cases problems can be minimised, and often avoided completely, by appropriate choice of form and location for the crossing.

8.12.4 Drainage

Every form of bridge requires some water management to ensure that water does not pond on the deck. This could cause a traffic safety hazard, rotting of timber, and corrosion of reinforcement or deterioration of masonry. For solid decks a transverse camber of 1 in 40 and a 1 in 100 longitudinal fall is sufficient to prevent ponding. Where kerbs are present, some means of disposing of water from the deck is required. For timber decks, a 20mm gap between planks is sufficient to allow adequate drainage. For solid decks, scuppers should be considered and should be carefully located and detailed to discharge excess water through the deck without causing erosion, staining or maintenance problems. The careful detailing of roadside drainage outfalls at the bridge site is essential to avoid erosion problems.

8.12.5 Maintenance

In bridge design there is a trade-off between initial construction cost and on-going maintenance costs, and bridges which are cheapest to build can end up being the most expensive when whole life costs are considered. Maintenance of a bridge must be considered at the design and construction phase. The designer should make allowances for access for inspection and should recommend a maintenance plan which includes extent and frequency of inspection and any routine works required. These maintenance costs and their practical arrangements should always be considered when selecting the preferred design solution.

In general, it is a good idea to design bridges to minimise future maintenance actions and costs. This is because maintenance is often neglected, particularly in rural areas where traffic levels are low and financial/physical resources and logistics may be severely constrained or challenging. It should be remembered that routine maintenance will always be required. This involves regular brief inspections on an annual basis and including preventative maintenance such as clearing of drains and removal of debris or garbage. This gives a clear indication of the performance of the bridge and the progress of any deterioration. Provided adequate guidance and a means of recording the results of the inspection are provided, these inspections do not require qualified engineers. However, a more detailed inspection at intervals of about seven years by a qualified engineer is recommended. The detailed cost of the bridge structure options should include the expected costs of the maintenance regime inspections over the design life of the structure in present day costs, and also an estimate of the likely routine maintenance activities. These should be estimated from maintenance records for existing similar structures.

Abutments and piers are often constructed within the watercourse. These should be designed and constructed to keep to an absolute minimum their effect on water flow. This minimises the possibility of scour and helps to avoid expensive maintenance work.

8.12.6 Choice of structure

The selection of structure type is discussed in Chapter 4.

8.12.7 Choice of materials and form of construction

The general properties of construction materials and how to identify and evaluate them are outlined in Chapter 7. For bridges, as for other road structures, the choice depends primarily on local conditions and on the availability of materials and labour and the costs of the feasible options. However, greater care is required in the selection of appropriate materials for bridge structures because the materials will be called upon to take greater loads and local weaknesses or defects may lead to total collapse of the bridge.

Reinforced concrete is generally considered to be the most economic material for construction of bridge spans up to 30m. This is because of the good durability characteristics and low maintenance costs. However, while well-constructed concrete is very durable and requires very little maintenance, construction requires a high level of technical skill as well as the availability of good quality materials. The guidelines in Chapter 7 must be followed if good quality structural concrete is required. Bad site practice and poor workmanship can lead to a very poor structure which may lack long term stability and may collapse. Typical faults include use of dirty water, sand and aggregate; inadequate mixing; poor placing and compacting of concrete; inaccurate fixing and positioning of reinforcement or formwork; and storing cement in humid conditions. Mix design (i.e. the proportions of cement, sand, coarse aggregate and materials to be used) is very sensitive to mistakes. Labourers often do not realise the consequences of poor practice and close supervision should always be carried out when structural grade concrete is required. If there are local shortages of formwork, steel fixing and structural concreting skills (which often have to be imported into a rural area), it may be more appropriate to adopt designs that utilise locally available building skills such as carpentry and masonry.

Each region tends to have its own local construction artisans (e.g. blacksmiths, carpenters and stonemasons), and materials (stone, brick, wood and gravel). These will affect the economics, and local resources should be used where possible, although other factors may also influence the final choice, for example, a local policy may influence preferences. The construction of stone or brick masonry arch bridges is labour intensive but these are the most durable and, arguably, the most aesthetically pleasing bridge forms. Simple arches are also technically the simplest form of bridge structure to construct with relatively limited supervision requirements. If suitable materials and stonemasons are available, this may be the most effective long-term solution.

Timber as a primary structural material has its advantages. Its low weight, low cost, general availability, and ease of construction make it attractive in many remote situations where it is grown locally. Timber can be assembled using non-skilled labour and in adverse weather conditions. It requires some protection against deterioration and insects, particularly in hot humid climates. Timber requires deeper sections than steel or concrete, mainly because of its lower stiffness. Experience in North America, where there are many timber bridges, suggests an average life of 50 years, although with good maintenance, the life can be considerably greater.

As timber is light it can easily be washed or blown away. All timber decks should be tied down at supports and these fixings should be inspected at regular intervals. Timber is easily set on fire, either by accident or maliciously. Garbage, driftwood, weeds, etc. should not be allowed to accumulate under the structure. See Chapter 7 for more details including tests to evaluate prospective timber sources.

Durable local stone in compression is the most economical material of construction when whole life maintenance costs are included. General properties of different stone are given in Chapter 7. Alternatively bricks can be used but for bridge structures it is important that they are consistent in strength and quality. Chapter 7 gives some background on the expected properties of locally produced bricks.

8.12.8 Foundations

Foundations for piers and abutments are discussed earlier in this chapter. Bridges are usually constructed on sub-soil with an allowable bearing capacity greater than $300kN/mm^2$. This is easily achieved in gravel, compacted sand and strong clay. A simple check to indicate this minimum capacity is:

- A man's weight bearing on a 30mm diameter bar only penetrates 100mm;
- A 2m rod driven into the ground with a 3kg hammer experiences increasing resistance.

On softer soils a bridge may not be appropriate and another site or form of structure should be considered. Bridges can be constructed on very soft soils using piles. Timber piles can be driven using fairly rudimentary equipment and manual or animal power. Where piles are used, design and supervision should always be carried out by a suitably qualified engineer. Where bearing capacity is limited, it should be noted that gabion abutments are lighter than concrete and spread the load well.

8.12.9 Arch bridges

Arch bridges usually provide the best solution in consideration of the level of maintenance required. This Manual is appropriate only for spans less than 10m. Section 8.11 deals with large bore culverts and provides general information on the construction of masonry arch structures. The following paragraphs refer to arch bridges appropriate for low volume roads suitable for pedestrians and vehicles less than 10 tonnes.

The key elements of an arch bridge are shown in Figure 8.39. The wedge shaped blocks, stones or bricks which form the barrel or ring of the arch are called voussoirs. These are usually placed symmetrically around a centre stone or key-stone. In fact, the key-stone has no special function and is an aesthetic rather than a structural requirement. The stone block in the abutment on which the arch barrel sits is called a skewback and the surface between the skewback and the end of the arch barrel is called the springing (see Figure 8.39 below). The highest point of the arch is called the crown and the lower sections are the haunches. The upper and lower boundary lines of the arch ring are called the extrados and intrados respectively. The outer walls which retain the fill are the spandrel walls and they become the wingwalls at either side of the arch.

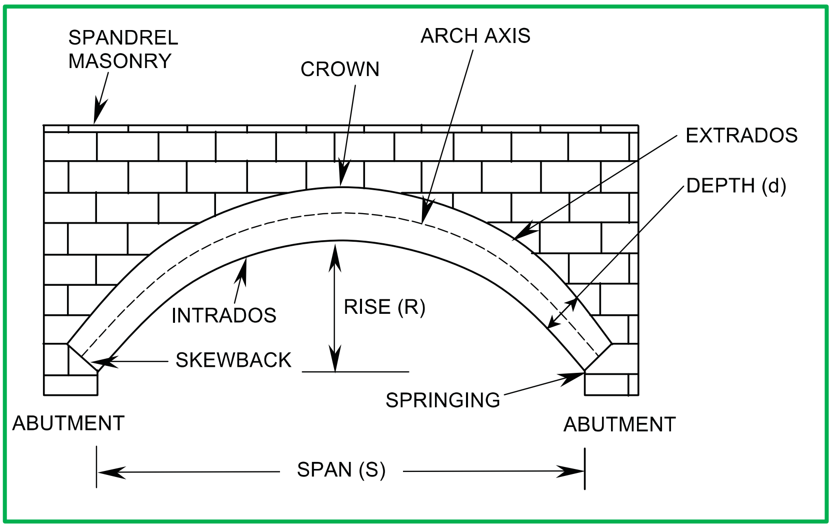


Figure 8.39: Arch bridge details

Arches can be constructed using any good quality stone or brick. Wedge shaped stone can be used without mortar but it is more common to use regular shaped rectangular stone or brick placed with a good quality mortar forming the slightly wedge shaped joints between each unit. The use of mortar can reduce the stresses in the stone by as much as 30% and should always be used if possible. If bricks are used, a high standard is required; they must be fired to a good engineering quality and be consistent in shape and strength.

Arch bridges are heavy structures and care should be taken to ensure that the foundation has sufficient bearing capacity. Foundations are usually relatively shallow spread footings or onto solid rock where this exists at the springing. It is essential that there is sufficient resistance in the abutments to resist the substantial horizontal spreading forces inherent in an arch design. Excavation must be taken down to firm material. In soft soils, timber, concrete or steel piles may be required but these are beyond the scope of this Manual. A cofferdam can be used to provide a temporary dry working area.

Piers in multi-span arch structures are usually thick structural components with widths about 25% of the arch span. These are massive enough so that individual arches of multi-arch bridges are self-supporting. Piers can be made using a double outer layer of bricks or blocks and the cavity filled with clay or rubble. However, it is good practice to make the piers of solid masonry where possible, particularly for smaller bridges.

Details on arch construction and formwork given in Section 8.11.4 also hold true for arch bridge construction.

To avoid having supports in the riverbed, formwork arching between the abutments can be used but this would not usually be required for small span arches of normal height.

As access to the riverbed may be required for a long period of time, arches may not be suitable where floods occur frequently.

Arch bridges are suitable where high clearances are required. As the section above suggests, the simplest arch shape is a semi-circle, which avoids horizontal thrust forces at the springings. It also provides maximum headroom and simplifies the geometric layout. Other shapes such as ellipses are used to reduce the height of large span bridges; these are considered to have a potential weakness at the quarter points. Any arch form where the ring is not vertical at the support will induce horizontal forces in the abutments or piers, which must be resisted.

The thickness of the ring or barrel of the arch is the main factor affecting the strength of a well-constructed bridge. Small arches may be built using a single layer of bricks laid radially providing a ring thickness of 215mm for a standard brick size. For larger arches the ring thicknesses shown in Table 8.24 should be followed. Because of the arch shape, the thickness of the mortar will vary through the depth of the ring. Most arches are made using two or more concentric rings with mortar providing the only bond. A header or stretcher bond may also be used, i.e. a brick laid radially to provide a key between the rings. For larger spans the number of rings can be increased towards the springings. It is recommended that skewed arches are avoided.

Once the arch ring has been completed the fill material is put in place. A large amount of fill is required. Any local material of consistent quality can be used, for example, the material excavated during the construction of the foundations. Strength is not a requirement, its only function being to distribute the load uniformly to the arch barrel. However, well-compacted fill can add considerably to the strength of an arch bridge. (Refer to the section on approach ways for appropriate materials and compaction requirements). A well-drained granular fill is the best material, being flexible enough to allow the bridge to tolerate some degree of movement. It is recommended that the arch formwork is only removed once all the fill material is in place.

For brick arches it is also recommended that the formwork be removed after the mortar has fully hardened (after about seven days) to avoid distortion of the arch while the mortar is still soft. For stone arches, this period can be reduced.

Spandrel and wingwalls retain the fill material and stiffen the arch ring at its edges. They should be thickened at the base to provide better stability. For larger spans it may be helpful to have wingwalls sloped outwards in plan for extra stability.

8.12.10 Deck

The deck, or superstructure, is that part of a bridge which carries the roadway. Its function is to transmit the load safely to the abutments and piers without damage to the bridge structure or undue distortion of the deck. For bridges with spans less than 10m, the only loads that need to be considered are the dead load of the deck itself, including parapets and any other bridge “furniture”, and the live load due to traffic or pedestrians.

It is always a good idea to carry out a design check if possible. A simple analysis can be carried out assuming the deck is a simply supported beam. The loading to be used should consist of the heaviest vehicle likely to use the bridge and a uniformly distributed load of $5kN/m^2$ of deck area to represent pedestrian loading (including cycles and animals). The maximum expected stresses can be obtained and compared with the strength of the material used. Maximum deflections can also be calculated once the deck details have been established. In general, it is a good idea to limit the maximum expected deflection to 1/100th of the span to avoid damage at the deck joints.

The deck can take many structural forms depending on local conditions and availability of materials and labour. Arch bridges have been described in Section 8.10; other types of bridges include reinforced concrete slab bridges, beam bridges (reinforced concrete, timber, steel), and truss bridges (timber or steel). The following gives general information on how different materials can be used to provide low cost bridge decks.

Material - concrete

Precast concrete beams are likely to be the most economical construction material. However, for small spans (<6m) simple cast in situ reinforced concrete slabs are likely to be the most economical solution. For larger spans beams will generally be required. A span to depth ratio of about 12 will generally be sufficient, although decks should not be constructed less than 300mm thick. As previously mentioned, reinforced concrete is a material requiring certain technical expertise and requires care in construction if an effective structural material is to be produced. Best practice as described above should always be followed and supervision of unskilled workers is necessary if structural grade concrete is to be produced. Reference should be made to the current MRB Bridge Design Manual and Overseas Road Note 9 (TRL 2000) for further information.

Material – timber

There are three basic elements to a timber beam deck:

Beams: These support the surface of the deck, although trusses can also be used. The beams form the main structural elements of the deck and are described in more detail below.

Deck planking: These are the boards which are nailed to the beams to form the surface of the deck. These boards spread the wheel load to the beams. As the beams are generally spaced at less than 1m the, individual pieces of floor planking do not need to be too long. A depth of 75-100m is normally sufficient.

Wheel tracks or running boards: These are boards which are fixed to the deck in the direction of traffic flow on which the vehicle wheels run. They provide protection to the floor planking from wear and tear from heavy vehicles. The geometry of the tracks must be such as to accommodate the wheelbase of all vehicles likely to use the bridge. For most cases, tracks 1200mm wide with a gap of 800mm between inside edges should be sufficient. In some cases, a cover of asphalt or sand can be applied to prevent damage from heavy vehicles. Worn out or damaged running boards, deck planks and beams should be replaced to avoid progressive damage and injury to bridge users. A beneficial additional detail is to fix a ‘threshold’ plank laterally across the road at each end of the running boards. This detail will help to reduce the vehicle impact loadings on the ends of the running boards (this location is particularly susceptible to loosening of the running board fixings).

Most codes refer to sawn timber of consistent quality. In the following it is assumed that a supply of well- seasoned hardwood timber is available which is free of rot or insect infestation. It also assumes that, in the worst case, the bridge will be loaded with light vehicles (< 6 tonnes in weight). Where heavier vehicles are expected more attention should be paid to structural details and reference should be made to the current MRB Bridge Design, Overseas Road Note 9 (TRL 2000) or similar documents to define the size and spacing of main structural elements.

The main deck supports can consist of either a number of beams spanning between supports or a pair of trusses along the edges of the bridge with transverse stringers carrying the deck. Simple beam bridges are easier to construct and require less skilled labour but are only suitable for short spans. For longer span bridges trusses provide a more efficient use of timber but these require specialist skills for design and construction. In particular, the joints and connections require careful attention. Design of timber truss bridges should only be carried out by a suitably qualified engineer.

Timber beams can be constructed from either sawn timber sections or from the original logs depending on the source of timber available. The factors affecting the strength of girder decks are:

- Type of timber (quality, strength);
- Depth of member;
- Width of member;

- Spacing.

It is possible to design the timber deck for a particular type of timber but this will require detailed knowledge of its properties. Where sawn timber is available commercially, this information may be obtainable from the supplier. Section 7.3.1 presents the general properties of different timber broadly classified into soft, medium, hard and very hard wood and gives samples of the tree species. This highlights the fact that strength is closely related to timber density.

Generally sawn timber is easier to use and fix in place because of the regular shape and flat surfaces. It is also easier to examine for defects such as knots or insect damage which can seriously reduce strength. Where minor flaws exist, the timber can be used provided the flaw is placed as close to the top of the beam as possible to reduce its effect on strength. Where sawn timber is not available, logs can be used. These require more care in selection for quality and size, positioning and fixing in place.

Table 8.25 provides the size and spacing of sawn timber beams required for various spans. These are appropriate for pedestrians and light vehicles only (up to 6 tonnes). For heavier vehicles, the tables in Overseas Road Note 9 should be used. Note that wide spacing makes fixing of deck planks more difficult.

Table 8.25: Sawn timber beam bridge deck for 6 ton vehicles

Span	Timber size* (width x depth in mm)	Beam spacing (m)
5	150 x 300	0.5
8	200 x 400	0.8
10	200 x 400	0.5
12	250 x 500	1.0

Note: * All timber to have a density greater than 450kg/m^3

Logs are best used round but with the top shaven to carry the deck. The bark should be stripped and each log checked for soundness and defects. Properly seasoned logs should be used. Particular care should be taken to ensure that the timber has not been attacked by insects. As with all timber, logs should be treated with creosote or other preservative agent, preferably by immersion for several days. Painting is not sufficient protection. The ends of the logs are particularly vulnerable as they are often in contact with soil. Moisture and garbage often collect at supports and can cause rotting. The logs should be closely matched for size and positioned with the top surfaces in the same plane and, to accommodate any variations in log diameter, with the large diameter at alternate ends on adjacent logs.

Running boards can be placed directly on top of the logs although deck planking is recommended if pedestrians and animals are to use the bridge regularly. In general, three or four logs of about 300mm diameter are sufficient to span up to 10m to carry a single lane of light traffic. Again, for heavier traffic, the tables in TRL Overseas Road Note 9 should be used.

One common problem with timber decks is excessive spacing of the longitudinal stringers. Excessive deflection of the stringers under vehicle loading can cause surface damage to the timber at the supports. This can lead to rotting and early deterioration of the deck. The deflection can also cause the deck planks to work loose leading to damage, rot or even complete loss. A general recommendation for heavily trafficked bridges is that the stringers be placed as close as is reasonable for the available timber sizes to avoid excessive differential movement across the deck. This can be relaxed for low-volume roads. Stringers should be placed so that the tops are at the same level; this ensures that deck planks bear evenly across the deck. If one stringer is higher than the rest, the underside should be trimmed where it bears on the support, or the seating for that stringer should be lowered. This avoids having to trim the whole top length of the timber. Floor planks 50x100mm make a very effective deck. These can be laid on edge and nailed to the preceding one to make a very stiff solid slab 100mm thick.

Where joints are made using nails or screws, the minimum spacing distances shown in Table 8.26 should be used (in terms of the nail diameter) to minimise the chance of damage to the timber and premature failure of the joint.

Table 8.26: Nailing requirements

Location of nail	Number of nail diameters
Edge distance parallel to grain	20 diameters
Edge distance perpendicular to grain	5 diameters
Distance between lines of nails	10 diameters
Distance between adjacent nails in a line	20 diameters

Material – Steel

Steel beams with a concrete or timber deck make a very effective bridge. Steel beams are imported, expensive and may be difficult to transport. However, they may be available from demolished steel truss bridges or buildings.

A concrete deck can be cast on top of the beams (composite construction). This must be made integral with the steel beams either by encasing the beams in concrete or using shear keys fixed to the top of the beam at 100mm spacing and penetrating 50mm into the concrete deck.

The deck can also be constructed using soil, rubble or lean concrete provided a method of supporting and retaining the fill is devised. This could consist of transverse arches supported by the bottom flange over which fill material is compacted. The arches can consist of brick or stone masonry, metal plates or concrete.

Steel beam decks tend to rattle and vibrate excessively due to inadequate fixing at the supports. Beams can be fixed to timber abutments using screws or nails driven through holes in the bottom flange. If a timber deck is used, the planks should be fixed securely to the beams.

If available and of suitable length, old railway lines can be used to form a bridge deck. Because of difficulty of fixing to abutments and attaching deck planks, the rails can be encased in concrete so that the rails act as reinforcement. This also protects the rails from corrosion.

8.12.11 Abutments

Abutments provide the support system for the deck and retain the soil under the approach road (see Figure 8.40 for details). They can be built using various forms and materials. The main function is to transfer the loads from the deck to the supporting foundations. They are also located at the transition between the approach embankment and the bridge deck. Effective abutments should provide good performance and stability to the bridge structure as a whole. The form of the abutment will depend on foundation material and on the deck type.

The bearing capacity of typical soils and rock are given in Chapter 6; this will dictate the size of the abutment and the bearing area required.

The material used for abutment construction depends primarily on the availability of local material. It is recommended that concrete or masonry be used to make abutments where possible. Mass concrete can be used provided the concrete is of sufficient quality and the abutment is of sufficient size.

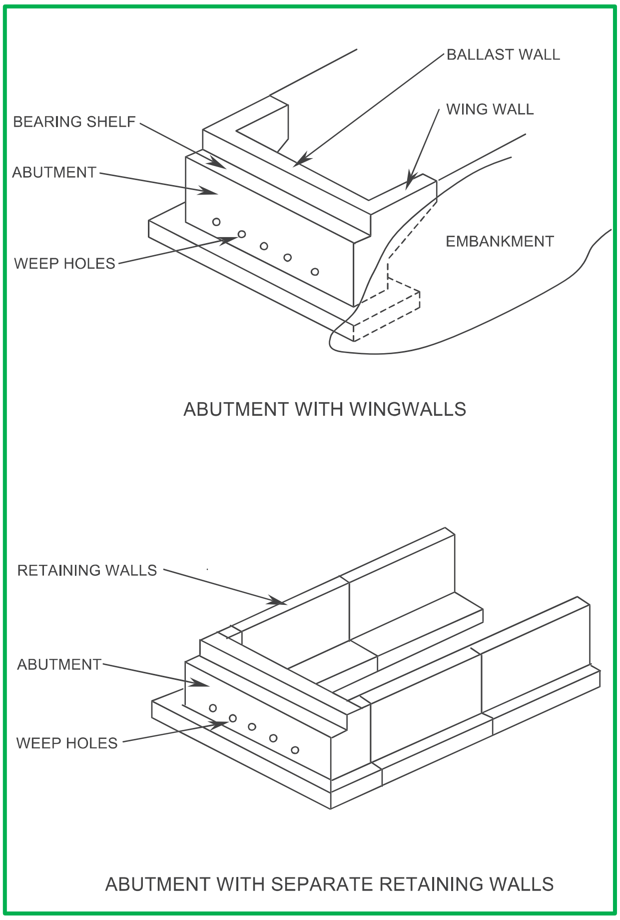


Figure 8.40: Abutment details

Timber abutments may be considered acceptable for low volume road structures but their vulnerability to deterioration and short service life should be recognised. Gabions can also be used (see Figure 8.41) providing fill material of suitable size and resistance to water damage is available. They have the advantage of providing natural drainage to the approach road. However, they are susceptible to damage and settlement due to scour and should be checked regularly to ensure that the wire has not corroded. Gabion abutments are not suitable for situations with a paved road surfaces because of the risk of settlement.

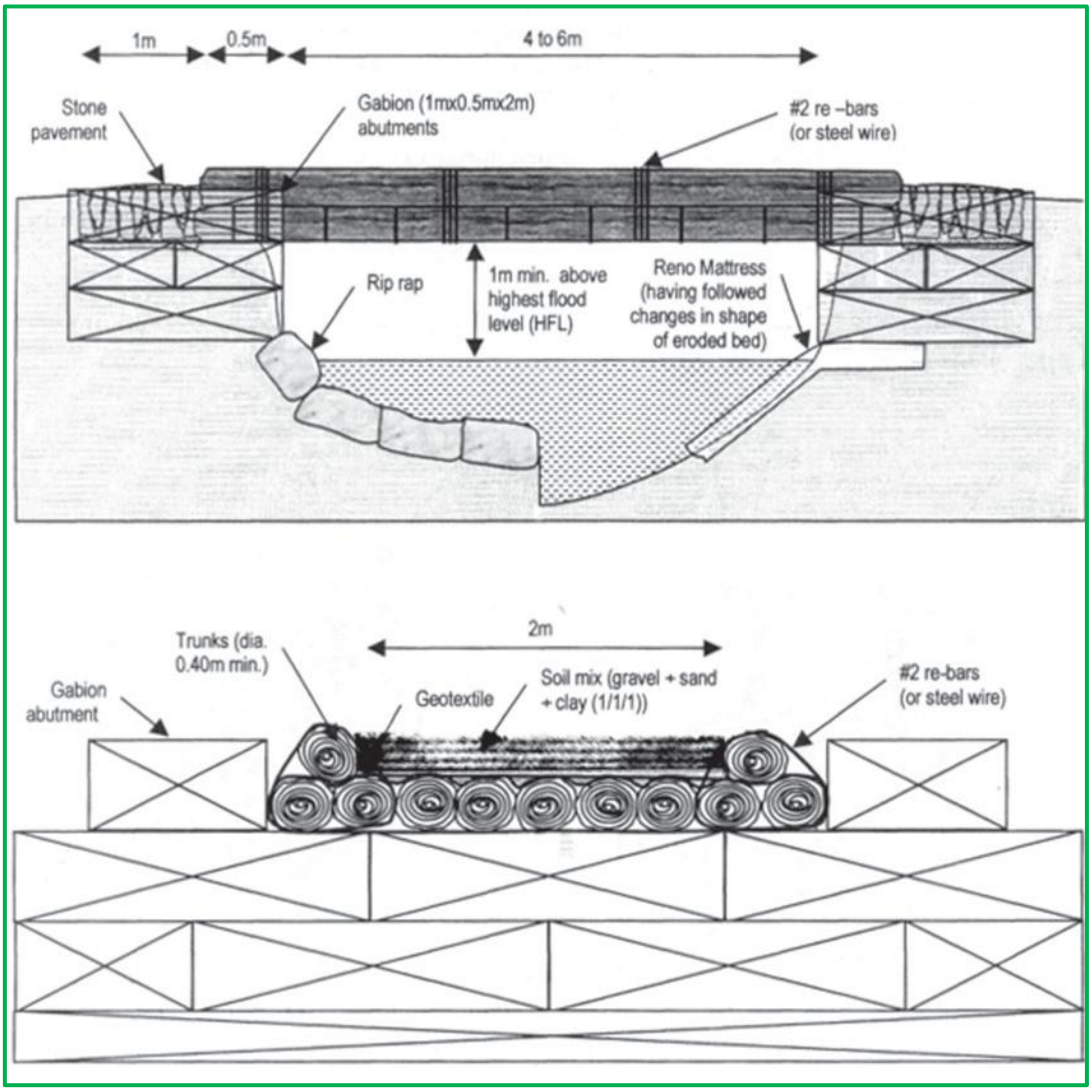


Figure 8.41: Gabion abutment log deck bridge

Abutments should be built away from the watercourse if possible to avoid scour problems even if it means an increase in length of bridge. High abutments are expensive and it may be more cost effective to increase the span if smaller abutments can be constructed further back from the watercourse. Further information about the options for filling behind abutments is provided in Section 8.8 on approach ways.

Abutments experience lateral loads resulting from the action of the backfill material. The most critical loading situation is often when the abutment has been constructed to full height but before the deck is constructed to provide propping support. To achieve this it may be convenient to delay completion of the backfilling operation until after the deck has been placed.

8.12.12 Piers

Piers can be the weakest parts of bridges and are most susceptible to damage by scour. The number of intermediate piers should be minimised and they should be omitted completely if possible. If it is necessary to include piers they should be oriented exactly in the direction of the water flow to minimise the obstruction and water turbulence. Typical pier shapes are shown in Figure 8.42.

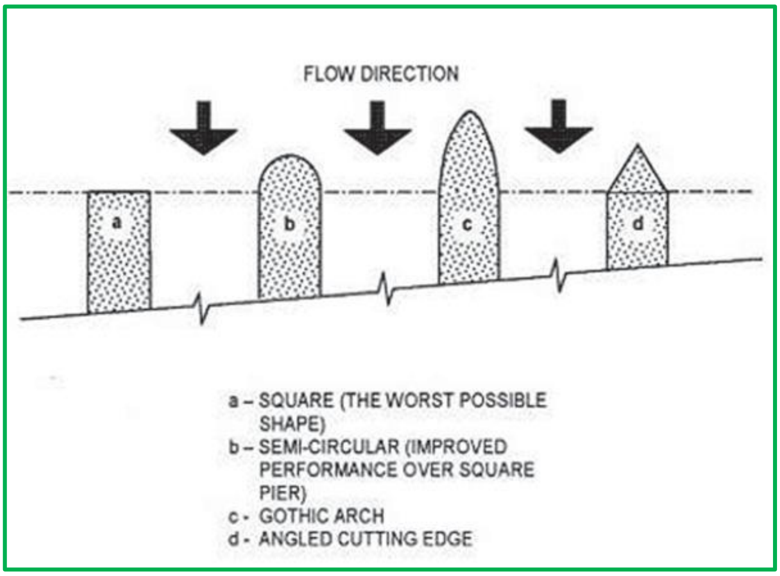


Figure 8.42: Pier shapes (Plan view)

Section 8.1 on scour presents a simple estimation of the potential scour depth that may be expected around a pier. The footing should be placed well below this depth unless a firm rock foundation is encountered. The shape of the pier will affect the amount of scour and designers should always aim to construct piers with cross-sections which will minimise their effect on the water flow.

Design procedures are similar to those for abutments and the guidelines given above should be followed, however, performance and stability requires more attention.

Piers are required to support the deck of a bridge or the base of an arch. They may therefore be called upon to carry large vertical loads to the foundations through footings. Footings may be considerably larger than the piers if the ground conditions are poor. The form and shape of the pier will depend on the bearing capacity of the foundation material. The bearing capacity of typical soils is given in Chapter 5, Section 5.1.5.

Stonework or brick masonry is the most suitable for pier construction due to its ease of construction, durability and resistance to scour. It can also be used to create permanent formwork for the pier and allow the use of other fill material in the middle (refer to Section 8.8 on fill material in approach ways). Reinforced concrete piers will tend to be more expensive than masonry due to the increased temporary works required; the probable need to transport steel to the bridge location; the need for shuttering and the required steel fixing skills. Timber would be a third choice although it requires frequent inspection and maintenance. Timber must be braced due to its lower strength capabilities; this will ensure lateral forces due to the water flow can be resisted. Gabions are not recommended for use as piers because of scour and settlement risks.

8.12.13 Bearings and joints

On major bridge spans (>20m) bearings and joints are required to allow movement of the structure to occur without structural damage. For bridges of less than 10m spans, these movements are small enough to be catered for by simple bearings such as a sheet of felt or rubber placed between the beams and the abutment, or can be resisted by stresses in the structural elements. Nevertheless, bridge movements cannot be ignored and should be considered as part of the design and construction of the bridge.

Movements arise from vehicle loading, pedestrian movement, temperature, wind and earthquakes. Wind and earthquake loading are major considerations for long span bridges but are not normally considered for bridges with spans less than 50m. Where high winds and earthquakes are expected, however, detailing should be such that lateral and lifting forces are resisted by suitably tying down the deck and structural elements. Vibrations from pedestrians, and particularly from vandalism, can cause problems on “lively” structures and decks should be prevented from jumping off their supports. Simple upstands at the supports on either side of the deck will be sufficient to prevent lateral movements in most cases. Steel or timber dowels can also be used where appropriate.

It is difficult to construct a road continuously over a bridge. The construction joints cause many problems even in well-designed structures and paved roads. The ingress of moisture and differential movements between the bridge structure and the backfill material invariably causes progressive damage which adversely affects vehicles as well as the bridge. On low volume roads, where vehicle speeds are low, the effect of this is not serious and routine maintenance is sufficient to maintain a smooth ride. In some cases, however, it may be a serious problem and a proper drainage system may be required to prevent major damage.

8.12.14 Parapets

Generally, bridges are constructed with parapets to prevent people from falling over the edge or to provide containment for vehicles in the case of accidents. For low volume roads, however, these are often not necessary. Some form of kerb to prevent vehicles from slipping over the edge or to provide some degree of protection to pedestrians should always be considered.

Where significant flows of pedestrians or animals use the bridge regularly, handrails are required particularly where a hazard such as a dangerous drop (greater than 2m) exists. Handrails should be 1m high and are most conveniently made from timber. Where children are expected to use the bridge regularly, a mesh type of barrier may also be necessary to prevent them climbing or falling through the parapet.

8.13 Other Design Issues

8.13.1 Debris control

During a flood, vegetation and other debris will be carried in the water. The designer must make sure that this debris will not either damage the structure itself or cause a blockage in the water flow which then damages the structure. In the case of bridges it is particularly important that the water does not overtop the deck because it not designed to withstand the water flow. Table 8.27 below provides minimum clearances that should be provided between the maximum water level and the bottom of the bridge deck.

Table 8.27: Minimum deck clearances

Discharge (m^3/s)	Minimum clearance (mm)
< 0.3	150
0.3 - 3.0	450
3.0 - 30	600
> 30	1000

8.13.2 Road signage

Bridges, drifts and any other structures causing a restriction in the road width should be well marked by signs to warn approaching drivers. Depending on the visibility along the road, the sign should be placed between 50 and 100m back from the obstruction and about 1.5m from the edge of the road. Fixings should be robust and tamper proof. If theft of metal signs/components is a problem at the structure location, then signs should be painted on a masonry backing. On surfaced roads, surface markings may be an option.

8.13.3 Carbon footprint

It is likely that there will be increasing concern regarding the sustainable use of resources and the carbon footprint of road works and, particularly, structures, both in the initial construction and life cycle of the infrastructure. The designer should accommodate any current national and regional requirements in the planning and design of the structures.

PLATES

Plate 1 Guide stones indicating narrowing road width at approach to bridge.	
Plate 2 Stream drift.	
Plate 3 Vented ford.	

Plate 4 Large bore multi-arch culvert.	
Plate 5 Masonry single span arch bridge on rock foundations.	
Plate 6 Block masonry used as wingwalls to a double concrete pipe culvert.	

Plate 7 Dry-stone wall.	
Plate 8 Gabion erosion control structure downstream of a culvert	
Plate 9 Fired clay bricks used as bridge abutment	

Plate 10 Failure of bridge structure due to a combination of constriction of the watercourse), scour and inadequate protection of abutments.	
Plate 11 Compaction of fill between twin corrugated steel culvert pipes.	
Plate 12 Timber bridge-deck	

LOW VOLUME ROAD MAINTENANCE BOOKLET

South Sudan

Ministry of Roads & Bridges (MRB)

Government of South Sudan

May 2013

Table of Contents

FOREWORD

This first edition of the Low Volume Road Maintenance Booklet has been prepared after circulation and discussion of a draft with the aim of gathering comments and contributions from stakeholders and potential users.

It is intended that the document will be further refined from time to time to gather further local experience and facilitate application for maintenance of Low Volume Roads throughout South Sudan.

Please send any comments and contributions to:-
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This Booklet forms part of the South Sudan Low Volume Roads Manual.

ACKNOWLEDGEMENTS

Some material for this Booklet has been taken from the World Road Association (PIARC) International Road Maintenance Handbook. Additional images have been provided by Intech Asset Management and UNOPS. Material has been adapted from the LVR Manual and Road Maintenance Booklet, and other regional experience and documentation. This SS LVR Booklet has been prepared under coordination by UNOPS with support provided by UKAID through AFCAP.

1. THE AIMS OF THIS BOOKLET

This Booklet has been developed by the Government of South Sudan as one of a number of initiatives to help rapidly expand, develop and maintain the Low Volume Road network to provide greatly improved road access and lower the costs of transport for rural communities.

The Booklet is applicable to earth, gravel and paved roads that may be carrying up to about 300 motor vehicles per day.

The Booklet specifically sets out guidance for road and other authorities and agencies, contractors, local communities, and private road owners on how to maintain road access making the best use of the limited resources available to them. It also advises how it may be possible to mobilise outside resources to enhance the impact of their own initiatives.

By focussing on the use and mobilisation of available local resources, such as a range of materials and local labour and skills, it is entirely possible to build and maintain durable all-weather road access suitable for all traffic from pedestrians and animal transport up to buses and trucks, and at reasonable cost.

The Booklet advises:

- What is Maintenance?
- What needs to be done to achieve all-year Basic Road Access,
- How to identify the main problems/defects and solve them,
- How to make the most of local materials and skills,
- How to maintain the road access at low cost,
- How to make priorities
- How to organise and plan the work
- Where to obtain further advice and outside assistance.

The Maintenance activities and codes used in this Booklet are provisional, pending development of National Road Maintenance Specifications.

2. SOME BASIC QUESTIONS

What is a road?

A road is a vital asset for economic and social development, constructed with a running surface to allow the passage of motor or other vehicles. It is defined as having a camber (crossfall) to shed rainwater to the side, and a system of side drains and other drainage features to discharge water away from the running surface. A track, by comparison, may have neither of these features. A road may be earth surface, gravel or paved.

What is a Low Volume Road?

A Low Volume Road (LVR) is generally one that generally carries less than 300 motor vehicles of traffic each day (total vehicle flow both ways).

What is Maintenance?

Maintenance is the range of activities necessary to keep a road and associated structures in an acceptable condition for road users, as intended when it was design and constructed.

What is the Essence of Road Maintenance?

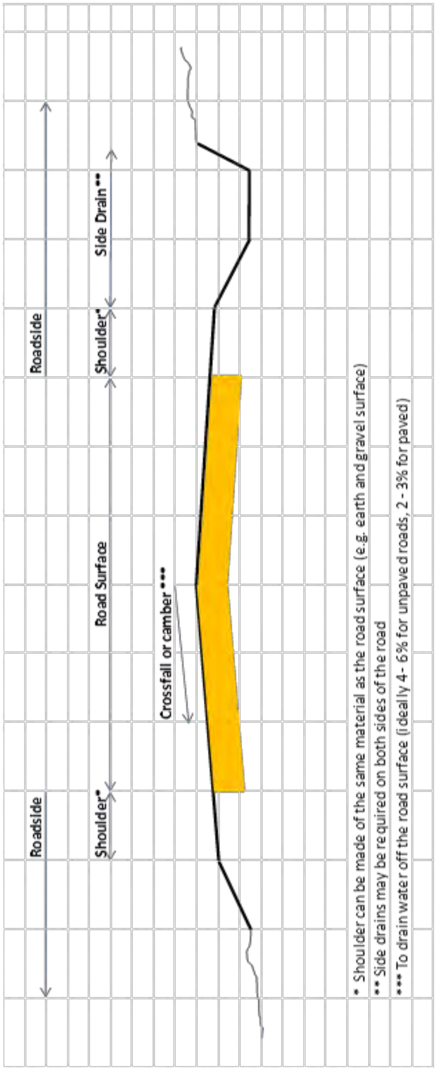
For Low Volume Roads, maintenance can be summarised in three basic aims:

- **Keep the road surface in good condition (for example, repair ruts and potholes),**
- **Maintain the road surface camber to shed water to the side of the road,**
- **Maintain the drainage system to safely lead water away from the road.**

All maintenance activities are organised to carry out or support these basic aims.

3. ROAD FEATURES

Road Cross Section (imagine a vertical slice through the road)

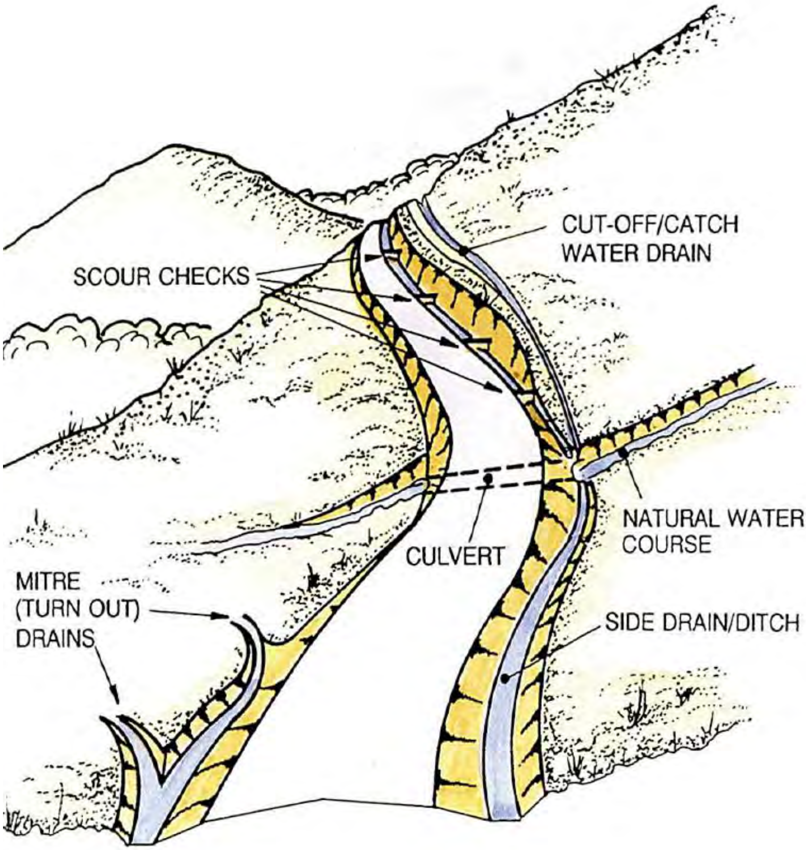


* Shoulder can be made of the same material as the road surface (e.g. earth and gravel surface)

** Side drains may be required on both sides of the road

*** To drain water off the road surface (ideally 4 - 6 % for unpaved roads, 2 - 3% for paved)

Drainage Features



Structures (bridges, drifts or culverts) are usually provided at watercourse crossing points.

The Terminology Section (15) provides the explanation for each road term or feature.

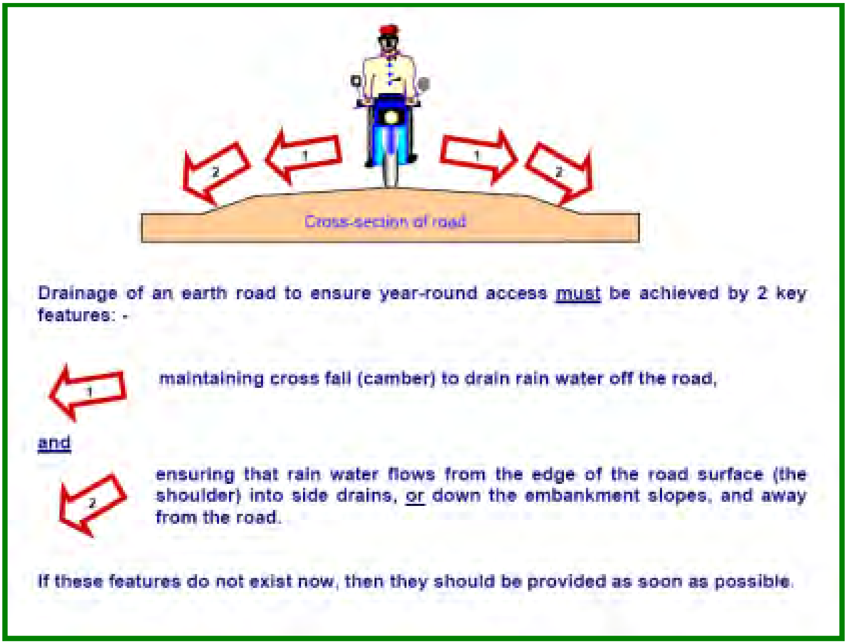
4. BASIC ACCESS

Basic Access is achieved to provide year-round passage to routes by turning them from weather-dependent tracks into proper roads. A proper road can be formed from the natural soil (Engineered Earth Road) in many locations.

The main features of a road are:-

- A camber to shed rainwater to each side of the road
- Side drains, turnout drains, drifts and culverts (or other structures) to manage the water collected from the road surface and to discharge it carefully to avoid erosion or other problems.

This usually means that the road surface needs to be slightly higher than the ground at the road side.



Most natural soils can be built into an (Engineered Natural Surface - ENS) Earth Road. However, for route sections with weak soils, or if traffic increases to more than about 50 motor vehicles per day, or on steep hills, it may be necessary to improve the road surface with gravel or various types of paving. This can be achieved at relatively low cost by applying **a Spot Improvement** approach to improve these limited problem sections, often using local labour and materials. Other Parts of the LVR Manual describe how such improvements can be designed and constructed.

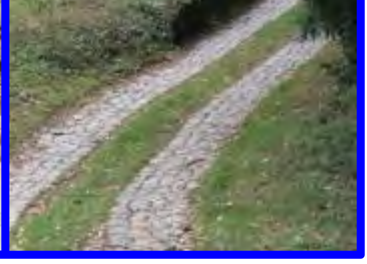
Most routes can be built to Engineered Natural Surface (ENS) – Earth road standard for most of their length. If in doubt about soil suitability, seek advice from the MRB or State Road Authority. The **Spot Improvements** at problem sections of the route may be selected from the following list of options and surface improvements:

- Drift or other structure
- Culvert
- Embankment
- S-01: Engineered Natural Surface (ENS)
- S-02: Natural gravel
- S-03: Waterbound/Drybound Macadam
- S-04: Hand Packed Stone
- S-05: Stone Setts or Pavé
- S-06: Mortared Stone
- S-07: Dressed stone/cobble stone
- S-08: Fired Clay Brick, Unmortared/mortared joints
- S-09: Bituminous Sand Seal
- S-10: Bituminous Slurry Seal
- S-11: Bituminous Chip Seal
- S-12: Bituminous Cape Seal
- S-13: Bituminous Otta Seal
- S-14: Non-reinforced concrete
- S-15: Wheel track paving





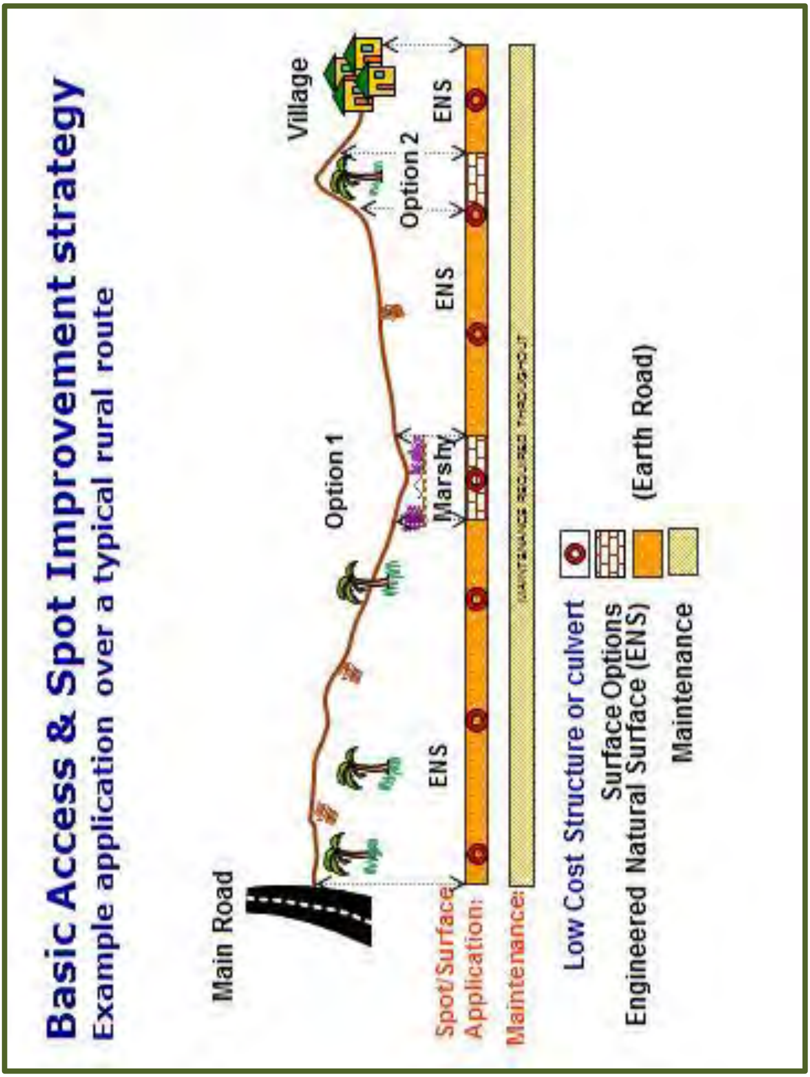


The choice of spot improvement should be based on the location features and the materials and skills available locally. Great care should be used in using gravel as a road surface in some circumstances. It is unlikely that it will be suitable due to high costs of replacing the surface material that will be lost due to rainfall or traffic, or dust nuisance in the locations; where:

- Traffic is more than 200 motor vehicles per day
- Annual Rainfall is greater than 2,000mm
- Slope of road surface is more than 6%
- Through community settlements
- The haul distance from the quarry/pit to the road site is more than 10km
- The road section experiences flooding, or
- The gravel is of poor quality.

Despite initial low construction costs, it is important to appreciate that under a **Basic Access and Spot Improvement** strategy it is essential to arrange the necessary **Regular** maintenance of the ENS and any gravel surface and drainage, and **Occasional** maintenance of the improved surface sections and structures, to preserve the initial construction investment.



5. FULL ACCESS

Where sufficient funds or resources are available, a Low Volume Road may be constructed to **Full Access** standard. This should provide uninterrupted all-year, high quality, relatively high speed, low surface roughness access. There should be no closures in the rainy season.

In practical terms **Full Access** may involve the provision of a gravel or sealed/paved surface throughout the length of the route link.

This level of access will also require appropriate levels of regular maintenance. The annual cost and resources required for this maintenance may be more than for **Basic Access**.

6. THE PURPOSE OF MAINTENANCE

From the moment that a road is constructed or upgraded, it will deteriorate due to the effects of weather and traffic. Maintenance is required to be carried out from time to time to restore its condition to be close to its as-constructed state. If maintenance is not carried out the road will continue to deteriorate making passage increasingly difficult, uncomfortable and expensive to road users. The road may even become impassable for part or all of the year.

It is convenient to view **Maintenance** as correcting **Defects.**

In practical terms it is useful to identify and quantify the **Defects**, and then arrange the necessary **Maintenance** to be carried out. In this Booklet **Defects** and **Maintenance** activities are grouped into the following colour coded groups:

Regular Maintenance (Routine)

Roadside Activities
Drainage
Road Surface
• Earth Road
• Gravel Road
Structures

Occasional Maintenance (Periodic)

Road Surface
• Gravel Road
• Paved Road
Structures

This Booklet covers the treatment of some 30 common **Defects**. From time to time, other defects/activities may be required. Advice should be obtained from the MRB or State road authorities for any problem or road aspect not covered in this Booklet.

7. REGULAR MAINTENANCE

These are the maintenance activities that are likely to be required somewhere on a road link every year. Most of the tasks may be carried out manually. Mechanised or equipment based alternatives are available for some tasks as indicated.

Regular Maintenance is conveniently divided into four main groups of activities that are often carried out on a seasonal basis:

- Roadside Activities
- Drainage
- Road Surface
  - Earth Road
  - Gravel Road
- Structures

Roadside Activities

Defect	**Maintenance Activity (Page No.)**
1. Trees and bushes growing on roadside	131 Brush clearing (P21)
2. Shoulder uneven or eroded, or does not drain properly	132 Shoulder Rehabilitation (manual) (P25)
3. Shoulder erosion	133 Plant grass and water (P28)
1. Grass on shoulder or in drain requires cutting	134 Cut grass (P21)
2. Shoulder uneven or eroded, or does not drain properly (minor)	240 Shoulder Blading (mechanised) (P25)
2. Shoulder uneven or eroded, or does not drain properly (major)	241 Shoulder Rehabilitation (mechanised) (P25)

Drainage

Defect	**Maintenance Activity (Page No.)**
4. Culvert silted/obstructed	121 Culvert Cleaning (P31)
5. Ditch silted	122 Ditch Clearing (Manual) (P34)

6. Ditch or slope eroded (minor)	123 Repair Erosion Damage (Selected Fill) (P42)
7. Ditch or slope eroded (major)	124 Repair Erosion Damage (rockfill) (P44)
7. Slope eroded (major)	129 Wattling (P44)
8. Mortared Masonry damaged	125 Mortared Masonry Repair (P48)
9. Dry Masonry damaged	126 Dry Masonry Repair (P51)
10. Gabion structure damaged	127 Gabion Structure Repair (P53)
11. Erosion in ditch	128 Build wooden/stone scour check (P56)
5. Ditch silted	230 Ditch clearing (mechanised) (P34)

Road Surface

Defects and maintenance requirements depend on the road surface type.

Earth Road

Defect	Maintenance Activity (Page No.)
12. Road surface potholed, rutted or uneven, and does not drain to edge	112 Reshape & Compact Earth Road Camber (P59)

Gravel Road

Defect	Maintenance Activity (Page No.)
13. Road Surface potholed	110 Spot Repair Selected Material (P68)
13. Road Surface potholed	111 Spot Repair Crushed Aggregate (P68)
14. Road Surface rutted or uneven, and does not drain to edge (Minor: <3cm))	220 Blade Gravel Road (light) (P73)

15. Road Surface rutted or uneven, and does not drain to edge (Major: >3cm)	221 Blade Gravel Road (heavy) (P80)

Structures (Bridges/Drifts/Large Culverts)

Some of these activities will require skilled personnel

Defect	**Maintenance Activity (Page No.)**
16. Debris or vegetation affecting or endangering structure	400 Cleaning, Clearing, Sweeping, De-silting, Unblocking or Removal of vegetation or flood/wind borne debris (Structure/ inlets/outlets) (P90)
17. Connectors/fixings are loose/damaged/missing	401 Repair of loose/missing connectors/fixings (P92)
18. Planks/kerbs are damaged/missing	402 Replace damaged or missing planks or kerbs (P93)
19. Paintwork defective or damaged	403 Paint main or minor parts of structure/furniture (P94)
20. Danger or evidence of insect or moisture attack of timber components	404 Apply wood preservative or insect treatment to timber components (P96)
21. Masonry or concrete or joints defective (minor)	405 Pointing or repair of masonry/concrete (P97)
22. Structure furniture defective	406 Repair parapets, marker posts, safety barriers, signs or other furniture (P98)

8. OCCASIONAL MAINTENANCE

These are the maintenance activities that may be required somewhere on a gravel or paved road section or link, or on a structure, after a period of a number of years. The category of repair depends on the type of road surface constructed. Some of the Occasional Maintenance tasks may be carried out manually with the aid of simple tools or equipment. Others will require skilled personnel or large equipment. Transport may be required for the haulage of materials. Many of the activities will require careful planning and mobilisation of the necessary resources.

Gravel or Paved Road

Defect	**Maintenance Activity (Page No.)**
23. Gravel layer too thin	317 Gravel Resurfacing (Selected Material) (P99) 318 Gravel Resurfacing (Crushed Aggregate) (P99)
24. Paved road pothole or surface defect	113a Spot /pothole Repair (Macadam) (P106)…….. 113b Spot /pothole Repair (Stone setts) 113c Spot /pothole Repair (Mortared stone) 113d Spot /pothole Repair(Dressed stone) 113e Spot /pothole Repair(Emulsion chip seal) 113f Spot /pothole Repair(Emulsion sand seal) 113g Spot /pothole Repair(Emulsion gravel/slurry seal) 113h Spot /pothole Repair(Un-mortared brick) 113i Spot /pothole Repair(Mortar jointed brick) 113j Spot /pothole Repair(Non- reinforced concrete) 217 Pothole Reinstatement (cold mix) 219 Pothole (Base Failure Repair)

Structures (Bridges/Drifts/Large Culverts)

Defect	Maintenance Activity (Page No.)
25. Random stone filling defective	410 Repair Random Stone filling (P116)
26. Retaining wall defective	411 Retaining wall repairs (P117)
27. River or stream bed scoured adjacent to structure	412 Watercourse scour repairs (P118)
28. Gabion walls or mattress defective	413 Gabion basket repairs (P120)
29. Structural repairs for the following serious defects: Structural timber decay, splitting or insect attack, bulging masonry, cracked concrete or masonry, honeycombed concrete, spalling concrete, serious rust or chemical stains, exposed or corroding reinforcement or pre-stressing steel, damp patches on concrete, seriously corroded structural steelwork, damaged/distorted structural steelwork, missing/loose rivets, bolts or other fixings, cracks in structural steelwork, settlement of deck, piers, abutments or wingwalls, expansion joint or bearing defects, erosion requiring piling works.	414 Major structural repairs. These will require the expertise of an Engineer to assess and design/specify the remedial works in response to the scale and nature of the defects (P122)

9. ROAD MAINTENANCE TOOLS

Road Maintenance activities require a range of simple and inexpensive tools and control aids. However construction quality tools are preferable to agricultural quality. For further guidance see Reference 5.

10. MAINTENANCE ACTIVITIES

REGULAR MAINTENANCE (ROUTINE)

ROADSIDE ACTIVITIES

Defect 1: Grass, weeds, bushes or trees have been allowed to grow unchecked at the side of the road.

Development, if neglected:

- drainage ditches cannot be cleaned
- surface water can pond at the edge of the road and weaken the road surface,
- silt can accumulate at the edge of the road,
- the visibility for road users is reduced, with increased risk of accidents with persons or animals,
- increased fire hazard in the dry season.

Maintenance Activity

- **134 Grass Cutting**
- **131 Bush Clearing**

These two activities may be required individually or together. With the exception of arid areas, these are Regular activities, involving control of grass, weeds, bush and trees where these are not controlled by animal grazing. They may be required to be carried out at least once a year after the rainy season, or more often where the climate causes vegetation to grow rapidly.

- Grass Cutting

Grass and weeds should be cut at least once a year after vegetation reaches full growth or according to local experience. The vegetation should be trimmed by hand. Sickles, scythes, slashers, bushknives, or similar handtools will be required.

- Bush control & Trees

Any bushes on the road shoulders or drains should be cut down. Dead or leaning trees within the right-of-way which may fall on the roadway or block the drainage system, or block sight lines should be removed. The felling of trees, or the removal of large branches at heights of more than 2 metres above ground level can be hazardous. This work should only be carried out under expert supervision or by experienced workers. Trees should be felled using one- or two-man saws or axes. Ladders should be used for climbing trees, and ropes should be used to restrain trees and control felling. Traffic should be halted when the tree is finally toppled. All debris should be removed and disposed of safely.

- Disposal of debris

All cuttings and debris should be disposed of safely so that there is no risk of drains being blocked or fire hazard.

- Herbicides

Herbicides (weed-killer) are chemical agents intended to destroy or reduce vegetation growth. It is not recommended that herbicides or any chemical methods be used to control roadside vegetation. Some reasons are:

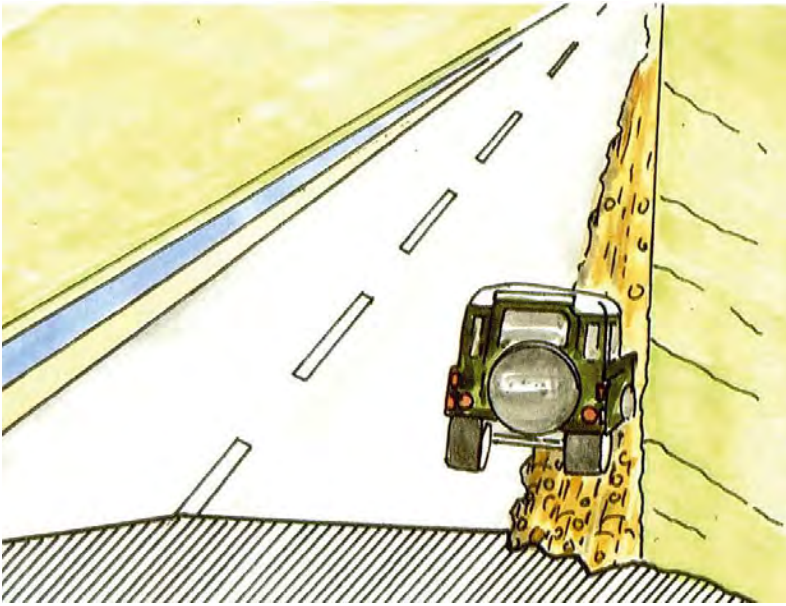
- herbicides can cause pollution of crops, rivers and streams and drinking water supplies,
- herbicides are often dangerous to health,
- herbicides are expensive, and must often be imported,
- herbicides do not always produce satisfactory results.

- Burning

Do not burn roadside vegetation to control its growth or the debris from Bush Clearing activities. The results may be more harmful than desired:

- the fire could spread and destroy valuable vegetation (trees, grass crops), and traffic signs,
- vegetation may grow faster after burning,
- smoke and flames blowing across the road are dangerous for traffic.

Defect 2: Shoulder eroded, mis-shaped or does not drain away from roadway



Development, if neglected:

- hazard to road users, increased risk of accidents,
- obstruction of water flow from roadway,
- inadequate support for the road surface,
- water collects and softens/weakens the shoulder and pavement
- the edge of the pavement will break when vehicle wheels run over it,
- the roadside ditch may become blocked by the excess material.

Maintenance Activity

- **132 Shoulder Rehabilitation (manual)**
- **241 Shoulder Rehabilitation (mechanised)**
- **240 Shoulder Blading (mechanised)**

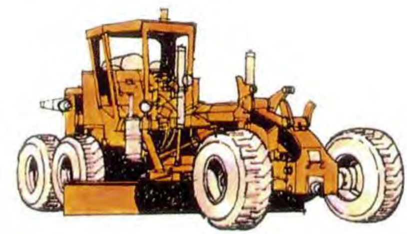
a) Rehabilitation Manual Method (132)

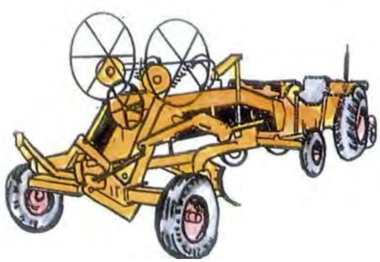
The low surfaces and all high material should be loosened with a pick axe or mattock. The shoulder should be reshaped to slightly above the final level and the correct crossfall using a shovel and rake. Any low spots should be topped up with fresh material of the same type and quality as the existing shoulder. The crossfall of the uncompacted material should be checked with a camber board. Excess material should be spread over the embankment slope or transported by wheelbarrow to a convenient and safe dumping site. Material should not be deposited on the roadway or in the drainage ditch. If the shoulder material is dry it should be sprinkled with water. The shoulder is then compacted with hand rammers or a hand roller. The compacted surface should butt smoothly onto the roadway. Check the finished crossfall with the camber board and repeat the reshaping if necessary. Brush all loose material and debris from the roadway.

b) Rehabilitation Mechanised Method (241)

The existing surface of the shoulder should be scarified with the tines of a motor or towed grader. This will loosen the raised areas and allow the loosened material to key into any existing low areas. The shoulders should be reshaped to slightly above the final level and the correct crossfall using a number of passes of the motor or towed grader blade. Care must be taken not to damage the edge of the roadway with the blade. Any low spots should be topped up with fresh material of the same type as the existing shoulder. The cross fall of the uncompacted material should be checked with a camber board. Excess material and vegetation should be graded to the embankment side slope. In cuttings, excess material and vegetation should be graded into a windrow for removal by wheelbarrow, tractor and trailer or truck. Material should not be deposited on the roadway or into the drainage ditch.

If the shoulder material is dry it should be sprinkled with water. The shoulder is then compacted using a self-propelled, towed or pedestrian roller. The compacted surface should butt smoothly onto the roadway. Check the finished crossfall with the camber board and repeat the reshaping if necessary. Brush all loose material and debris from the roadway.





c) Shoulder Blading (mechanised) (240)

This Regular maintenance activity may be carried out if no additional material is required to be added to the shoulder. The shoulder material should contain sufficient moisture to enable the reshaped material to be compacted by the grading equipment or a roller. It is therefore ideally carried out in the rain season. Otherwise, water should be added to ensure a more durable surface finish.

Defect 3: Existing roadside surface requires protection from erosion (this activity may be required as a follow up from Maintenance Activity 123)

Development, if neglected:

On some steep slopes or erodible soils surface scour may occur if vegetation cover is not established. This could damage to the roadway, shoulders, drainage system or earthworks.

Maintenance Activity

- **133 Plant grass and water**

a) Seeding

Grass seeding will only be successful if climate and soil conditions are favourable. The best advice can be provided by the local department of agriculture on:

- topsoil required,
- seed type, rate of spread,
- fertilizer types, rate of spread,
- most favourable season and weather for seeding,
- other preparatory treatment of the soil (for example mixing-in ground limestone).

Typical procedure:

- loosen the soil to a depth of 10 cm in the area to be seeded using rakes or similar tools,
- spread the topsoil to a depth of at least 5 cm,
- water the area to be seeded,
- apply fertilizer at the specified rate,
- (apply ground limestone/additive at the specified rate and mix-in,)
- apply seeds by hand at the specified rate,
- lightly roll the seeded area within 24 hours using hand roller, only if the soil does not adhere to the roller,
- the seeded area should be watered as required until the grass has taken hold.

b) Turfing (grass sodding)

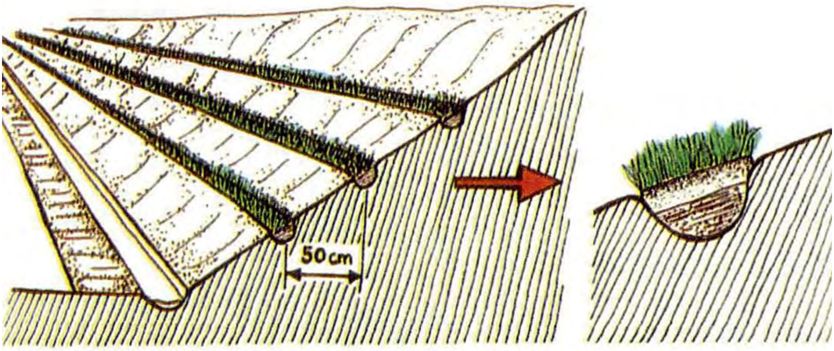
This method is suitable when climate and soil conditions are favourable and when fresh grass sods (soil clumps containing grass and its roots) are available.

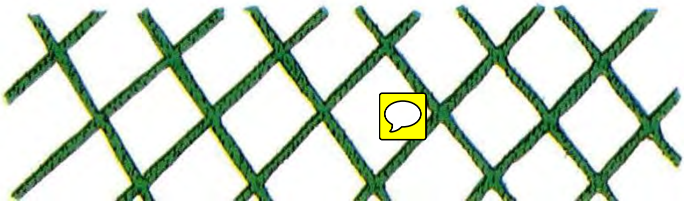
The general procedure is:

- prepare the area to be turfed to required levels and slopes,
- where no topsoil is present, haul suitable topsoil to site and spread evenly to a depth of not less than 5 cm.
- water as required,
- cover the area with freshly cut sods without weeds. Sods are to have thickly matted roots which should not have dried out. Tamp sods with tamper or use hand roller. On slope use stakes to hold sods in position,
- water the turves at intervals until the grass takes hold.

Other patterns of sodding are:

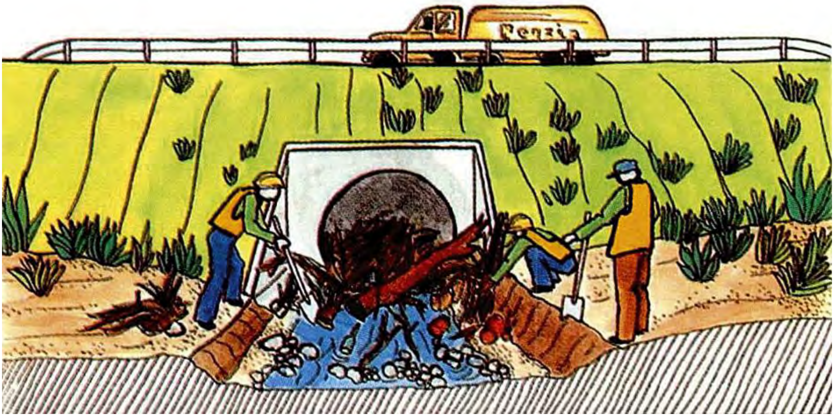
- spot sodding (sods spaced about 50 cm in holes deep enough to take sod and about 5 cm topsoil),
- trench sodding. Lay sods on 5 cm topsoil bed in parallel trenches. Trench spacing about 50 cm along contour or x-shaped pattern.


50 cm



DRAINAGE

Defect 4: Culvert silted or obstructed with debris



Development, if neglected:

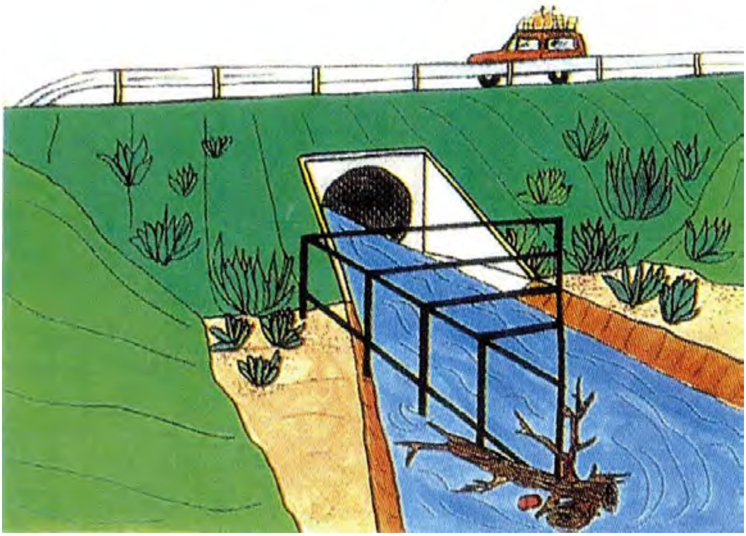
The intended waterway opening will be so reduced that flood water cannot flow as intended. Flood water will back-up or pond on the upstream side of the culvert and may eventually over-flow the road embankment. The road is then in danger of being washed away.

Maintenance Activity

- **121 Culvert Cleaning**

In order to function properly, a culvert must retain the full opening over its complete length. In addition, the upstream approaches and the downstream area must be free of obstructions. Floating debris (tree branches, bushes, etc.) carried by water is a great danger to culverts. The debris may completely block the culvert inlet. The following Regular Maintenance activities may be required:

– if debris racks are already provided, these as well as the culvert opening should be freed of all accumulated obstructions,



– Clear any sand, silt or debris from inside the culvert. Sanding or silting of culverts, especially those with openings smaller than 1 metre, can be a particular problem. These culverts can be cleaned by pulling a cable or rope through, to which is attached any suitable object (e.g. a bucket). Alternatively a long handled trowel and spike can be used.

If the silting problem continues despite regular clearing, it may be necessary to reconstruct the culvert at a higher level or enlarge it.

Material and debris from the culvert must be spread or dumped where they cannot cause an obstruction to water flow, preferably on the downstream side of the culvert, well away from the watercourse.

This Maintenance task is best carried out before the rains and after any heavy rainstorm.

Defect 5: Ditch silted

Ditch partially or fully blocked by vegetation growth, bushes, fallen trees, debris, loose silt, loose rocks.

Development, if neglected:

Concentration of flood flow causing erosion and possible overtopping and damage to roadway, paving or shoulders.

Maintenance Activity

- **122 Ditch Clearing (Manual)**
- **230 Ditch clearing (Mechanised)**

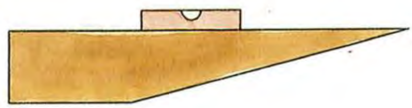
a) Manual Method (122)

This is a **Regular Maintenance** activity. The object is to remove all soil, high vegetation, materials and objects from the ditch which could possibly interfere with water flow or cause an eventual blockage of the ditch. This can include for example, rocks, loose silt and sand, weeds, trees, bushes, including their roots, etc. Dispose of these materials well away from the roadside so that water flow will not be impeded and they will not fall or wash back into the ditch. NO soil material or debris should be placed on the roadway. On unlined ditches a short grass cover can help to stabilise the bottom and sides of the ditch. Therefore where a side ditch is established to the correct depth and profile with grass cover and no erosion, it is advisable to merely cut the grass short. This will leave the roots in place to bind the drain surface together.

At some locations it may be necessary to RESHAPE/REGRADE/DEEPEN the ditch.

It is advisable to adopt a trapezoidal ditch shape when using labour methods. The excavation using a hoe/mattock and shovel is easier than for a V-shaped ditch. An added advantage is that the flat invert causes less concentration of water than a V-ditch.

A ditch & slope template should be used to obtain the correct drain shape.



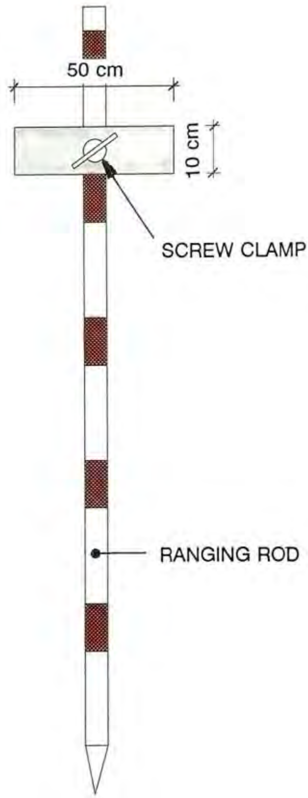
DITCH AND SLOPE TEMPLATE

- using the template a 50 cm wide slot should be excavated to the correct ditch shape every 10 metres along the drain. The slots act as a guide for excavating the ditch to the correct shape,
- in flat areas, the gradient of the ditch should be checked using ranging rods and profiles or similar methods, to ensure that water will not pond. The levels at adjacent slots should be checked using a line and level or abney level, and the level of the slot adjusted if necessary.

– excavate all surplus material between the slots and to the correct shape with the aid of stringlines stretched between the slots. If necessary the intermediate invert levels can be checked using a traveller sighted between the ranging rod profiles.
– material excavated from the drain must be removed and spread well clear of the drain so that it cannot later fall or wash back into the ditch.
– the shape can be checked during the excavation activity using the ditch template.

When excavating a completely new ditch it is preferable to split the task into two operations:

i) cut the central rectangular shape and check with a template (INVERT).
ii) cut the slopes and check with the full ditch & slope template (SLOPES).

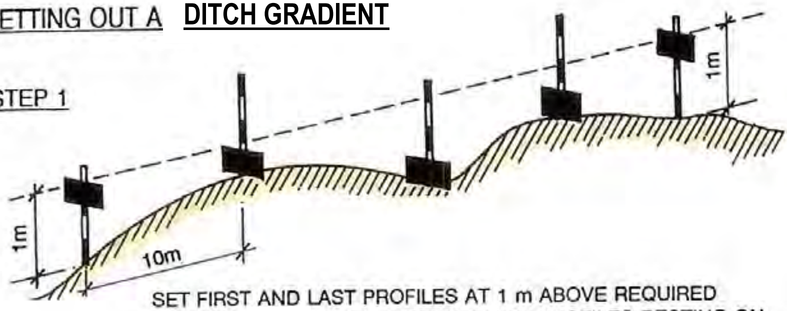


The alignment or route of the drain should be set out using stringlines and pegs. The ranging rods and profiles should be set up at the start and outfall of the ditch. Intermediate profiles may be required on long ditches. The levels of intermediate slots can be determined using the traveller.

This Maintenance task is best carried out before the rains and after any heavy rainstorm.

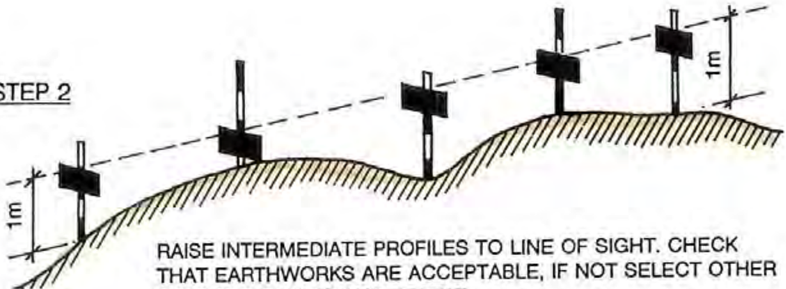
SETTING OUT A DITCH GRADIENT

STEP 1



SET FIRST AND LAST PROFILES AT 1 m ABOVE REQUIRED FINISHED DITCH LEVEL, INTERMEDIATE PROFILES RESTING ON GROUND

STEP 2

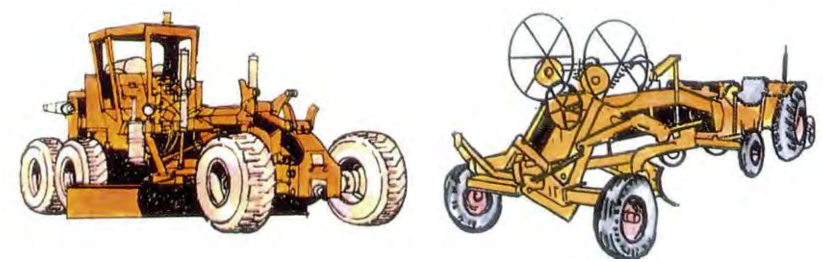


RAISE INTERMEDIATE PROFILES TO LINE OF SIGHT. CHECK THAT EARTHWORKS ARE ACCEPTABLE, IF NOT SELECT OTHER STARTING POINTS AND REPEAT

STEP 3

PLACE NEW DITCH LINE PEGS AT EACH RANGING ROD WITH TOPS AT 1 m BELOW THE PROFILE BOARDS - THIS IS THE FINISHED DITCH CENTRE LINE LEVEL.

b) Mechanised Method (230)



This activity is suggested where long sections of V- shaped ditches are to be maintained and cleaned and where high daily outputs are possible. The activity may be carried out by a motor or towed grader. The grader should always work by cutting in the direction of water flow in the ditch.

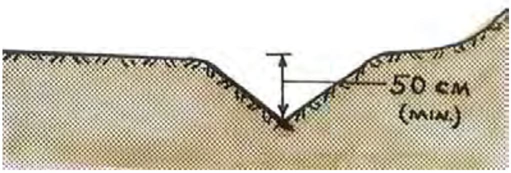
Case 1:

When the grader can operate only on the shoulder and in the ditch, but not beyond the ditch:

- start by grading the outside slope of the ditch, using the blade to windrow the soil to the bottom of the ditch between the rear wheels. (This can be repeated to obtain the desired depth of ditch. This part of the task can also be done manually),
- the next blade pass(es) are to clean the invert of the ditch by removing the windrow to the top of the ditch at road shoulder,
- the final pass is required to move the windrow material away from the shoulder ditch edge.

If the recovered material quality is inferior to that of the road surface, THE MATERIAL MUST BE REMOVED FROM THE SITE.

- on completion, the ditch should generally have a depth of 50 cm (minimum), which can be checked with a ranging rod and tape/rule,
- if necessary the grade of the ditch invert can be checked using the methods described in a) Manual Method (122).


50 CM
(MIN.)

Case 2:

When the grader can operate beyond the ditch. Reverse the operations shown previously:

- grade the inside slope, windrowing material to the bottom of the ditch. Repeat as necessary to achieve the desired depth of ditch,
- remove the windrow material to the top of the outside slope,
- move windrow away from ditch edge and spread the material so that it will not wash back into the ditch,
- on completion, the ditch should have a depth of 50 cm (minimum), which can be checked with a ranging rod and tape/rule,
- if necessary the grade of the ditch invert can be checked using the methods as described in a) Manual Method (122).

Defect 6: Ditch or slope eroded (minor)

Development, if neglected:

Damage to drainage system, roadway, structures, paving or shoulders.

Maintenance Activity

- **123 Repair Erosion Damage (Selected Fill)**

This activity may be sufficient for minor erosion damage to a ditch. However, reconstructing the ditch profile with selected fill material alone may not be sufficient to prevent the defect recurring within a short time. Loose stones or boulders should be removed. The defective section of ditch should be cut back to firm material and fresh material placed in layers not exceeding 15cm thickness and compacted with a hand rammer. If the material is dry it should be sprinkled with water before compaction. The added material should be trimmed back to the correct ditch profile and checked with the ditch template. Dispose of the excess materials well away from the roadside so that water flow will not be impeded and they will not fall or wash back into the ditch.

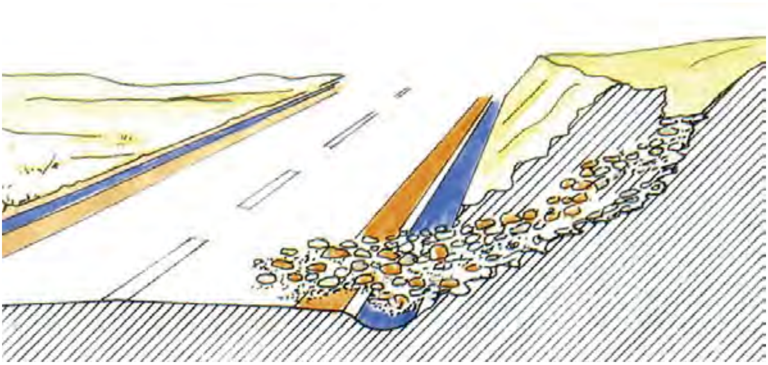
Scour checks may need to be installed to prevent recurrence.

Similar minor repairs may be carried out to eroded slopes.

It is likely that additional measures will be required such as:

- 133 Plant grass and water
- 124 Repair Erosion Damage (rockfill), or
- 128 Build wooden/stone scour check
- 135 Wattling

Defect 7: Ditch or slope eroded (major)



Development, if neglected:

Damage to drainage system, roadway, structures, earthworks paving or shoulders.

Maintenance Activity

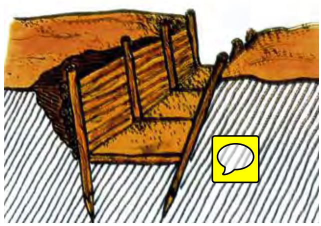
- **124 Repair Erosion Damage (rockfill),** or
- **129 Wattling**

A number of activities are possible to repair erosion damage to ditches and slopes. However it is important to try to determine the cause of the erosion so that the repair will minimize the risk of it recurring. It is advisable to obtain Engineer's advice where erosion is extensive.

Ditches

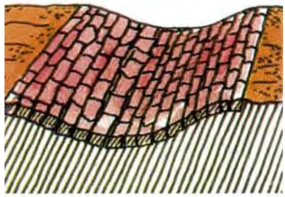
Drain sections are often laid at a steep gradient or on sharp bends without erosion protection along or at the outfall of the drain. The following options should be considered:

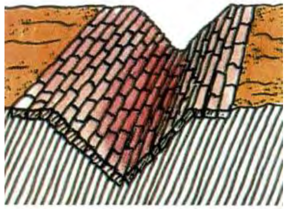
- **Repair the ditch with rockfill lining**
- Repair the ditch with timber lining
- Provide masonry lining

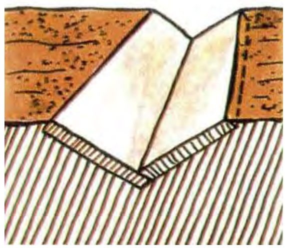


– Regrade/Realign ditch
– Provide relief ditch or culvert

Slopes







Slips or slope erosion/ instability are usually caused by adverse ground conditions or ground/surface water or both. The remedial works should be specified by an Engineer after an inspection of the site and the necessary investigations. Works are likely to be expensive and it is important to ensure an appropriate solution to the problem.

Dealing with slips and unstable slopes is hazardous and particular care should be taken to safeguard manpower, equipment and the road users.

The cheapest solution (if appropriate) is expected to be **Wattling**. Other principal, but more expensive, remedial options are:

– counterfort drains
– stone pitching the slope
– reducing slope angle,
– clearing slip material,
– surcharging the slope,
– gabions,
– cribwork,
– masonry retaining wall,
– concrete retaining wall.

Wattling (129)

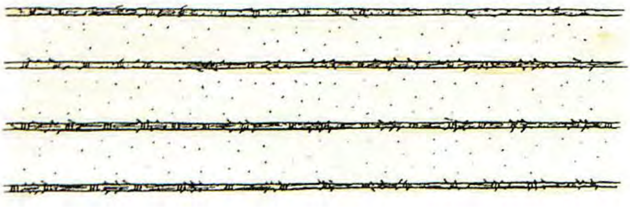
This activity may be suitable after repairing an eroded slope with Maintenance Activity: **123 Repair Erosion Damage (Selected Fill)**

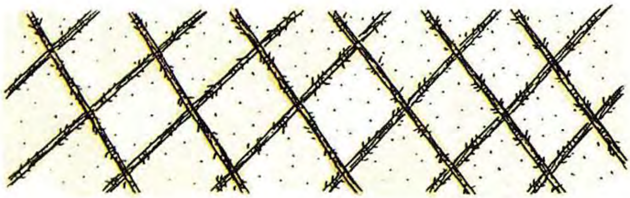
Wattling will help to resist surface water erosion of a slope. Wattles are bundles of plant stems up to 3 m long, tied together and laid in shallow trenches, staked into position on contour lines (lines of the same height), or x - form lines. As with turfing and seeding, a favourable climate and soil conditions are essential for the successful use of wattling.

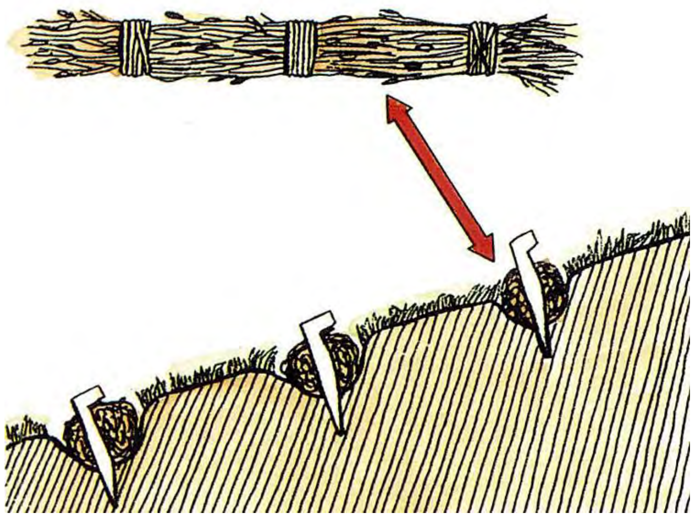
Wattling helps to stabilize slopes, reduce surface erosion and provides a bench on which grass can become established. Plant stems which root easily are preferred. Advice on suitable plants and planting time should be obtained from the local department of agriculture.

Typical procedure:

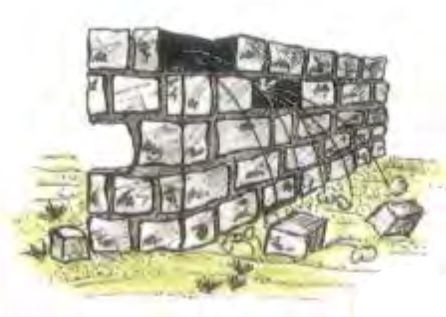
- cut wattling stems at suitable source and transport them to site immediately. Stems should not be allowed to dry out,
- tie bundles of stems 15 - 20 cm diameter, alternating the ends,
- excavate a trench in the slope along the desired line. The trench should be deep enough to accommodate tied wattling stems (this work can be completed beforehand),
- place wattling stems in trench and use stakes to fix them in position. Overlap bundles and stake through the overlaps,
- cover the wattling with topsoil and tamp them firmly in place,
- watering may be necessary until the roots take hold.







Defect 8: Mortared Masonry damaged



Development, if neglected:

Further damage to structure or roadway, slope or structural failure.

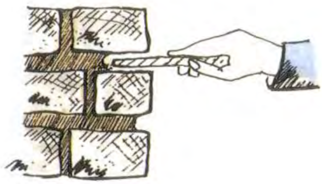
Maintenance Activity

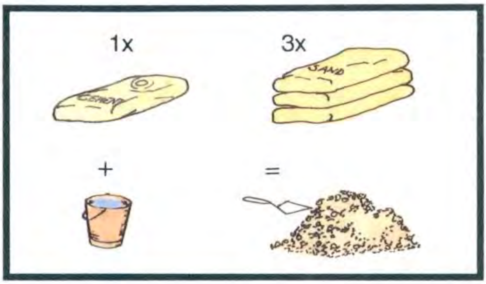
- **125 Mortared Masonry Repair**

This activity should only be carried out on masonry structures in reasonably good condition. If the structure has settled or is in danger of collapse, only complete reconstruction can be recommended.

- clean and rake out defective joints of weak mortar, soil and vegetation using compressed air or a water spray, hammer and chisel,
- at locations where the joint has to be completely renewed, the stone or brick should be eased out of place temporarily until a new mortar bed is placed,
- replace missing stones with sound pieces
- use templates and stringlines if necessary to ensure the correct shape and incline of the face of the mortared masonry work,
- dampen the joint surfaces where fresh mortar has to be applied,
- mix a mortar of cement and sand as required or specified (normally 1 cement: 3 sand) and add only enough water to permit mortar to be well mixed and applied,

- apply fresh mortar to joint, filling all space available, compacting with a suitable wooden rammer. Do not use mortar which has fallen on the ground,
- smooth joints with a suitable tool (a piece of rubber or plastic water hose, or bent reinforcing steel),
- the final mortar surface should be inset slightly from the stone/brick surface to achieve a tidy finish,
- in dry or windy weather conditions, mortar can dry out too quickly. Prevent this by sprinkling water on joints after the mortar has set and until mortar has completely hardened. Alternatively cover the work area with wet jute sacks or similar,
- clean visible stone or brick surfaces which have been stained by mortar or cement-water in the process of the work so that the finished work will present a neat appearance,
- remove surplus materials and leave the site in a clean and tidy condition.




1x
3x
CEMENT
SAND
+
=

Defect 9: Dry Masonry damaged

Development, if neglected:

Further damage to structure or roadway, slope or structural failure.

Maintenance Activity

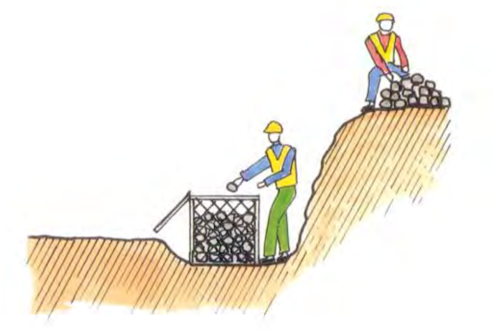
- **126 Dry Masonry Repair**

Try to use the established local dry stone construction techniques.

This activity should only be carried out on dry masonry structures in reasonably good condition. If the structure has settled or is in danger of collapse, only complete reconstruction as a dry masonry or more substantial structure can be recommended.

- carefully take down the defective areas of dry stone masonry, stacking the stone for re-use,
- clean and rake out defective joints of soil and vegetation using hammer and chisel, and brush,
- re-build the dry stone work using the salvaged stones and carefully selecting each stone to ensure good bonding horizontally and through the width of the stonework. Use smaller stones to wedge the larger ones where necessary,
- add new stones if necessary,
- use templates and stringlines if necessary to ensure the correct shape and incline of the face of the dry masonry work,
- pack the spaces between stones with soil or gravel,
- remove surplus materials and leave the site in a clean and tidy condition.

Defect 10: Gabion structure damaged



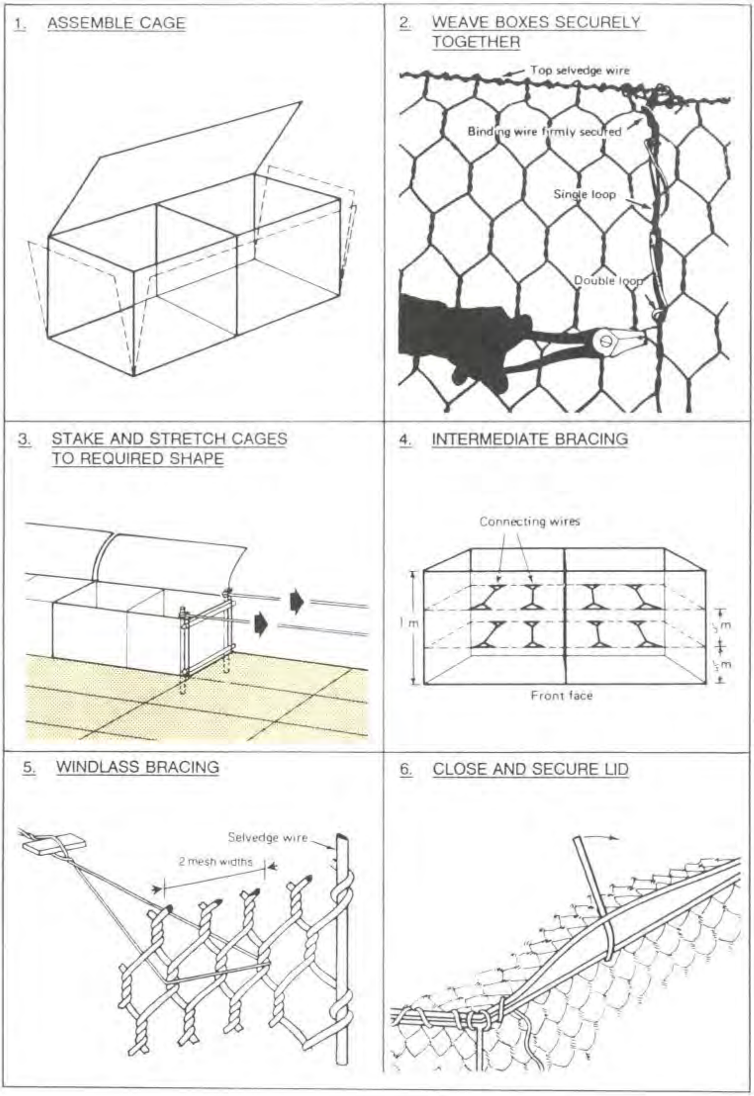
Development, if neglected:

Further damage to structure or roadway, slope or structural failure.

Maintenance Activity

- **127 Gabion Structure Repair**

Gabions are usually made of zinc coated steel baskets, although may also be made from welded mesh sheets, galvanised chain link fencing and woven wire depending on the circumstances and locally available materials. The baskets are hand-filled with rock and stones between 12 and 30 cm size. In this way they attain great stability, but will allow minor settlement. Repairs may be required due to bulging or breaking of the basket due to foundation or backing movement, or settlement of the stone within the basket. Gabions are designed to allow some settlement. Repairs should aim to ensure that the stone continues to be contained. Repairs will normally consist of opening the baskets, re-packing the stone inside, topping up stone if necessary, renewing bracing ties and re-securing the lid of the gabion. It may be necessary to weave new cage material over broken or deformed areas, and any suitable steel mesh or woven sheets can be used for this. Where a gabion box is required to be replaced or added, the procedure for building a new gabion box should be used as follows.



The gabion baskets are normally supplied folded flat complete with tying wire so that the transport volume is minimised. Foundations should be excavated level and cleaned as for a conventional structure, with any unsuitable material removed and replaced with good soil, stone or gravel, and compacted. The baskets should be erected in their final position. Cages should be woven together using 3 mm binding wire securing all edges every 15 cms with a double loop. The binding wire should be drawn tight with a pair of heavy duty pliers and secured with multiple twists (1 and 2). The centre gabion only should be filled initially to act as an anchorage. The connected baskets should be stretched and staked with wires and pegs to achieve the required shape (3). Filling should be carried out by hand using hard durable stones not larger than 250 mm and not smaller than the size of the mesh. The best size range is 125 to 200 mm. The stones should be tightly packed with a minimum of voids. Boxes of 1 metre height should be filled to 1/3 height. Horizontal bracing wires should then be fitted and tensioned with a windlass to keep the vertical faces even and free of bulges (4 and 5). Further bracing should be fixed after filling to 2/3 height. 500 mm height boxes should be braced at mid height only. 250/330 mm deep gabions do not require internal bracing. The stones should be carefully packed to about 3 to 5 cms above the top of the box walls to allow for settlement. Smaller material can be used to fill the voids on the top face, but excessive use of small stones should be avoided. The lids are then closed and stretched tightly over the stones, (carefully) using crowbars if necessary (6). The corners should be temporarily secured to ensure that the mesh covers the whole area of the box. The lid should then be securely woven to the tops of the walls removing stones if necessary to prevent the lid from being overstretched.

Defect 11: Erosion in ditch

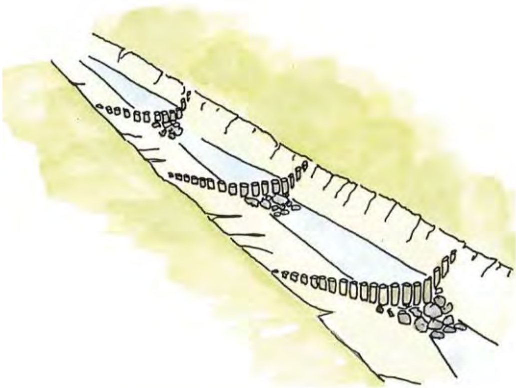
Development, if neglected:

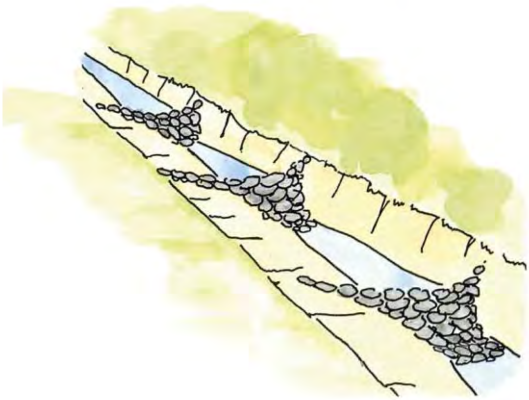
Damage to drainage system, roadway, structures, paving or shoulders.

Maintenance Activity

- **128 Build wooden/stone scour check**

Unlined ditches may suffer from scour of the invert and sides. Simple repairs may be achieved by filling the affected areas with soil and trimming to the correct profile, and turfing where climatic conditions are favorable. The turves will probably need to be pegged in place to retain them, and watered until established. Simple scour checks may be constructed of wood or stones. Larger ones may be constructed of stone masonry, brick or concrete. They reduce the speed and erosion force of the water. They also hold back the silt carried by the water flow to provide a series of gently sloping sections of ditch separated by steps.





The scour checks must not be too high otherwise water will be forced onto the surrounding ground, the shoulder or the roadway. The scour check construction should therefore be controlled with the aid of a template. Scour checks should not be constructed on ditches with gradients of less than 4%. This will encourage too much silting of the drain and could lead to road damage. The gradient of the side drain should be checked with an Abney level or line and level to determine the requirements for scour checks (spacing guidance in the SS LVR Manual).

After the basic scour check has been constructed, an apron should be built immediately downstream either using stones or grass turves pinned to the ditch invert with wooden pegs. The apron will help resist the forces of the water flowing over the scour check. Grass sods should be placed against the upstream face of the scour check, to prevent water seeping through the scour check and to encourage the silting behind the scour check. The long term objective is to establish complete grass cover over the silted scour checks to stabilise them.
Well constructed scour checks will allow the water to gently cascade over (and not through) the checks, removing energy from the water and reducing erosion power.

ROAD SURFACE

Whenever works are carried out on the road surface, warning signs should be placed before each end of the work site.

EARTH ROAD

Defect 12: Road surface potholed, rutted or uneven, and does not drain to edge

Development, if neglected:

Road becomes waterlogged or impassable.

Maintenance Activity

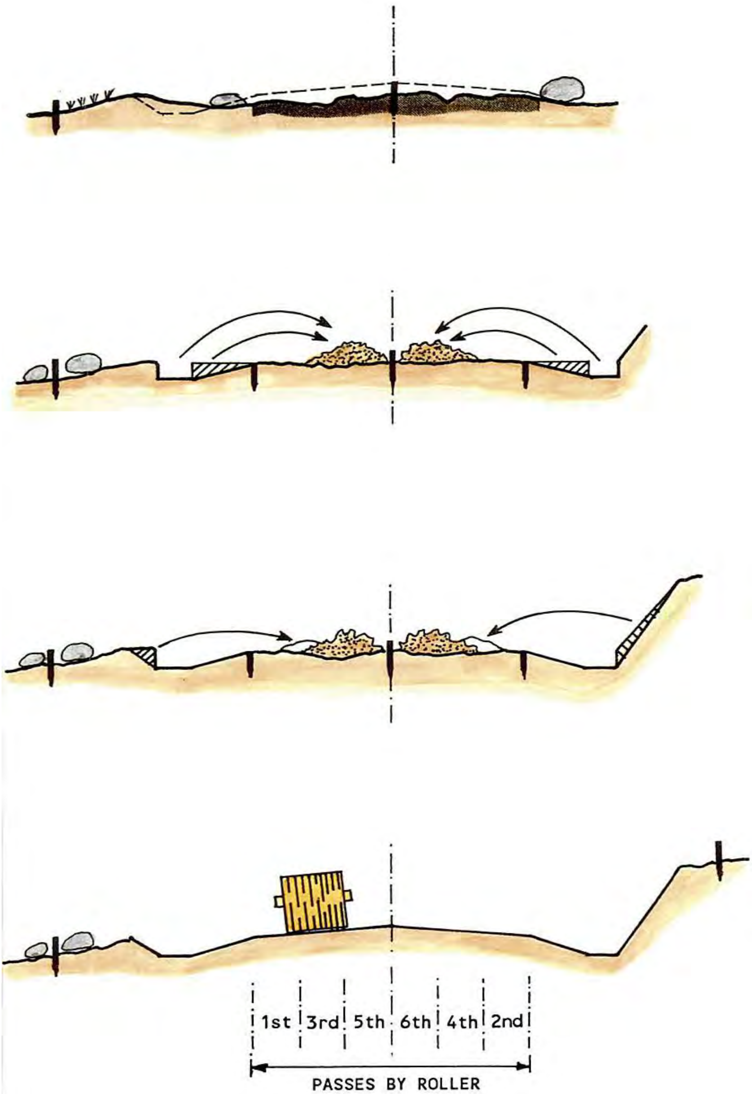
- **112 Reshape & Compact Earth Road Camber**

This activity is carried out using labour, basic hand tools and control aids. The Method comprises the following steps:

- SETTING OUT
- EXCAVATION OF DITCH AND SLOPE
- EXCAVATION OF BACKSLOPE

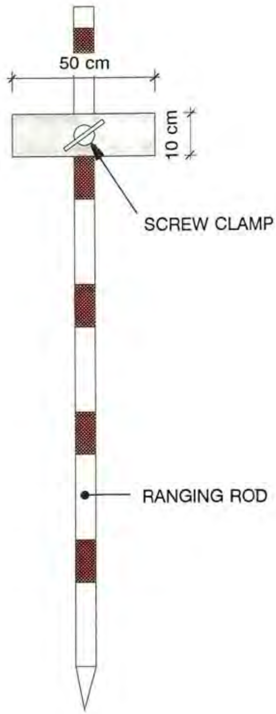
- CAMBER FORMATION AND FINAL COMPACTION

These steps are shown on this page**.**



SETTING OUT

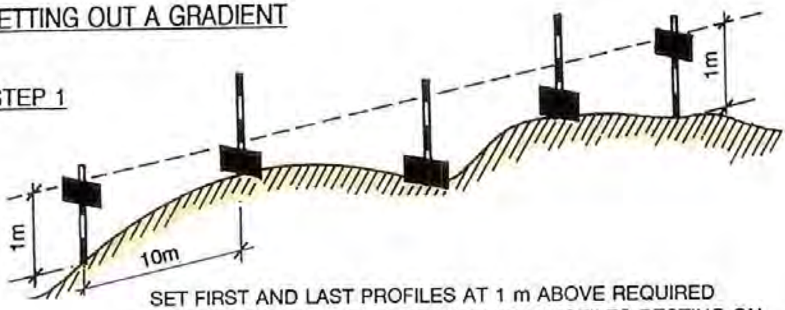
- The PROFILE method of setting out enables a smooth vertical alignment to be re-established on a severely deteriorated road surface.
- The alignment will consist of straight gradients and vertical curves.
- The centre line of the road is pegged every 10 metres.
- A ranging rod is fixed at each 10 metre peg.
- Each ranging rod is fitted with a profile board. The profile board can slide up and down the ranging rod and be clamped at any height.



Setting out is arranged in sections of 60 to 100 metres, which approximate to either a straight gradient or vertical curve on the road line.

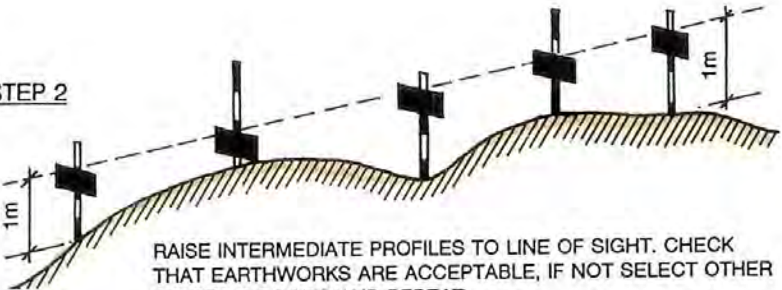
SETTING OUT A GRADIENT

STEP 1



SET FIRST AND LAST PROFILES AT 1 m ABOVE REQUIRED FINISHED ROAD LEVEL, INTERMEDIATE PROFILES RESTING ON GROUND

STEP 2

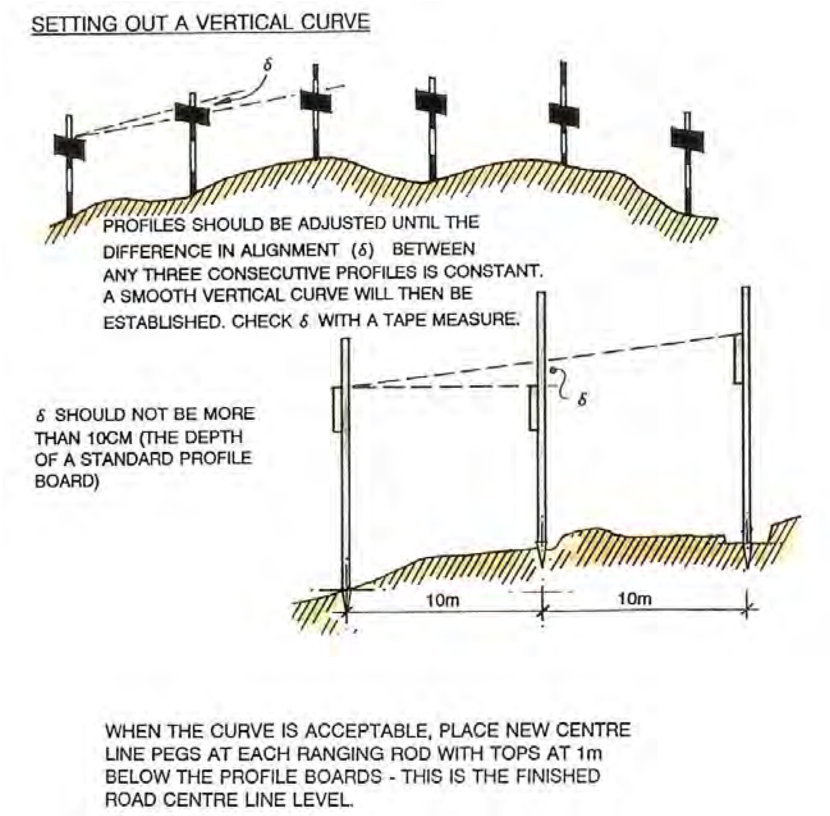


RAISE INTERMEDIATE PROFILES TO LINE OF SIGHT. CHECK THAT EARTHWORKS ARE ACCEPTABLE, IF NOT SELECT OTHER STARTING POINTS AND REPEAT

STEP 3

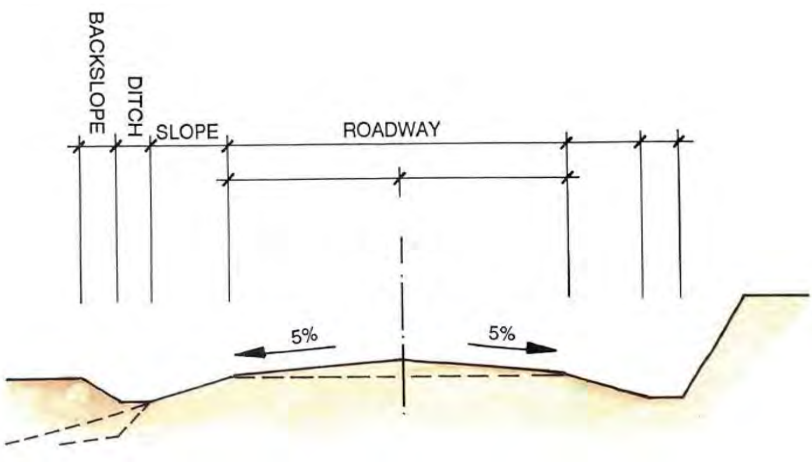
PLACE NEW CENTRE LINE PEGS AT EACH RANGING ROD WITH TOPS AT 1 m BELOW THE PROFILE BOARDS - THIS IS THE FINISHED ROAD CENTRE LINE LEVEL .

Check that the amount of earthworks at each centre line (finished level) peg is acceptable, or repeat the procedure using different assumptions.



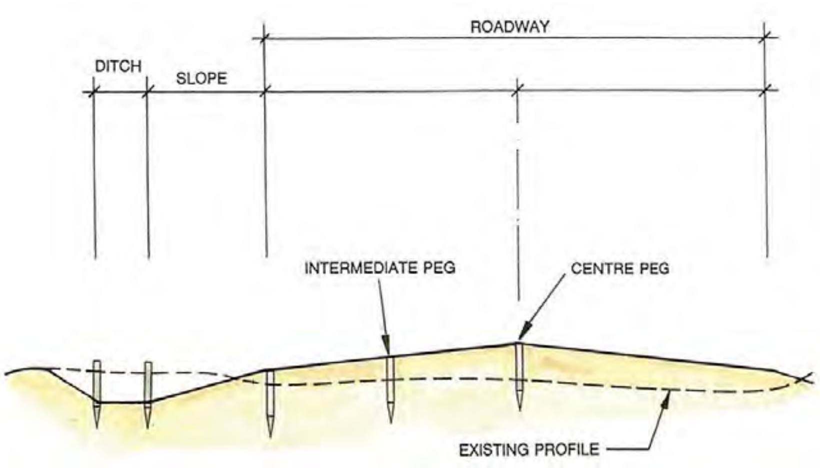
Once the centre line level pegs are fixed, set out the pegs for the edge of the roadway and both sides of the ditch using the tape measure, camber board and spirit level for the required road cross section.

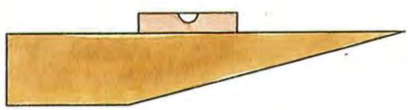
Pegs should be driven in to the required finished cross section level, or a fixed height above.



EXCAVATE DITCH AND SLOPE

- Material is excavated from the ditch and slope area and used to form the camber until the required shape of ditch and slope is achieved.
- Check shape with the ditch and slope template, and spirit level.
- If too much material is excavated, discard the surplus material well beyond the side drain.
- If the filling placed is greater than 15 cm deep, then it is preferable to spread and compact the fill material with rakes and hand rammers or a hand/animal drawn roller in 15-20 cm layers.

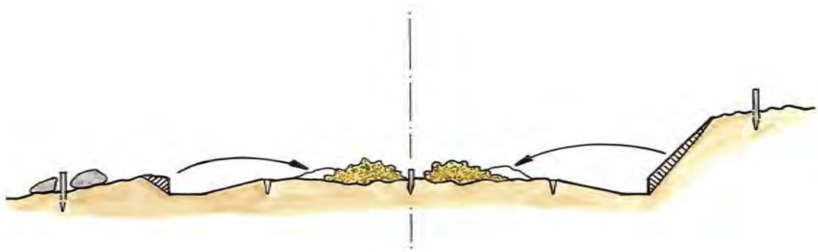




DITCH AND SLOPE TEMPLATE

EXCAVATE BACKSLOPE

If insufficient material is excavated to form the camber, dig additional material from the backslope or from beyond the side drain.



CAMBER FORMATION AND FINAL COMPACTION

- Continue adding material to the camber to achieve the required profile after compaction.
- Stringlines stretched directly and diagonally across the running surface between the setting out pegs can be used to check the shape.
- Compact the fill material to the final profile, preferably using a hand or animal drawn roller.
- If a roller is not available, use hand rammers or the tyres of any vehicle to uniformly compact the soil across the roadway width.

The shaped and compacted earth road surface is a suitable foundation on which one of the surface options can be constructed directly.

Gravel Road

Defect 13: Road Surface potholed

Development, if neglected:

Gravel surface loss increases. Road becomes very rough, slowing and damaging traffic, and may become waterlogged or impassable.

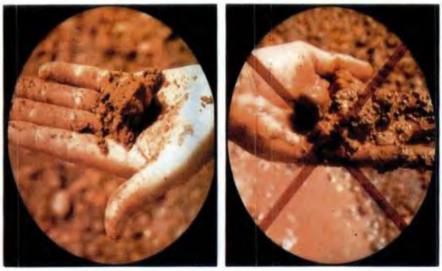
Maintenance Activity

- **110** **Spot Repair – Selected Material**
- **111** **Spot Repair – Crushed Aggregate**

Potholes and ruts should be repaired with materials similar to the surrounding surface. This can be either selected gravel material (110) or crushed stone aggregate (111) with sufficient fines to bind the material together.

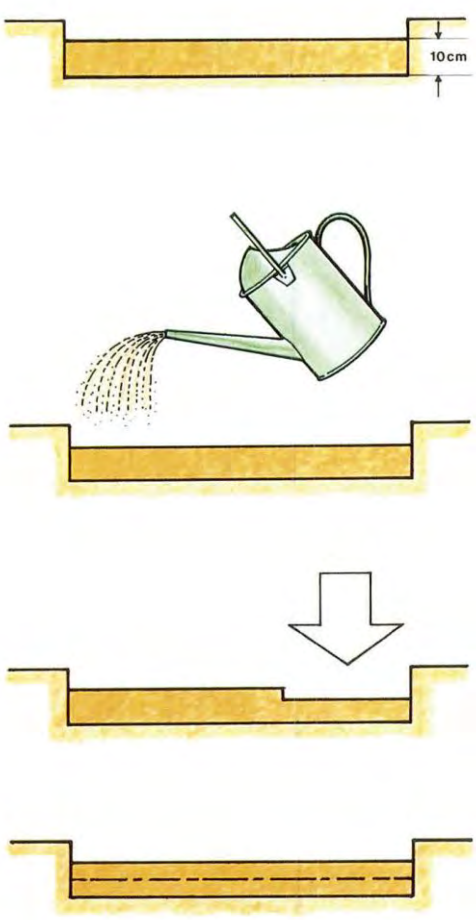
- Loose material and standing water is brushed from the pothole or rut to be patched.
- Large or deep potholes should have their sides cut back to be vertical and to reach

sound material.



- The moisture content of the material can be checked quickly by squeezing it in the hand. If the material is wet enough to stick together, it is suitable for use. If water runs out of the material, it is too wet and should not be used.

- If the material is dry, the area to be patched should be sprinkled with water and water should also be added to the patching material.

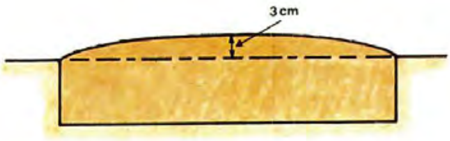


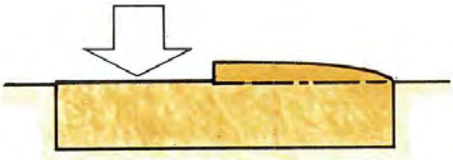
– The area is filled with gravel to a depth of about 10 centimetres.

– If the material is dry, it should be sprinkled with water to help compaction.

– The layer is then compacted using the roller or hand rammer.

– In this way the thickness of the patch is built up in layers.





– Finally, the patched area is filled evenly with the gravel to approximately 3 centimetres above the level of the surface and is spread and raked to the correct shape.
3 centimetres is approximately the thickness of a rake handle.

- The patch is then compacted using the roller or hand rammer to give a surface which is only slightly above the level of the surrounding road to allow for further traffic consolidation.
- Both large or small areas to be patched are repaired in the same way, the rammer is used for the smaller potholes. The roller if available is used for larger areas, although the hand rammers will still be required for the corners and short edges.
- Patching work started must not be left unfinished overnight. At night the site should be made safe for traffic and all signs and obstacles removed from the road.

Defect 14: Road Surface rutted or uneven, and does not drain to edge (Minor: <3cm)

Development, if neglected:

Gravel surface loss increases. Road becomes very rough, slowing and damaging traffic.

Maintenance Activity

- **220 Blade Gravel Road (light)**

Light grading may be carried out with a motor grader or a tractor towed grader to correct minor defects on the gravel road surface such as corrugations, shallow ruts and flat camber. The task may also be achieved using labour with handtools.

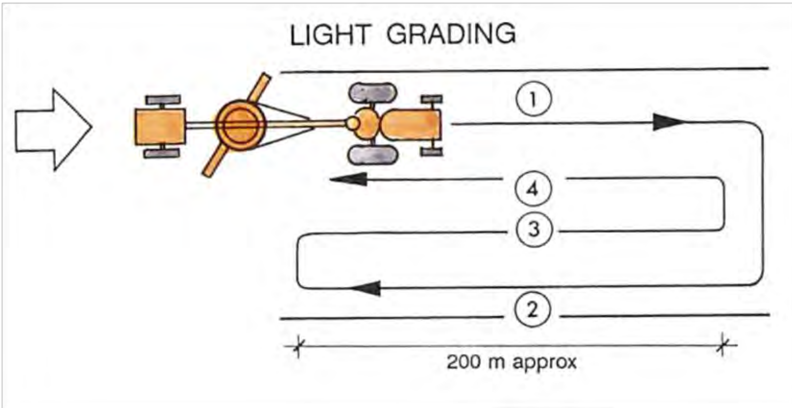
a) Light reshaping, Manual Method

- The surface material may be loosened, trimmed and reshaped with a pickaxe, hoe or mattock and rakes to form the required camber and crossfall.
- The shape is checked with the camber board and spirit level.

- If gravel stockpiles are provided, any local depressions are filled with material transported in a wheelbarrow, pannier or other device.
- The loose material is compacted with the hand rammer.
- Pegs and string lines can be used to help to achieve the correct shape and camber.

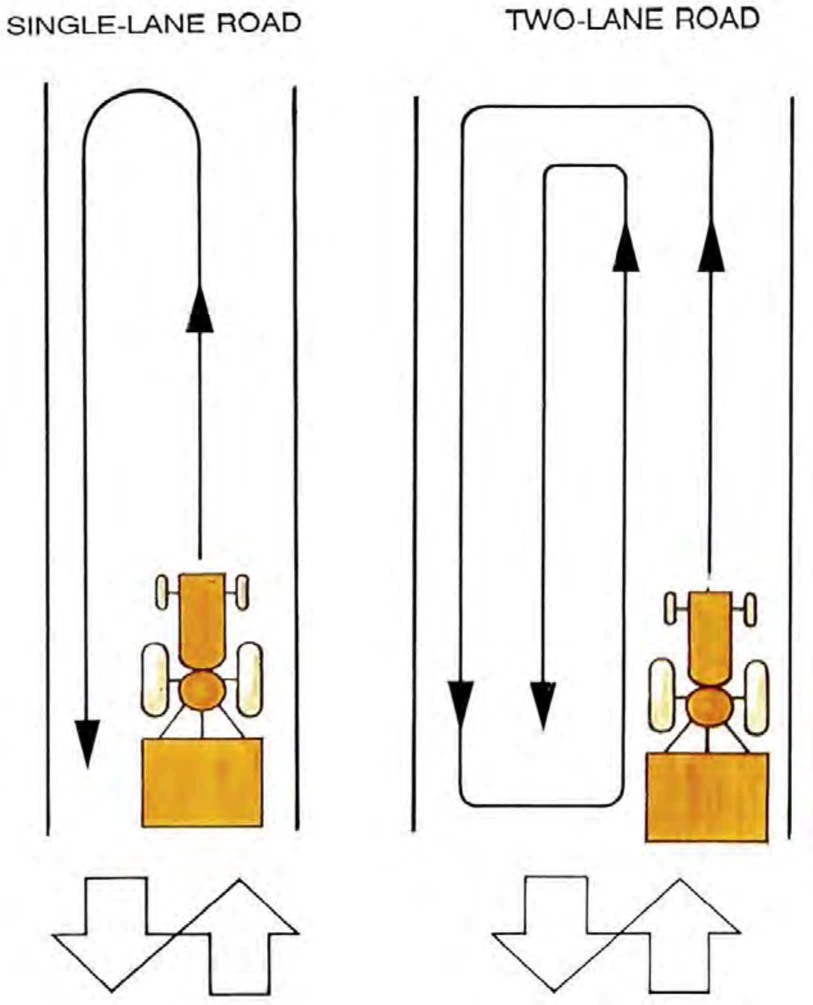
b) Light reshaping, Mechanised Method

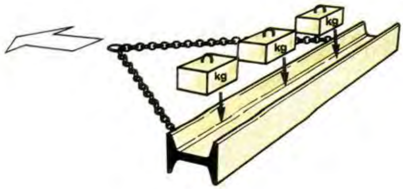
The motor grader or tractor towed grader is used to draw the surface material back to the crown of the roadway. Normally only 4 passes will be required to achieve this minor reshaping. It is best carried out during the rains when there is sufficient moisture in the material for reconsolidation under traffic, so that expensive watering and compaction operations will not be required.



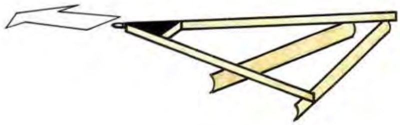
Minor corrugations can be dealt with by using a low cost drag towed by a tractor or other vehicle.

Drags can be made cheaply from old tyres or various arrangements of discarded steel sections.

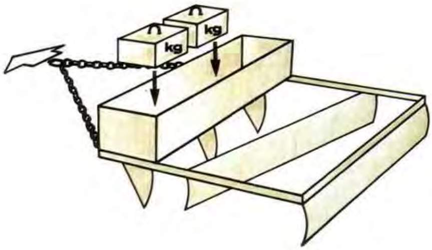

SINGLE-LANE ROAD
TWO-LANE ROAD



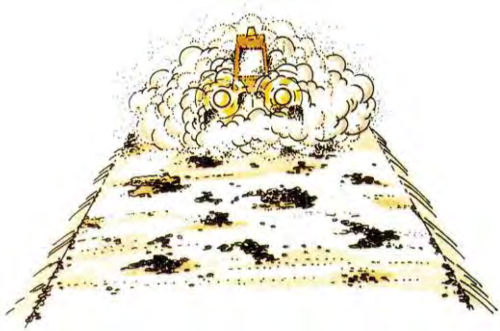
- The tractor tows the drag at up to 5 km/hour depending on the type of drag and on the type and condition of the road surface.



- The length of pass should be as long as possible.
- The number of passes needed will depend upon the conditions and the width of the road.



- The equipment should work in the same direction as the traffic flow.
- By adjusting the length of each towing chain, a degree of lateral material redistribution may be achieved.
- DO NOT drive too fast or the drag will jump over the surface irregularities and raise a lot of dust, it will also cause a hazard to traffic.



IMPORTANT NOTE ON 'BLACK COTTON' SOIL

Expansive clay (often referred to locally as black cotton soil), is a major challenge for road works and is found extensively in the north eastern part of the country. The soil is capable of taking up large qualities of water in the rains, or if soaked, with a corresponding almost total loss of strength. In the dry season it will shrink with extensive cracking. This gives rise to serious stability problems in road foundations, for road pavements and structures.

There are a number of proven techniques for treating these soils. Unfortunately, these are all expensive in the context of South Sudan Low Volume Roads.

For LVR with a black cotton soil surface, the most effective and cheapest approach is to ensure that the road camber and drainage system are well maintained, and to PREVENT traffic from passing over the road when it is raining or soaked. This can be achieved naturally by the steep camber itself, or by installing road barriers to prevent vehicle passage during the rain, and immediately after. Usually this can be achieved by agreement between the road users and community on a Low Volume Road.

With an effective and ***maintained*** *camber and drainage system the road surface will normally drain within a number of hours after the rain ceases and regain sufficient strength to allow vehicles to pass without destroying the road surface.*

Defect 15: Road Surface rutted or uneven, and does not drain to edge (Major: >3cm)

Development, if neglected:

Road becomes very rough, slowing and damaging traffic. Water ponds on road surface. Gravel surface loss increases and danger of total gravel layer loss and road being impassable.

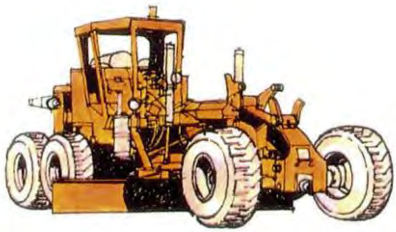
Maintenance Activity

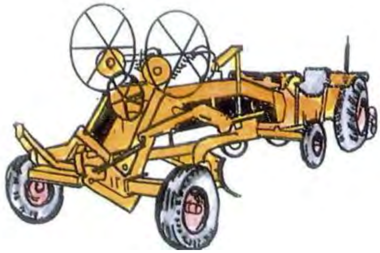
- **221 Blade Gravel Road (heavy)**

Heavy grading may be carried out with a motor grader or a tractor towed grader. However the task will also require towed or self-propelled watering and compaction equipment. The task may also be achieved using labour and hand tools by adapting the methods of Maintenance activity **112**.

Preparation

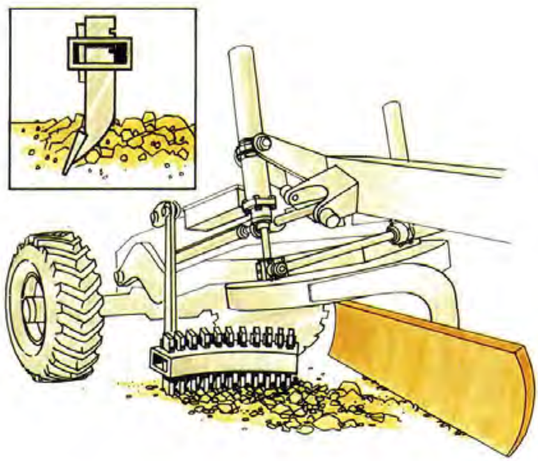
Patching (Activity **110** or **111**) of large potholes or depressions should be carried out in advance of the grading. Areas of standing water should be drained. This preparation will ease the work and make the resulting surface last longer.





Scarifying

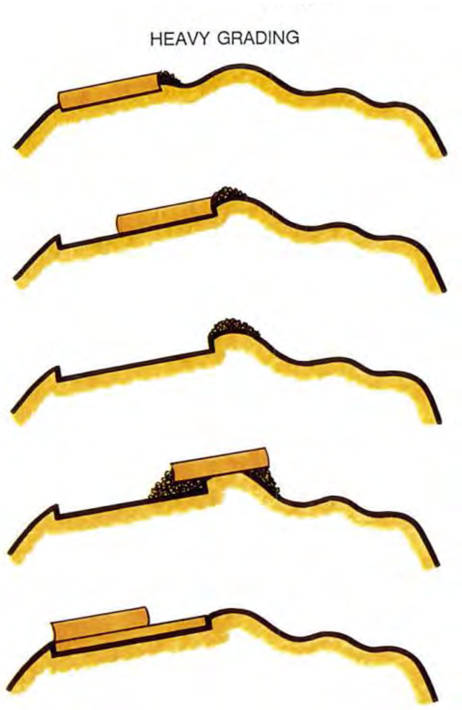
Using a motor or tractor towed grader it may be necessary to scarify the existing surface to cut to the bottom of any surface defects and loosen the material for reshaping.



Machine Attendants

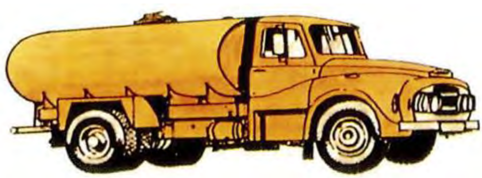
These help direct traffic and grader turning, and remove large stones and other unwanted material from the path of the grader.

Grading



The grader works on one side of the road at a time and works in passes about 200 metres long to convenient and safe turning points. Heavy Grading will require additional passes to achieve the required camber. Work should be completed on one side of the road at a time. An even number of passes should be used to avoid a flat finished crown. Normally initial cutting passes are required to bring material in from the edges of the road. Spreading passes redistribute the material away from the crown. The initial passes cut to the bottom of the surface irregularity and deposit a windrow just beyond the centre line.

Watering



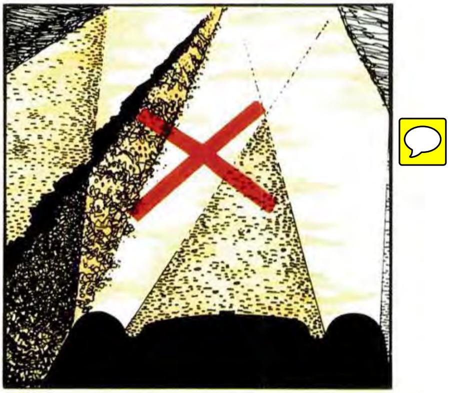
The towed or self-propelled water tanker sprays the windrow with water, if required. The windrow is spread back across the road depositing all the material to give the correct camber. A second application of water may be required to obtain the correct moisture content for compaction.

Cambering

The aim should be to develop a proper crown on the road. The road should be cambered to fall away from the crown at a rate of about 6 to 7 cm for each metre from the centre of the road before compaction. This should achieve a crossfall of about 4 to 6 cm per metre (4 to 6%) after compaction. If there is insufficient camber, water will not drain easily from the surface of the road, potholes will form and the road will deteriorate quickly. This is particularly important on gradients, where the rain water tends to run along the road forming erosion channels.

Do not make a final pass down the centre of the road with the grader blade horizontal. This flattens the centre of the road and causes water to pond leading to rapid deterioration of the surface.

Do not leave a windrow on the road overnight as this is a danger to traffic.



Compaction

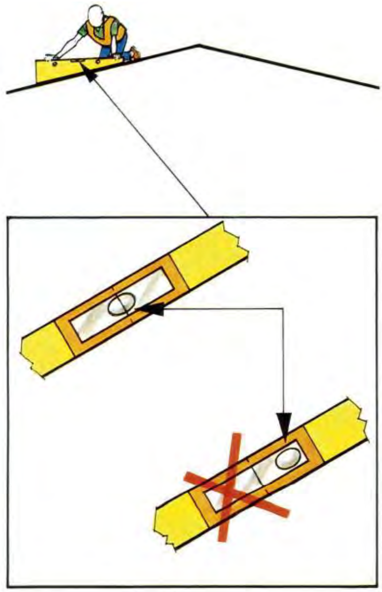
When towed, self-propelled compaction plant is being used, it must follow close up behind the grader, but only on sections where grading has been completed. Usually about eight passes of a roller will be needed to achieve full compaction (less passes with vibration), working towards the centre of the road. Shoulders are treated as part of the running surface.

Junctions and Bends

Graders must not park up near junctions or bends where they will be a danger to traffic.

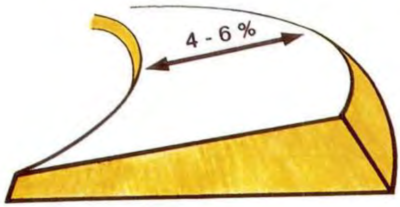
Check the Camber

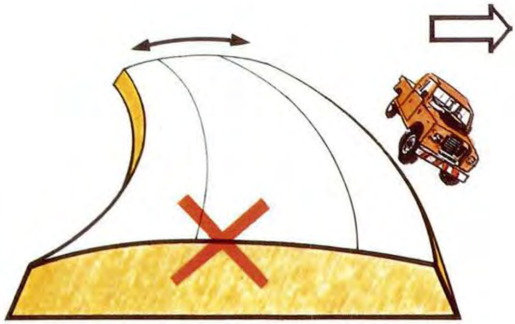
Camber should be checked with a camber board at about 100 metre intervals along the road. To use the camber board place it on its edge across the road with the shorter end pointing towards the centre line. Check the level bubble. If it is central, the camber is correct. If it is not central, the camber is either too steep or too flat and further grading and compaction are required.



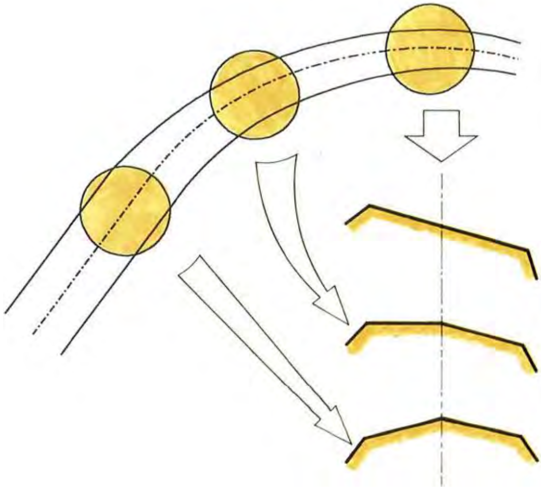
Superelevation

On bends the surface must be straight (at 4-6%) from shoulder to shoulder with the outer shoulder higher. This is called superelevation. This is because any crown on a bend can be very dangerous to traffic. The superelevation must be retained for the complete length of the bend.





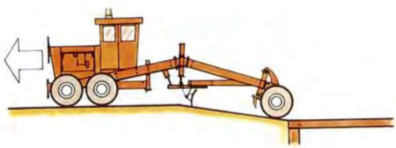
On the transition at each end of the bend into the straight sections, the superelevation should be gradually reduced until the normal cross section shape with about 1 in 25 to 1 in 17 (4-6%) crossfall is obtained again.



Structures

The shape of the road must be maintained over culverts to avoid a hump. Material should be brought in if necessary from either side of the culvert to maintain a cover to the top of the culvert of at least 3/4 culvert diameter.

Bridge decks should be kept free from gravel. Loose material should be swept away by the attendants. It is important to have smooth approaches to the bridge. They should be smoothed out using the back of the blade with the grader working in reverse, or by hand.



Blade position

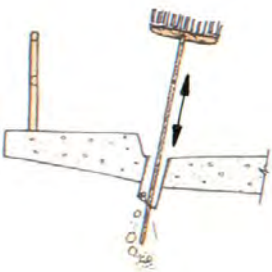
For most grading work, the cutting blade is set to be vertical.

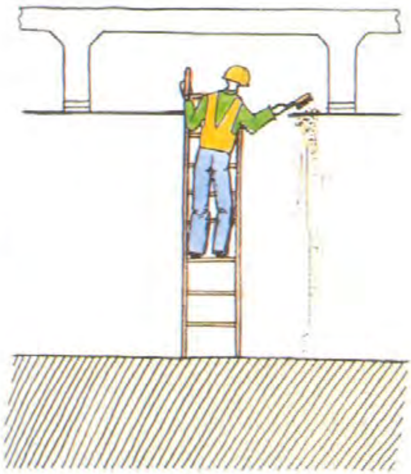
For cutting hard surfaces, the cutting blade should be set back at the top to give the most effective cutting angle. Scarifying passes should also be made before cutting.

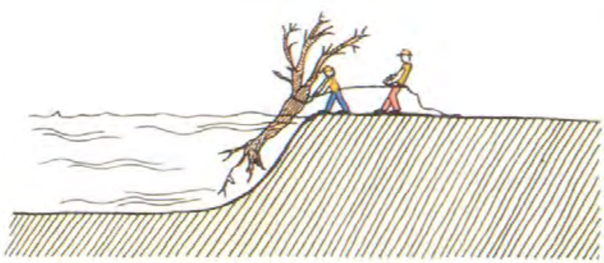
For spreading, the cutting blade should be set forward at the top.

STRUCTURES

Defect 16: Debris or Vegetation affecting or endangering Structure







Development, if neglected:
Structure may be damaged or become impassable

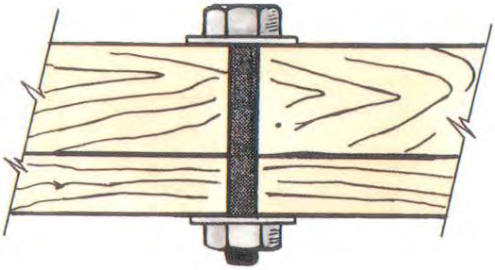
Maintenance Activity

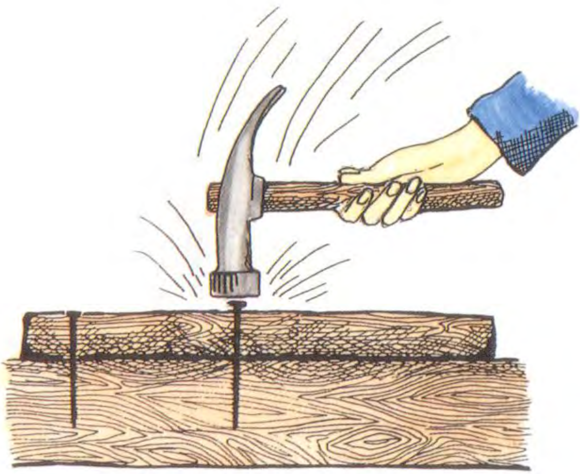
- **400 Cleaning, Clearing, Sweeping, De-silting, Unblocking or Removal of vegetation or flood/wind borne debris (Structure/inlets/outlets)**

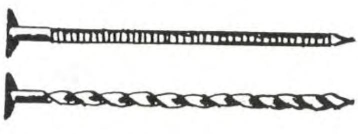
Debris can be a hazard to traffic, or can cause blockage or turbulence at a structure causing erosion and damage. It can be expected that each year there will be an accumulation of debris from road users, waterborne and flood flows, or normal vegetation growth, which should be cleared. This is best carried out in the dry season in preparation for the structure to function properly in the rains.

All debris should be disposed of safely so that there is no further risk to traffic or structure.

Defect 17: Connectors/fixings are loose/damaged/missing







Development, if neglected:

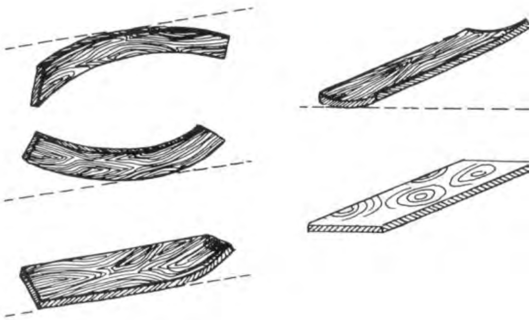
Structure may be damaged or become impassable

Maintenance Activity

- **401 Repair of Loose/missing connectors/fixings**

Particularly on timber or steel structures, the fixings may become loose or be damaged by traffic. If unattended this can lead to part or all of the structure being damaged. Annual inspections should check all components of the structure to ensure that the fixtures and fittings are secure and functioning as intended. Any necessary remedial work should be arranged.

Defect 18: Planks/Kerbs are damaged/missing



Development, if neglected:

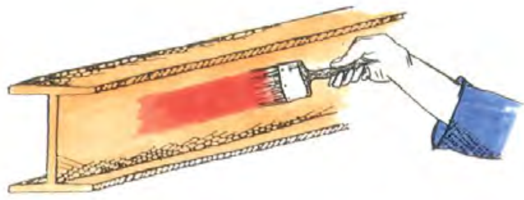
Structure may be damaged or traffic hazard may develop

Maintenance Activity

- **402 Replace damaged or missing Planks or Kerbs**

Particularly on timber structures, the running boards or kerbs may be damaged by traffic, may work loose, or be subject to insect attack. Any damaged, loose or missing components should be re-fixed or replaced.

Defect 19: Paintwork defective or damaged



Development, if neglected:

Structural components may corrode and weaken/damage structure

Maintenance Activity

- **403 Paint main or minor parts of structure/furniture**

Paint will deteriorate with age and its protective function for steelwork may be impaired. Paintwork may need to be renewed from time to time. Signs may require to be repainted. Any loose or corroded material should be removed by wire brushing or paint remover before applying new paint. Ensure that a suitable type of paint is used.

Defect 20: Danger or evidence of insect or moisture attack of timber components

Development, if neglected:

Structural components may weaken/damage structure

Maintenance Activity

- **404 Apply wood preservative or insect treatment to timber components**

Timber components will require to be re-treated from time to time to preserve them. Any evidence of insect attack should be investigated and suitable treatment of the timber carried out. If timber components become soft or rotten, they should be carefully replaced under the supervision of an Engineer.

Wood preservation of structural timber can only be thoroughly and reliably achieved by pressure impregnation where the preservative liquid is injected deep into the timber. When pressure treatment of replacement sections cannot be employed, apply a superficial treatment. This method is only of very limited value and cannot be regarded as permanent, especially if the wood comes into contact with the soil or is used in moist climates.

A suggested procedure for superficial treatment is as follows, working with protective gloves and clothing:

1. Apply the wood preservative) with a paint brush.
2. Ensure the preservative completely covers the wood surface and ends, and that every crack is also filled with oil. Brush-in at the same time. No part should be left untreated as fungi could then easily enter.
3. Allow the first coat time to dry.
4. Repeat a second application in the same manner.
5. When the surface of treated wood has been damaged by handling, transport, bored-bolt holes, or sawing, apply oil treatment to the exposed surfaces as above before installing in the bridge.
6. After brushing work is completed, clean all brushes and containers with solvent.

Wash all traces of preservative where it comes in contact with the skin!

Defect 21: Masonry or concrete or joints defective (minor)

Development, if neglected:
Structure may become damaged by water penetration/seepage

Maintenance Activity

- **405 Pointing or Repair of Masonry/Concrete**

Minor damage to concrete, masonry or pointing may be repaired by re-pointing with sand-cement (4:1 ratio) mortar. If there is evidence of movement in the structure which may have caused the defect to occur, an Engineer should be advised to check the condition of the structure.

For further guidance refer to **Defect 8** Repairs (Page 48).

Defect 22: Structure Furniture defective

Development, if neglected:
Components may not carry out their intended function

Maintenance Activity

- **406 Repair parapets, marker posts, safety barriers, signs or other furniture**

The various furniture components can deteriorate due to weather, traffic damage or age. These are important parts of the structure and should be repaired if necessary to keep them in the intended condition and function.

OCCASIONAL MAINTENANCE – GRAVEL ROAD

Defect 23: Gravel layer too thin

Development, if neglected:

Road becomes very rough, slowing and damaging traffic. Water ponds on road surface. Gravel surface loss increases and danger of total gravel layer loss and road being impassable.

Maintenance Activity

- **317 Gravel Resurfacing (Selected Material)**
- **318 Gravel Resurfacing (Crushed Aggregate)**

Gravel surfaces wear down due to the wasting effects of traffic and weather. Loss rates can be up to 5cm thickness each year or more even on a Low Traffic Volume Road. Re-gravelling will be required when (or before) the residual thickness of gravel reduces to about 5 – 8 cm, otherwise there is a danger of vehicle wheels 'punching' through to the weaker material below. This would result in mixing and effectively the loss of the gravel layer.
Great care should be taken in locating and selecting suitable gravel material. It should be obtained from a recognized approved source and meet materials specification requirements. This can be either selected gravel material, or crushed stone aggregate with sufficient fine material to bind the material together.

Gravel or crushed stone should not contain any pieces larger than 3cm as this will seriously affect performance. 'Oversize' pieces should be hand-picked or 'screened' out. Due to the high cost of re-gravelling, technical advice should be obtained on sources and material suitability. It is likely that re-gravelling will be very expensive if the material has to be hauled more than 10km, and other types of road surface may be more economical.

Diversion?

Wherever possible, before the re-gravelling work starts, a diversion should be opened up adjacent to the road. If traffic is diverted from the work site, it will enable the job to be carried out more efficiently and safely.

Quarry or Borrow Pit

Before the regravelling work starts, gravel should be tested for compliance with specifications and stockpiled at the quarry or borrow pit. It may also be helpful to start hauling the material to site.

Plan the quarry excavations and stockpiles so that:

- the quarry can be fully exploited with removal of the maximum amount of good gravel,
- the overburden is stockpiled so that it will not hinder future extension, and that it can be used to reinstate the quarry,
- the best material is taken, where gravel quality is variable within the quarry,
- material is stockpiled to minimise segregation,
- environmental damage by poor drainage and erosion is minimised both during and after exploitation of the quarry.

The quarry layout should:

- permit efficient excavation and stockpiling of gravel,
- allow the trucks, tractor and trailers or other haulage vehicles to enter and leave without obstructions.

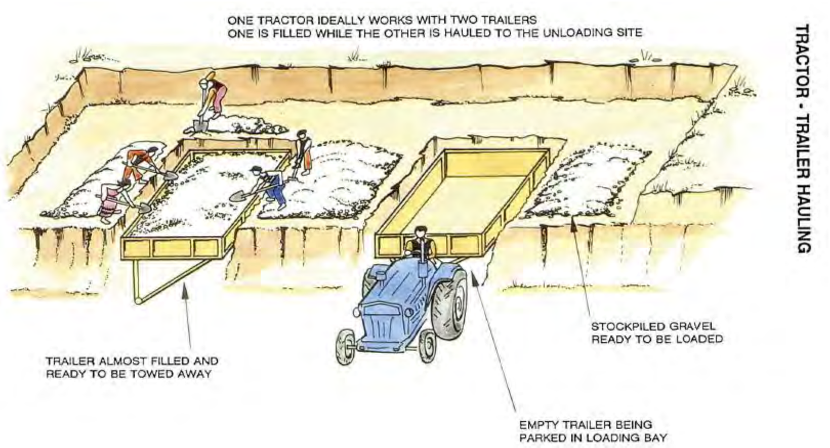
Repair the quarry access road, if necessary, to ensure safe passage of haulage vehicles.

Site Preparation

Traffic warning signs should be place at either end of the re-gravelling site.

The existing road surface must be graded-off or reshaped by hand to provide a firm regular surface on which to work. Where possible, the edges should be 'boxed' to provide lateral support for the new gravel. The graded/reshaped surface should be watered and compacted. The camber should be checked with a camber board and the road level should fall 4 to 6 cm for each one metre width of road (4-6 %). The road drainage system should be checked and repaired if necessary (see Drainage defects and activities), otherwise the performance of the new gravel surface will be affected.

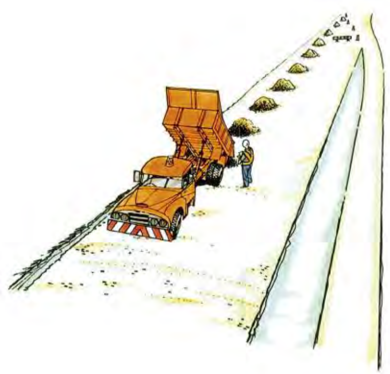
At the quarry or borrow pit, the bulldozer or excavation labourers should have stockpiled sufficient gravel for the work. The excavating and stockpiling of gravel should create low, broad heaps to prevent segregation of the coarser material.



Gravelling operations

When the initial grading/shaping of the road surface is complete, the loader or the quarry labour should start to load the tippers or trailers with gravel for transport to the re-gravelling site.

The supervisor at the quarry should ensure that gravel is taken from the correct stockpiles and that the trucks/trailers are loaded correctly. Tippers or tractor trailers should always circulate continuously between the quarry and the site. Loading resources should be adjusted to try to keep the haulage equipment working continuously.

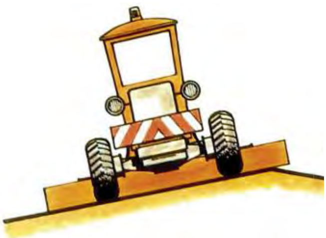


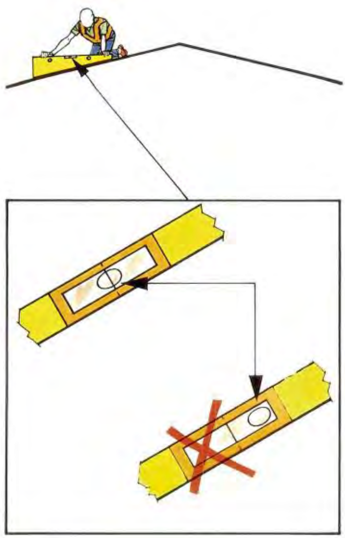
- Dumping should start at the far end of the site so that the heaps of gravel do not impede tippers or other haulage vehicles delivering later loads.
- Material should be dumped on one side of the road only.
- Loads should be placed at the correct spacing as instructed by the supervisor, necessary to give the required thickness of gravel over the complete road width after compaction.

- If the road is not closed, material should be dumped on the shoulder, or dumped and spread immediately by labour.
- The tankers or towed bowsers should have filled up with water using the pump and then have driven to the site.
- Initially the existing road surface is sprayed with water.
- Spreading of the gravel can start when there is a working length of about 200 metres of dumped material if using a motor or towed grader. If spreading is by labour, the gravel can be spread as soon

as it is dumped, or even unloaded by labour if non-tipping haulage equipment is used.

- The material is alternately spread by the grader/labour and watered with the tanker/bowser until its moisture content is correct for compaction.
- The amount of water to be added must be determined by moisture content tests on site or by the supervisor.
- The tankers/bowsers circulate continuously between the site and the source of water.
- The new material is now graded or spread by labour to produce a camber of 4 to 6 cm for each one metre width of road (4 to 6 %). Guide pegs and stringlines should used if labour spreading is used.





- The camber should now be checked with the camber board at approximately 100 metre intervals along the road for machine spreading and every 10 metres if labour is used.
- To use the camber board, place

it on its edge across the road with the shorter end pointing towards the centre line. Check the level bubble.

- If it is central, the camber is correct.
- If it is not central, the camber is either too steep or flat and further grading/manual reshaping, and compaction are required.
- When the correct camber has been achieved, compaction can start using a self propelled or towed roller, or a pedestrian vibrating roller for labour works.
- Water should not be added during rolling as the material may stick to the wheels or drums.
- Rolling should start at the edge of the road and work towards the middle. The roller should aim to progress from section to section at the same rate as the grader or labour operations.

- Typically about eight passes of the roller will be needed to achieve full compaction. Test the placed gravel for specification compliance.
- It is possible to re-gravel without the use of water and compaction, but it is difficult to achieve satisfactory results, and subsequent gravel material loss from the surface will be faster. The watering and compaction help to preserve the investment in the gravel.

OCCASIONAL MAINTENANCE – PAVED ROAD

Defect 24: Paved road pothole or surface defect

Development, if neglected:

Road becomes very rough, slowing and damaging traffic. Water ponds on road surface, speeding the deterioration and increasing risk of accidents. Road user costs increase substantially. Road may become impassable.

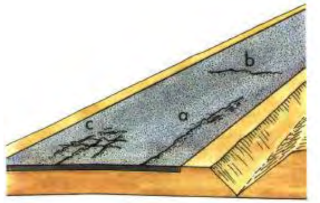
Maintenance Activity

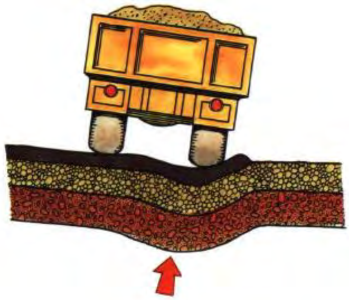
Depending on the type of paved road surface:

113a	**Spot /pothole Repair (Macadam)**
113b	**Spot /pothole Repair (Stone setts)**
113c	**Spot /pothole Repair (Mortared stone)**
113d	**Spot /pothole Repair (Dressed stone)**
113e	**Spot /pothole Repair (Emulsion chip seal)**
113f	**Spot /pothole Repair (Emulsion sand seal)**
113g	**Spot /pothole Repair (Emulsion gravel/slurry seal)**
113h	**Spot /pothole Repair (Un-mortared brick)**
113i	**Spot /pothole Repair (Mortar jointed brick)**
113j	**Spot /pothole Repair (Non- reinforced concrete)**
217	**Pothole Reinstatement (cold mix)**
219	**Pothole (Base Failure Repair)**
114	**Crack Sealing**

Although well constructed paved roads or sections should give many years of trouble-free service, from time to time defects can be expected to develop in any surface, such as:

- Cracking
- Rutting
- Potholes, or
- Edge break





These defects are normally limited in extent and can be repaired using labour, suitable hand tools and limited materials. Heavy equipment is not normally required. Compaction equipment may be required. However, light equipment or hand rammers will normally be adequate. Any work on the road surface should be signed either side of the repairs to warn road users and for the safety of those carrying out the work.

For all of the paved road surface types, the repair techniques are very similar, and consist of:

- Marking out the area to be repaired
- Excavation of the area to be repaired
- Backfilling the hole with new material

Marking out the area to be repaired
The area to be treated is marked out with chalk by drawing a rectangle around the defects.

Excavation of the area to be repaired

It is necessary to:

- remove all loose or damaged material from within the marked out area of the road surface back to a firm, sound material. Sledgehammers, crowbars, hammers and chisels may be required,
- increase the depth of the hole until firm, dry material is found and then trim the walls of the hole so that they are vertical. If water or excessive moisture is present, then arrangements must be made to drain it away from the pavement foundation,
- trim the bottom of the hole such that it is flat, horizontal and free from loose material then compact it with a hand rammer.

Backfilling the hole with new material

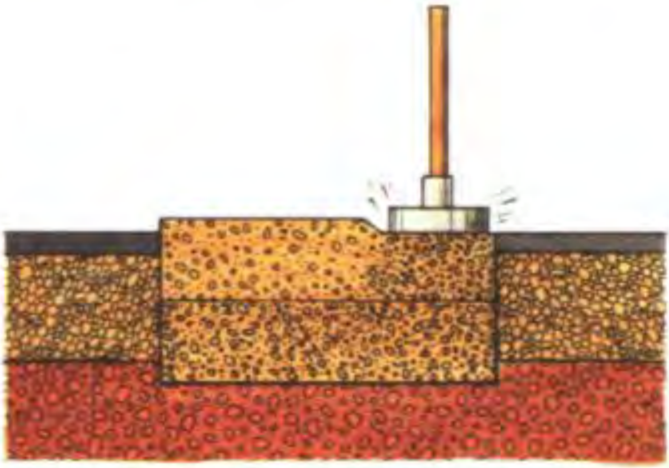
The repair will depend on the type of surface. Specifications and requirements on each material are contained in the South Sudan Specifications for new works. The same specifications and standards should be applied to the repair.

The hole is filled with a selected material to match the existing surrounding good surface and base materials. This can consist of new material, or in the case of e.g. stone paving, recycled undamaged pieces.

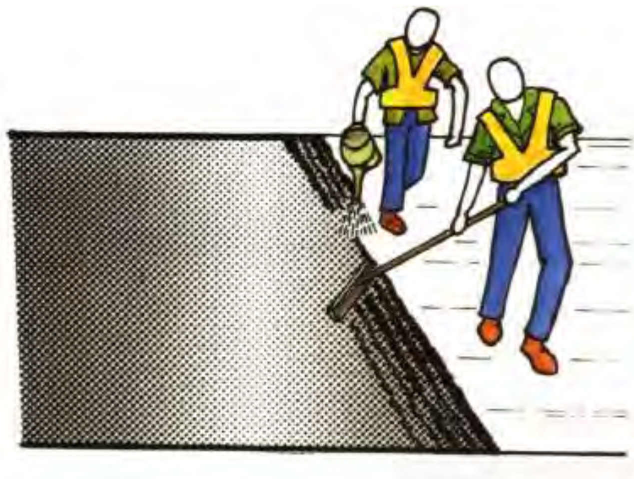
The material is placed in the hole and compacted in one or more layers of regular thickness depending on the depth and materials involved.

When using granular materials, generally, the last layer, prior to compaction, must have an excess thickness of about 1/5 the depth of the final layer, in order to allow for settlement on compaction.

Compaction is continued depending on the size of the excavation, using the vibrating roller, plate compactor or with a hand rammer, until the surface is level.



Porous repairs will require a seal coat to prevent penetration of water.



STRUCTURES

Cross drainage structures (bridges, drifts or culverts) usually account for a high proportion of the total cost of a road. They are the potential weak points in a road network due to the possible damaging effects of floods and high water flows being concentrated at the points where the water crosses the road. The failure of these structures would result in high replacement costs and long delays and user inconvenience due to the closure of the road. It is particularly important therefore, that sufficient attention is given to structures to ensure that they are maintained in good condition.

A bridge, culvert or other structure is an integral part of the road, and its condition will affect the level of service that the road provides. A structure should be designed so that no major repair works should be required during its 'design life' (e.g. replacement of abutments, piers or deck structural members). Eventually major works may be required such as a complete new timber bridge deck or safety barrier replacement. However, the structure should be designed to provide many years of service through its design life with only minor maintenance.

Importantly, if the maintenance is not carried out, there can be serious consequences for road users. It can result in increased safety hazards, reduced quality of service or even loss of the structure and severing of the transport link.

It is usually not possible with the resources available in developing countries to devise a 'maintenance-free structure' for a watercourse crossing. However, application of the design and construction guidelines contained in this South Sudan LVR Manual should reduce maintenance requirements to an acceptable and manageable level. Conversely, poor design or construction will result in an abnormally high requirement for maintenance, or even eventual loss of the structure.

There are a number of aspects which should be appreciated in devising appropriate management and maintenance arrangements for structures. This applies to consideration of an individual structure, or a large number constructed at various locations on a road network.

- Structures will often need no maintenance for periods of many months or sometimes even years.
- Deterioration or damage to a structure can progress slowly (e.g. corrosion, attack by insects), or suddenly (e.g. in a flood or vehicle accident).
- The need for repairs may not be obvious to road users or through casual observation from the road. However, the deterioration can progress, if not checked, to result in the need for major works at great cost and requiring substantial unplanned resource mobilisation.
- The resources for maintenance and repair of a typical structure are required intermittently, not continuously.
- It is usually most efficient to provide maintenance resources only when the structure requires maintenance or repair works.

It is important to ensure the maintenance of a structure so that it remains in its intended condition, providing the service and benefits to road users and the community that it was designed for. It is an asset that needs to be managed.

It is advisable to inspect all structures at least once each year. This is best achieved after the rains, so that any remedial works can be planned to be carried out before the next rains.

Defect 25: Random stone filling defective

Development, if neglected:
Erosion of structural protection and possible structural damage

Maintenance Activity

- **410 Repair Random Stone filling**

Random stone filling is provided to protect the structure and the adjacent areas from erosion, particularly when the watercourse is in flood condition. The stone filling may become defective due to ground settlement or erosion in flood conditions. Minor repairs can be carried out by topping up the stone with similar material to the original constructed profile. If the defects are extensive, an Engineer should be consulted to investigate the cause and plan suitable remedial works.

Defect 26: Retaining wall defective

Development, if neglected:
The road works, earthworks or structure protected by the retaining wall may be endangered and the route may become impassable

Maintenance Activity
411 Retaining Wall Repairs

It is important to determine the cause of the defective retaining wall, which may be due to settlement, erosion, water seepage or structural failure. Any defects should be brought to the attention of an Engineer to investigate the cause and plan suitable remedial works.

Defect 27: River or stream bed scoured adjacent to structure

Development, if neglected:

Scour adjacent to the structure can cause failure of the abutments or piers and causing the structure to become un-usable.

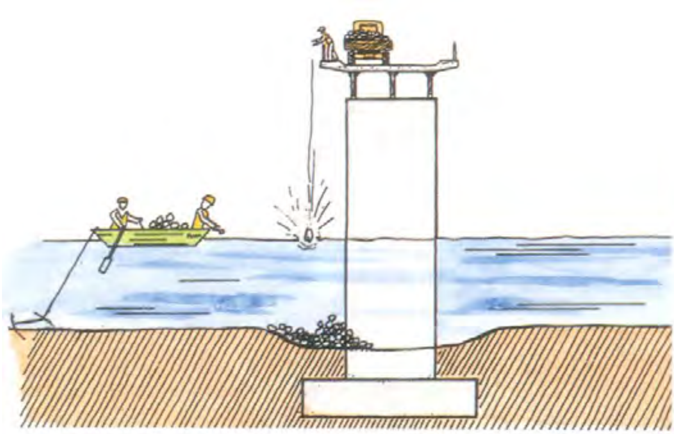
Maintenance Activity

412 Watercourse scour repairs

Loss of riverbed material by fast flowing water at piers, abutments and wing walls is best identified and repaired at low water level or when the river bed is dry.

The scoured area should be refilled with rock using stone pieces of 10 to 30 kg weight, or heavier. The decision on stone size must be made, taking into account what is locally economically available.

In serious cases further protection, such as gabions, may be required.



IF SCOUR AREA DRIES OUT:

1. Stake out the area around the pier or wall where scour has occurred.
2. Excavate to estimated lowest scour level.
3. Place riprap stone in layers in the excavation, starting with the smaller size stone in the lowest layer.
4. Fill spaces between stones with smaller size stone.
5. Continue work layer after layer until normal bed level is reached. The top layer should contain the heaviest stones and have a flat even surface at river bed level.

IF SCOURED AREA IS SUBMERGED:

When it is not possible to place the riprap apron in regular layers due to water flow, the scour area can be filled by random filling of the scour depression.

1. Establish the extent of scour by survey, plumbing the riverbed. Use poles or marker buoys to identify the extent of the work required.
2. Using stone blocks as above, drop riprap material into the scour depression from the bridge, a boat or from the bank until the depression has been filled. Re-plumb the riverbed throughout the work to check progress.

Defect 28: Gabion walls or mattress defective

Development, if neglected:
The road works, earthworks or structure protected by the gabions may be endangered and the route may become impassable

Maintenance Activity
413 Gabion Basket Repairs

If the defects are extensive, the gabion structure, or part of it, may need to be reconstructed.

Refer to the details and description for **Defect 10**.

Defect 29: Structural Repairs of serious defects

Development, if neglected:
Serious damage to or failure of the structure. Route may become impassable.

Maintenance Activity
414 Major Structural Repairs

Structural repairs may be required for the following serious defects:

- structural timber decay, splitting or insect attack
- bulging masonry
- cracked concrete or masonry
- honeycombed concrete
- spalling concrete
- serious rust or chemical stains
- exposed or corroding reinforcement or pre-stressing steel
- damp patches on concrete
- seriously corroded structural steelwork
- damaged/distorted structural steelwork
- missing/loose rivets, bolts or other fixings
- cracks in structural steelwork
- settlement of deck, piers, abutments or wingwalls
- expansion joint or bearing defects
- erosion requiring piling works.

These major defects will require the expertise of an Engineer to assess and design/specify the remedial works in response to the scale and nature of the defects. It is likely that Plans, Drawings, Specifications and Bills of Quantities will need to be prepared for these major works.

IN SUMMARY

GOOD, REGULAR ROAD AND STRUCTURES MAINTENANCE WILL PRESERVE ASSETS AND SHOULD PREVENT ACCESS BEING SEVERED,

AND RURAL COMMUNITIES BEING ISOLATED!

11. MANAGEMENT & PRIORITIES

With limited resources, it is usually necessary to set priorities for carrying out maintenance work. Maintenance should always take priority over any route upgrading or improvement works. **Protect what you have before extending your assets and liabilities!**

Furthermore, maintenance is most effective when applied to 'maintainable' routes, that is, those with a road camber and drainage system already established. This is preferable to trying to work on un-drained tracks and sunken road sections, which will consume a lot of resources with limited impact and durability.

The usual questions are:

- Which Route?, and
- Which maintenance activity?

Route Priorities

Within the community, the routes with the higher maintenance priorities should be agreed. For simplicity and clarity it is best to divide all routes into 2 or 3 priority groups based on the following suggested criteria:

- Strategic inter-community or main road links
- Is it maintainable? That is, does it already have camber and working drainage system?
- Traffic: high (e.g. more than 25 motor vehicles/day) or low
- Population served
- Value of volume of crops extracted each year
- Serving markets, educational or health facilities

It is useful to list the routes as an Inventory of assets to be managed, as an aid to planning and management, for example:

EXAMPLE INVENTORY

Route	Length (km)	Daily traffic in motor vehicles (date of survey)	Reasons for priority	Days impassable last year
Priority A				
Main road to A	6.4km gravel	65 (July 2010)	Main Access, No alternative route	0
A to village B	3.5km earth with spot paving	50 (April 2010)	School and crop exports	0
Priority B				
A to village C	4.5km earth	20 (January 2010)	Horticultural, Key bridge	2
Village B to C	5.0km earth	12 (October 2009)	Dispensary	10
Village C to D	7.0km earth	<10 (July 2010)	Pottery, sunken sections	25

It is beneficial for this information to be displayed at prominent community locations, and updated regularly.

Maintenance Activity Priorities

Where it is possible to arrange route maintenance on a number of occasions each year, the following seasonal priorities should be made for each group of maintenance activities:

BEFORE RAINS: Drainage & Structures

DURING RAINS: Drainage & Road Surface unpaved road sections

AFTER RAINS: Road Surface paved sections & Roadside activities & Occasional maintenance, Inspect Structures.

In this way the vital road drainage system and crossings are prepared before the rainy periods and are kept functioning through the rains. The earth and gravel surfaces are most effectively maintained during the rains (provided they have not been allowed to deteriorate too much to require reconstruction) when there is moisture in the materials to help consolidate them after reshaping. Paved road surfaces will usually develop any defects during the rains and are best repaired when the drier weather comes.

Some variations to these general priorities may be applied due to local conditions.

If a route becomes blocked or totally impassable, this is no longer a maintenance problem. It will usually require the reasons to be investigated and additional resources required to re-open it. Assistance or advice may be required from MRB or local authorities.

Upgrading or Spot Improvement Priorities

Each year, and for each route, an assessment should be made of any desirable spot improvements that should be made if resources are available. These could include any of the options listed on Page 8.

Management of Structures

The maintenance works required to be carried out on a structure will range from basic seasonal clearing of silt and debris (Regular or Routine Maintenance) to ensure it continues to function properly, through to replacement of components of the structure when they are worn out or damaged. It can be expected that ALL structures will normally require at least some basic maintenance each year.
It is necessary to set up a management system to ensure that the structure stays in a condition that it is able to carry out its function in a safe manner.

In essence this 'system' should identify **defects** and when work needs to be carried out. From this assessment the maintenance funding and works can be arranged and supervised to ensure that the maintenance is completed satisfactorily.
A system of inspections is required to identify any damage or deterioration of the structure, or problems adjacent to the structure which may threaten its stability.
The key components of a structures management system are:

- An inventory of all structures (i.e. What is the asset? What are its key features? These are management records which generally do not change with time, except for new structures or after major structural changes to an existing one);
- An inspection system (to determine the condition and repair needs);
- Arrangements for specifying, arranging, supervising, recording/reporting and paying for the works. Arrangements should also be in place for checking the 'value for money' of maintenance operations and expenditures.

TRL Overseas Road Note 7 (Reference 12) provides comprehensive guidelines on the inspection and documentation of inventory and condition information on structures. A paper based system is quite adequate for Low Volume Roads. Computer systems can help if the number of structures being managed is substantial and the operating environment can support the maintenance of the computer system itself, including arrangements for the on-going support, costs and skilled resources required. In a limited resource environment it can be difficult to justify and secure the recurring costs of administration, computer support personnel and inevitable software and hardware upgrades required for a computer system; i.e. there can be an undue and unnecessary dependence on external resources.

Certain maintenance activities such as de-silting and removal of debris should be carried out under a routine programme of works. For example, before the rainy season all silt should be removed from culverts, their inlets and outlet channels. After the rains, and particularly after individual floods, silt and debris should be cleared from structures to avoid later damage due to blockages or diversion/ concentration of water.

These routine clearing operations are an ideal opportunity to carry out an inspection of a structure. With the scarcity and expense of engineering personnel, it is possible to train persons with limited education (e.g. the gang leader) to carry out inspections and to alert engineering staff to situations that require their action.

Inspections of ALL structures should be carried out after a flood situation as this is the most likely time for damage to have occurred. Particular attention should be paid to identifying any movement, especially at joints, cracking/spalling and assessing whether erosion has occurred around abutments and piers, or at the ends of aprons. Where water is permanently standing against the structure, probing with ranging rods, poles or plumb lines should be carried out to identify unseen scouring. A boat or raft may be required for this inspection.

All structures, from culverts to bridges, should receive a documented routine inspection at least once each year. As indicated above these can be carried out by relatively unskilled personnel if the appropriate training is provided. Inspection records should be carefully filed for future reference. Even a report of ‘no defects’ is important management information.

The management of a structure costs money and, even before a structure is built, the ongoing provision of the funds and resources for the management (including inspections), as well as the maintenance of the structure, should be assured.

11. WORK OPTIONS

There are a number of ways that maintenance work can be organised depending on the financial and human resources available, and 'in-house' capacity of the responsible authority or organisation.

In practical terms, the maintenance of Low traffic Volume Roads (LVR) will be carried out principally by labour methods with possible occasional support of intermediate or heavy equipment. The last option is often too expensive to mobilise and inefficient for remote rural road works.

All options will require appropriate levels of training and mentoring, and management arrangements.

The main work organization options are detailed in this section with their typical advantages and disadvantages. The Works Options are:

- **Option 1- Small Contractor (Private)**
- **Option 2 - Force Account**
- **Option 3- Community Group**
- **Option 4 - Length Person or Family Contract**
- **Option 5 - Compulsory/Voluntary Labour**
- **Option 6 - Hire-in equipment**
- **Option 7- Large Contractor Based System**

Option 1- Small Contractor (Private)

The small enterprises will be based in the state or local area of the road. They may be general or building contractors with established contracting experience in earthworks, masonry and concrete. They would be expected particularly to make use of local labour, and may have access to light equipment such as a small compacter, concrete mixer or tractor. This implementation option can be suitable for All Maintenance activities and for all types of road surface.

Advantages:

- Overheads lower than big contractor
- Low mobilization and demobilization costs
- Construction experience of the enterprise
- Available range of building and maintenance skills
- Local enterprise committed to the community
- Good prospects for local employment and money being injected into the community

Disadvantages:

- Time, resources and costs involved with preparing and managing the contract
- Market for maintenance works currently not developed so prices may be distorted (guideline unit costs should be available from MRB or local authorities)
- Small contractor may have to hire in some equipment
- May initially require some training/ mentoring, or a higher level of supervision than large contractors
- May have difficulty in obtaining credit for purchases, or financing cash flow
- Insufficient funds currently available to pay for this approach for all maintenance work (but may be suitable for selected works – see also Option 6)
- Risks of disputes over interpretation of contract responsibilities

Option 2 – Force Account (sometimes called Direct Labour)

This option makes use of a permanently employed and equipped workforce to carry out the maintenance work such as local road management units. This implementation option can be suitable for All Maintenance activities and for all types of surfaces.

Advantages:

- Direct response to all maintenance needs
- Rapid mobilization when funds are available
- Retain skills and experience within organization, familiarity with the network, standards, work methods
- Minimum of works documentation requirements
- Dealings/ disputes with outside parties minimized.

Disadvantages:

- In some cases no budget or funds are currently available for this option
- Difficulties in equipment procurement & the lowest initial purchase cost policy can hinder the standardization and efficiency
- Poor mobility of the workforce around the network unless transport is provided (at considerable cost)
- Paid labour and equipment may be standing if no funds available for works
- Possible low efficiency and poor management/use of available resources, poor cost-awareness
- Little pressure to try new solutions/ technologies
- High mobilization and demobilization costs if sourced from state or national level

Option 3– Community Group

The use of a group of persons based within the community and organized specifically to carry out the maintenance works under an agreement or contract with the community or local authority. This can be for a single route, or a number of routes serving the community. This approach differs from the Length person or Family contract approach only in that the number of persons expected to be involved would be greater, and that consequently work would probably be concentrated at a particular time or times of the year. Possibility of organizing annual or regular community 'day of road action' when the whole community works on the road for nominal payment or arrangement. This implementation option can be particularly suitable for the Regular Maintenance activities.

Advantages:

- Low cost compared to most other forms of contract (due to low overheads, low mobilization and demobilization costs, absence of profit component, and by local participation)
- Can be cash or in-kind payment according to community circumstances
- Simple contract/agreement required
- Direct response to Regular maintenance needs – Rapid mobilization, or planned seasonal inputs
- Retain skills and experience within the community, familiarity with the network and any problem sections
- Close control of the works personnel
- Pride of 'ownership' for the network
- No dealings/disputes with parties outside of the community
- Employment and money/resources recycled within the community
- Employment can be targeted at poor or disadvantaged persons in the community.

Disadvantages:

- Possibly insufficient cash funds available to pay for this approach in poor communities
- Possible difficulties in controlling output and quality
- Not suitable in areas of dispersed or low population density
- No equipment capability

- May not have access to construction quality hand tools

Option 4 – Length Person or Family Contract

A contract or agreement is drawn up for an individual or family to carry out specified Regular maintenance activities on a section of road, at certain times of the year, for a payment in cash or in-kind for work on a full or part time basis.

Usually a labourer is appointed for a distinct section of road close to his/her home, typically 1 to 2 km in length. The person walks or cycles to the work site each work day. He or she is provided with all the necessary hand tools to carry out all the regular maintenance activities as instructed by the local authority. An advantage is that regular maintenance of the entire road can be arranged at all times and one person can be made fully responsible of a road section. A disadvantage is that supervision has to mobile and frequent to ensure that performance does not deteriorate.

Advantages:

- Low cost compared to most other forms of contract (due to low overheads, low mobilization and demobilization costs, absence of profit component, and by local participation)
- Can be cash or in-kind payment according to community circumstances
- Simple contract/agreement required
- Flexible approach to seasonal needs.
- Rapid mobilization by person living ‘on site’
- Pride of ‘ownership’ for the network
- No dealings/disputes with parties outside of the community
- Employment and money/resources recycled within the community

- Employment can be targeted at poor or disadvantaged persons in the community

Disadvantages:

- Possibly insufficient cash funds available to pay for this approach in poor communities
- Possible difficulties in controlling output and quality
- Not suitable in areas of dispersed or low population density
- No equipment capability
- May not have access to construction quality hand tools
- System will degenerate if supervisor is not continuously mobile and effective in management

Option 5 – Compulsory/Voluntary Labour

The use of local (community) labour to carry out maintenance works on the roads is one of the options for maintaining community roads. The approach can be suitable for Regular Maintenance activities. If the whole community can be persuaded to attend a 'maintenance day' once or twice a year with their hand tools, there will be sufficient labour resources to carry out the necessary maintenance work under the guidance of a trained supervisor. This is the cheapest way to maintain a LVR and involves no taxation or levy to the community. Everybody contributes and benefits equitably. Wealthier inhabitants, traders or other well-wishers could contribute hand tools, equipment hire or food to create a community occasion.

Advantages:

- No financing or cash accounting involved
- In richer communities, individuals can elect to pay cash instead. This can provide funding for materials, handtools and equipment hire, or even paid labour
- Minimum of works documentation requirements

- Direct response to all maintenance needs
- Rapid mobilization
- Retain skills & experience within community
- Direct supervision of works
- Pride of 'ownership' for the network
- No dealings/disputes with outside parties

Disadvantages

- All persons contribute equally, whether rich or poor
- Can be a severe burden on the community's poorest persons
- Difficulties in controlling output and quality
- Not suitable for work during the agricultural 'high' season
- Not suitable in areas of dispersed or low population density
- Few prospects for PAID community employment or money being injected into the community
- No equipment capability
- May not have access to construction quality hand tools
- May initially require some supervisor and 'gang leader' training/ mentoring,

Option 6 – Hire-in equipment

This is an option to supplement the other options to provide equipment for specific operations such as towed grading or haulage. The funding could be provided by the local authority if available, or a benevolent trader, farmer or other well-wisher.

Option 7 – Large Contractor Based System

The employment of a large equipment-based contractor may be considered. They are usually based in state centres or Juba and their overheads, mobilization and demobilization costs and profit components would be very high. Therefore, the costs would be extremely high and unlikely to be affordable by the community or local authority. In cases where a contractor is funded externally to construct a road, this contractor may be engaged as part of the contract to maintain the road for some years after the final construction acceptance is finalized.

12. PLANNING AND PRODUCTIVITY

It is important to plan the maintenance works according to the defect repair needs, the priorities and the resources available to carry out the works.

The following labour resource requirements were developed from research in East Africa and can be used as an outline planning guide.

OUTLINE REGULAR MAINTENANCE PLANNING FOR LVRs

Number of Person-days of work expected/km/year

Number of "wet" months	Gravel <50vpd	Gravel >50vpd	Earth <50vpd	Earth >50vpd
4	40	45	45	52
8	68	75	79	88
12	100	107	115	125

NOTES:

i *Number of "wet" months per year are with rainfall >25mm.*

ii *Estimates assume 'maintainable' road with proper camber and drainage system and gradients <6%. Not applicable for problem soils such as 'black cotton'.*

iii *Does not include Occasional works such as re-gravelling.*

With good record keeping a similar table can be developed for each community. Equipment inputs may be required for materials haulage and towed grading. Earth and gravel roads require reshaping/grading typically between 1 and 4 times per year. These estimates will help to make resource and cost estimates for each road each year.

Productivity Targets

To plan and manage maintenance works it is useful to have productivity Standards, Norms or Targets. These need to be flexible considering the variable nature of LVR maintenance works, experience of the supervisor and workforce, and whether the work is carried out on a paid or voluntary basis. Development of local Norms or Targets can take considerable time to achieve. The following Targets were developed from research in East Africa and practice in Southern Africa, and can serve as a reference point. The standards were developed under close supervision conditions, with a well trained workforce. They represent the best productivities that can be achieved with a well organised and managed workforce. They should therefore be as targets to be worked towards. It is expected that under normal conditions 60 – 80% of the productivity standards should be achieved. Good record keeping can allow local productivity standards to be developed over time.

PRODUCTIVITY TARGETS PER PERSON-DAY			TASK DIFFICULTY				NOTES
CODE	MAINTENANCE ACTIVITY	UNIT	1	2	3	4	
110 111	Spot Repair – Selected Material/Aggregate	wheel barrows / day	25	18	13	8	Difficulty = Hauling distance from stockpile 1. no haul 2. up to 100m 3. 100m to 200m 4. over 200m
112	Reshape & Compact Earth Road Camber	route m/day	70	50	-	-	Difficulty = Type of reshaping over road width 1. (Light) up to 75mm cut 2. (Heavy) over 75mm cut
121	Culvert Cleaning	As Shown	4 Culverts /day	1 Culvert /day	2 Days /Culvert	4 Days /Culvert	Difficulty = Silt Depth in Culvert barrel 1. up to 1/4. 2. 1/4 to 1/2. 3. 1/2 to 3/4. 4. over 3/4. Tasks for 600 dia. Culverts 7m. long
122	Ditch Clearing - Manual (Culvert outfall)	m/day	55	40	25	-	Difficulty = Silt depth 1. up to 10cm 2. 10 to 20cm 3. over 20cm
122	Ditch Clearing - Manual (Turnout drains)	m/day	60	45	30	-	Difficulty = Silt depth 1. up to 10cm 2. 10 to 15cm 3. over 15cm
122	Ditch Clearing - Manual (Side drains)	m/day	Wet areas 65 Dry soft soil 55 Dry hard soil 30	45 40 23	30 30 18	-	Difficulty = Silt depth 1. up to 10cm 2. 10 to 15cm 3. over 15cm
123	Repair Erosion Damage (Selected Fill in drains)	m/day	Wet areas 100 Dry areas 100	80 50	60 23	-	Difficulty = Depth of erosion 1. up to 15cm 2. 15 to 30cm 3. over 30cm
126	Dry Masonry Repair	m/day	7	4	-	-	Difficulty = Type of repair 1. minor repairs 2. major repairs Task for linear metres of dry stone wall
128	Build wooden/stone scour check	No/day	5	7	-	-	Difficulty = Type of scour check 1. wood 2. stone

PRODUCTIVITY TARGETS PER PERSON-DAY			TASK DIFFICULTY				NOTES
CODE	MAINTENANCE ACTIVITY	UNIT	1	2	3	4	
131	Bush clearing - light	m/day	425	260	190	-	Difficulty = Width of bush 1. up to 1.0m 2. 1.0 to 2.0m 3. over 2.0m
131	Bush clearing - dense	m/day	275	225	175	-	
132	Shoulder Rehabilitation (manual)	m/day	100	80	65	-	Difficulty = Depth of erosion 1. up to 10cm cut 2. 10 to 15cm cut 3. over 15cm cut
133	Plant grass and water	m/day	100	80	65	-	Difficulty = Planting width 1. up to 0.5m 2. 0.5 to 1.0m 3. over 1.0m
134	Cut grass - light	m/day	Wet areas 425 Dry areas 310	260 230	190 170	-	Difficulty = Width of grass cutting 1. up to 1.0m 2. 1.0 to 2.0m 3. over 2.0m
134	Cut grass - dense	m/day	310	240	175		
220	Blade Gravel Road (light)	route km/day	10	-	-	-	Difficulty = 4 passes up to 3cm of cut. Excludes mobilisation & demobilisation
221	Blade Gravel Road (heavy)	route km/day	4	-	-	-	Difficulty = 8 passes more than 3cm of cut. Excludes mobilisation & demobilisation

13. FURTHER ADVICE AND ASSISTANCE

Documentation

The following documents and publications may be accessed for further information. Some of these documents may be accessed or downloaded free of charge from www.gtkp.com

1. Ethiopian Road Authority, LVR Design Manual, 2011
2. Ethiopian Road Authority, Maintenance Technical Specifications
3. Ethiopian Road Authority & Intech, Intermediate Technology Roadworks Equipment, Final Report, November 2010
4. Gongera K & Petts R C, A Tractor and Labour Based Routine Maintenance System for Unpaved Rural Roads, 2nd Edition, 2003
5. ILO, Guide to Tools and Equipment for Labour Based Road Construction, 1981
6. Intech Associates & MOPW Kenya, Road Maintenance Manual, 1992
7. Intech Beusch & Ministry of Roads and Public Works, Operations Manual Roads 2000, 2005
8. I&D Consult & MOPW Kenya, Headmans Handbook for Maintenance, 1991
9. Jones T E & Petts R C, Maintenance of Minor Roads in Kenya, TRB Fifth International Conference on Low Volume Roads, USA, 1991
10. OtB, Low Volume Rural Road Surfacing and Pavements - A Guide to Good Practice, 2013
11. Petts R C, Handbook of Intermediate Equipment, 2012
12. Transport and Road Research Laboratory, Overseas Road Note 7, Volume 2, Bridge Inspector's Handbook, 1988
13. World Road Association (PIARC), International Road Maintenance Handbook, 4 Volumes, 1994 and revisions

Knowledge Sources

1. Global Transport Knowledge Partnership, www.gtkp.com, info@gtkp.com
2. Transport Research Laboratory, UK
3. CSIR, South Africa
4. Indian Roads Congress
5. Various road sector Technology Transfer Centres

Expertise

1. Ministry of Roads and Bridges , Juba
2. State Road Authorities
3. Locally operating agencies (in 2012 these included UNOPS, WFP, USAID and some specialist Engineering Consultants).

Financial or other support

It is appreciated that communities and local authorities have very limited resources and funding available for improving or maintaining rural access roads. However, regional, national and international organisations may be interested to help with partial funding for cost-effective, well-targeted rural transport development initiatives which can demonstrate rural development or poverty reduction benefits.

The following organisations have previously supported rural transport initiatives. Details of their headquarter and local representative offices may be obtained from the internet.

- African Development Bank
- Arab Bank for Economic Development in Africa
- CARE
- DANIDA
- DFID, UK
- DGIS (Netherlands)

- FINNIDA (Finland)
- Helvetas (Switzerland)
- Irish Aid
- Islamic Development Bank
- Kuwait Fund
- NORAD (Norway)
- OPEC Fund for International Development
- Saudi Fund for Development
- Swiss Development Cooperation (SDC)
- SIDA
- UNOPS
- USAID (USA)
- WFP
- World Bank

14. TERMINOLOGY

Abney Level - Small hand held slope measuring and levelling equipment.
Aggregate - Hard mineral elements of construction material mixtures, for example: sand, gravel, crushed rock.
Aggregate Brooming - Using a broom to spread chippings on a surface.
Alligator Cracks - See Crazing.
Apron - The flat invert of the culvert inlet or outlet.
Asphalt - Another word for bitumen. Sometimes used to describe plant mixed bituminous materials.
Asphaltic Concrete - A high quality manufactured mixture of bitumen and aggregates. Expensive and usually only used on main roads.
Attendant or Lengthman - A person contracted or appointed to maintain a section of road. Can be male or female and the term 'Attendant' or 'Lengthman' assumes either sex.
Basin - A structure at a culvert inlet or outlet to contain turbulence and prevent erosion.
Berm - A low ridge or bund of soil to collect or redirect surface water.
Bituminous Slurry (Slurry-Seal) - Mixture, usually of fine-grained aggregates, water, bituminous binder (emulsion), cement, and sometimes an additive, for a road surface seal.
Bituminous Binder (Asphalt) - A petroleum oil based or natural product used to bind or coat aggregates for road pavements.
Black Cotton Soil - An expansive clay found widely in the North East of the country that expands and looses most of its strength when wetted
Bleeding - Defect: Excess binder on the surface of the pavement.
Blinding -
a) A layer of lean concrete, usually 5 to 10 cm thick, placed on soil to seal it and provide a clean and level working surface to build the foundations of a wall, or any other structure.
b) An application of fine material e.g. sand, to fill voids in the surface of a pavement or earthworks layer.
Block Cracking - Defect: Interconnected cracks forming a series of large blocks usually with sharp corners or angles.

Brick (clay) - A hard durable block of material formed from burning (firing) clay at high temperature.

Bridge - A structure usually with a span of 5 metres or more, providing a means of crossing above water, a railway or another obstruction, whether natural or artificial. A bridge consists of abutments, deck and sometimes wingwalls and piers, or may be an arch.

Camber - The road surface is normally shaped to fall away from the centre line to either side. The camber is necessary to shed rain water and reduce the risk of passing vehicles colliding. The slope of the camber is called the crossfall. On sharp bends the road surface should fall directly from the outside of the bend to the inside (superelevation).

Camber Board - Apparatus for checking the crossfall of the road camber, or the shoulder.

Cape Seal - A road surface layer formed by slurry seal laid on top of a bituminous chip seal.

Carriageway - The road pavement or bridge deck surface on which vehicles travel.

Cascade - A drainage channel with a series of steps, sometimes with intermediate silt traps or ponds, to take water down a steep slope.

Catchpit - A manhole or open structure with a sump to collect silt.

Catchwater Drain - See Cutoff.

Causeway or Vented Drift - Low level structure constructed across streams or rivers with openings to permit water to pass below road level. The causeway may become submerged in flood conditions.

Chippings - Clean, strong, durable pieces of stone made by crushing or napping rock. The chippings are usually screened to obtain material in a small size range.

Chip Seal - A surface layer formed by stone chippings laid onto a bituminous seal coat.

Chute - An inclined pipe, drain or channel constructed in or on a slope.

Cobble Stone (Dressed stone) - Cubic pieces of stone larger than setts, usually shaped by hand and built into a road surface layer or surface protection.

Coffer Dam - A temporary dam built above the ground to give access to an area which is normally, or has a risk of being, submerged or waterlogged. Cofferdams may be constructed of soil, sandbags or sheetpiles.
Compaction - Reduction in bulk of fill or other material by rolling or tamping.
Counterfort Drain - A drain running down a slope and excavated into it. The excavation is partly or completely filled with free draining material to allow ground water to escape.
Cracking - Defect: Narrow breaks in a surfacing or pavement material caused by overloading, fatigue or weakness of the material.
Crazing (Alligator Cracks) - Defect: Interconnecting network of cracks in the road surfacing.
Cribwork - Timber or reinforced concrete beams laid in an interlocking grid, and filled with soil to form a retaining wall.
Cut-off/Catchwater Drain - A ditch constructed uphill from a cutting face to intercept surface water flowing towards the road.
Debris Rack or Grill - Grill, grid or post structure located near a culvert entrance to hold back floating debris too large to pass through the culvert.
Deck - The part of a bridge that spans between abutments or pier supports, and carries the road traffic.
Depression - Defect: Localised low areas of limited size in the pavement surface or in any other surface.
Ditch (Drain) - A long narrow excavation designed or intended to collect and drain off surface water.
Drag - An apparatus towed behind a vehicle or piece of equipment to remove minor irregularities and redistribute loose surface material.
Drainage - Interception and removal of ground water and surface water by artificial or natural means.
Drainage Pipe - An underground pipe to carry water.
Dressed Stone - See Cobble Stone.
Drift or Ford - A stream or river crossing at bed level over which the stream or river water can flow.
Earth Road - See ENS.

Edge Cracking - Defect: Longitudinal cracking near the edge of the pavement.
Embankment - Constructed earthworks below the pavement raising the road above the surrounding natural ground level.
ENS (Engineered Natural Surface) - An earth road built from the soil in place at the road location, and provided with a camber and drainage system
Excess Aggregate - Defect: Aggregate particles not coated with binder after application of binder.
Flow Spreader - A structure designed to disperse the flow at the outfall of a ditch or drain to minimise the risk of erosion down stream.
Fog Seal - A very light film of binder sprayed onto a road to bind or enrich the surface.
Ford - See Drift
Formation - The shaped surface of the earthworks, or subgrade, before constructing the pavement layers.
Fretting - Defect: The loss of chippings from the surface seal or premix layer due to poor bond between the aggregate and the seal or binder.
Gabion - Stone-filled wire or steel mesh cage. Gabions are often used as retaining walls or river bank scour protection structures.
Glazing - Defect: Wear or embedment of chippings in the surfacing giving a smooth, shiny appearance.
Hand Packed Stone - A layer of large, angular broken stones laid by hand with smaller stones or gravel rammed into the spaces between stones to form a road surface layer.
Incremental paving - Road surface comprising small blocks such as shaped stone (setts) or bricks, jointed with sand or mortar.
Invert - The lowest point of the internal cross-section of a ditch or culvert.
Layby - An area adjacent to the road for the temporary parking of vehicles.
Lengthman - See Attendant.
Loss of Surface Aggregate - Defect: Removal of aggregate from a surface dressing, or from surfacings with coated aggregate, or concrete.
Macadam - A mixture of broken or crushed stone of various sizes (usually less than 3cm) laid to form a road surface layer.
Manhole - Accessible pit with a cover forming part of the drainage system

and permitting inspection and maintenance of underground drainage pipes.

Margins - The right of way or land area maintained or owned by the road authority.

Mitre Drain (Turn Out Drain) - leads water away from the Side Drains to the adjoining land.

Occasional Maintenance - Operations that are occasionally required on a section of road after a period of a number of years. Sometimes referred to as Periodic Maintenance.

Ottaseal - A surface layer formed by rolling natural gravel into a soft bituminous seal coat.

Outfall - Discharge end of a ditch or culvert.

Parapet - The protective edge, barrier, wall or railing at the edge of a bridge deck.

Pass - A single longitudinal traverse made by a grader, roller or other piece of equipment working on the road.

Patching - The execution of minor local repairs to the pavement and shoulders.

Pavé - See Sett

Paved Road - For the purpose of this booklet, a paved road is a road with a Stone, Bituminous, Brick or Concrete surfacing.

Pavement - The constructed layers of the road on which the vehicles travel.

Permeable Soils - Soils through which water will drain easily e.g. sandy soils. Clays are generally impermeable except when cracked or fissured (e.g. ‘Black Cotton’ soil in dry weather).

Plumbing - Using a calibrated line, with a weight attached to the bottom, to measure the depth of water (e.g. for checking erosion by a structure).

Profile - An adjustable board attached to a ranging rod for setting out.

Ravelling - See Stripping.

Regular Maintenance - Operations required to be carried out once or more per year on a section of road. These operations are typically small scale or simple, but widely dispersed, and require un-skilled or trained manpower. Sometimes referred to as Routine Maintenance.

Reinforced Concrete - A mixture of coarse and fine stone aggregate bound with cement and water and reinforced with steel roads for added strength.

Riprap - Stones, usually between 5 to 50 kg, used to protect the banks or bed of a river or watercourse from scour.
Road Base and Subbase - Pavement courses between surfacing and subgrade.
Road Maintenance - Suitable regular and occasional activities to keep pavement, shoulders, slopes, drainage facilities and all other structures and property within the road margins as near as possible to their as constructed or renewed condition. Maintenance includes minor repairs and improvements to eliminate the cause of defects and avoid excessive repetition of maintenance efforts.
Roadway - The portion within the road margins, including shoulders, for vehicular use.
Sanding - Spreading course sand onto a bituminous road surface that is bleeding.
Sand Seal - A surface layer formed by sand laid onto a bituminous seal coat.
Scarifying - The systematic disruption and loosening of the top of a road or layer surface by mechanical or other means.
Scour - Defect: Erosion of a channel bed area by water in motion, producing a deepening or widening of the channel.
Scour Checks - Small checks in a ditch or drain to reduce water velocity and reduce the possibility of erosion.
Scuppers - Drainage pipes or outlets in a bridge deck.
Sett (Pavé) - A small piece of hard stone trimmed by hand to a size of about 10cm cube used as a paving unit.
Shoulder - Paved or unpaved part of the roadway next to the outer edge of the pavement. The shoulder provides side support for the pavement and allows vehicles to stop or pass in an emergency.
Slip - Defect: Slope material sliding downhill because of instability, water penetration or flow.
Slope - A natural or artificially constructed soil surface at an angle to the horizontal.
Slot - A sample cross section of the road or drain constructed as a guide for following earthworks or reshaping.
Slurry Seal - A mixture usually containing fine graded aggregates, water,

bitumen emulsion, cement and sometimes an additive, spread on the road surface by a specially equipped machine, or by hand.

Sods - Turf but with more soil attached (usually more than 10 cms).

Soffit - The highest point in the internal cross-section of a culvert, or the underside of a bridge deck.

Special Maintenance - Certain serious, unforeseen situations necessitating remedial action to be taken as soon as possible, e.g. flood damage, major slips. Consult the regional authorities regarding these.

Spray Lance - Apparatus permitting hand-application of bituminous binder at a desired rate of spread through a nozzle.

Squeegee - A small wooden or metal board with a handle for spreading bituminous mixtures by hand.

Streaking - Defect: Alternate lean and heavy lines of bitumen running parallel to the pavement centre line, caused by blocked or incorrectly set spray nozzles.

Stringer - Longitudinal beam in a bridge deck or structure.

Stripping (Ravelling) - Defect: The loss of surface seal from the pavement due to poor bond between the seal and the lower pavement layer.

Subbase -See Road Base.

Subgrade - Upper layer of the natural or imported soil (free of unsuitable material) which supports the pavement.

Sub-Soil Drainage - See Underdrainage.

Surface Dressing - A sprayed or hand applied film of bitumen followed by the application of a layer of stone chippings, which is then rolled.

Surface Treatment - Construction of a protective surface layer e.g. by spray application of a bituminous binder, blinded with coated or uncoated aggregate.

Surfacing - Top layer of the pavement. Consists of wearing course, and sometimes a base course or binder course.

Tar Binder - A binder made from processing coal.

Template - A thin board or timber pattern used to check the shape of an excavation.

Traffic Lane - The portion of the carriageway usually defined by road markings for the movement of a single line of vehicles.

Transverse Joint - Joint normal to, or at an angle to, the road centre line.
Traveller - A rod or pole of fixed length (e.g. 1 metre) used for sighting between profile boards for setting out levels and grades.
Turf - A grass turf is formed by excavating an area of live grass and lifting the grass complete with about 5 cms of topsoil and roots still attached.
Turn Out Drain - See Mitre Drain.
Underdrainage (Sub-Soil Drainage) - System of pervious pipes or free draining material, designed to collect and carry water in the ground.
Unpaved Road - For the purpose of this booklet an unpaved road is a road with a soil or gravel surface.
Vented Drift - See Causeway.
Weephole - Opening provided in retaining walls or bridge abutments to permit drainage of water in the filter layer or soil layer behind the structure. They prevent water pressure building up behind the structure.
Windrow - A ridge of material formed by the spillage from the end of the machine blade or continuous heap of material formed by labour.
Wingwall - Retaining wall at a bridge abutment to retain and protect the embankment fill behind the abutment.
2WD - Two Wheel Drive vehicle or equipment.
4WD - Four Wheel Drive vehicle or equipment.