

**FEDERAL DEMOCRATIC REPUBLIC OF**

**ETHIOPIA**

**ETHIOPIAN ROADS AUTHORITY**



**DESIGN MANUAL FOR LOW VOLUME ROADS  
PART E**

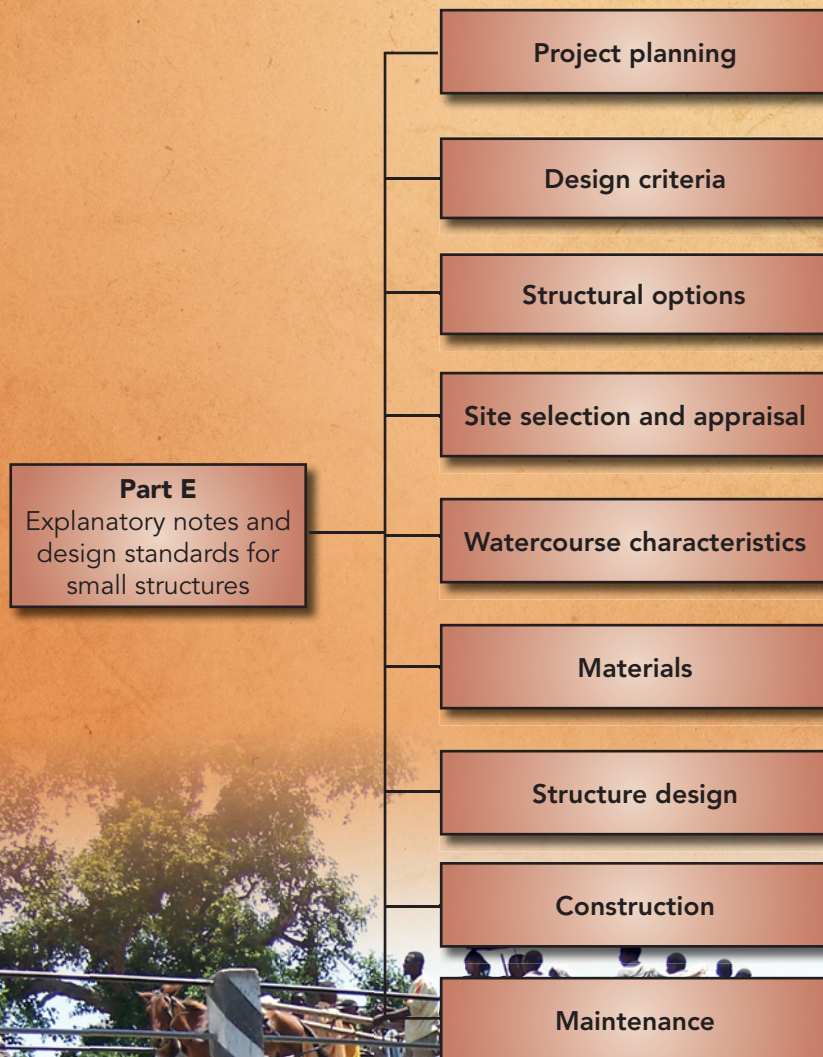
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# Part E

## EXPLANATORY NOTES AND DESIGN STANDARDS FOR SMALL STRUCTURES







## E

## TABLE OF CONTENTS

<b>E.</b>	<b>TABLE OF CONTENTS .....</b>	<b>E.III</b>
<b>E.</b>	<b>LIST OF TABLES .....</b>	<b>E.IX</b>
<b>E.</b>	<b>LIST OF FIGURES .....</b>	<b>E.XI</b>
<b>E.</b>	<b>LIST OF PLATES .....</b>	<b>E.XIV</b>
<b>1.</b>	<b>INTRODUCTION .....</b>	<b>E.1</b>
1.1	Definition of a small road structure .....	E.2
1.2	Scope of the guidance .....	E.2
1.3	Types of structures.....	E.3
1.4	How to use Part E.....	E.5
<b>2.</b>	<b>PROJECT PLANNING .....</b>	<b>E.7</b>
2.1	Setting priorities .....	E.7
2.2	Assessment of the problem or need .....	E.8
2.3	Assessment of potential structures .....	E.8
2.3.1	Desk Study.....	E.9
2.3.2	Field study .....	E.9
2.4	Collection of initial design data.....	E.9
2.5	Field assessment practicalities .....	E.12
<b>3.</b>	<b>DESIGN CRITERIA .....</b>	<b>E.14</b>
3.1	Selecting design parameters.....	E.14
3.2	Design life .....	E.14
3.3	Design flood.....	E.14
3.4	Traffic categories and widths.....	E.15
3.5	Design code .....	E.19
3.6	Serviceability .....	E.19
3.7	Drainage of the structure.....	E.19
3.8	Maintenance capability .....	E.19
3.9	Safety.....	E.19
3.10	Future changes in road use .....	E.20
3.11	Funding .....	E.20
<b>4.</b>	<b>STRUCTURAL OPTIONS .....</b>	<b>E.21</b>
4.1	Drifts.....	E.21
4.1.1	Key features.....	E.22
4.2	Culverts .....	E.23
4.2.1	Key features .....	E.24
4.3	Vented Fords and Causeways .....	E.25
4.3.1	Key features .....	E.26



4.4	Large Bore Arch Culverts .....	E.27
4.4.1	Key features .....	E.28
4.5	Bridges (arch or simply supported deck).....	E.29
4.5.1	Key features .....	E.30
4.6	Structure selection .....	E.31
4.6.1	Costs .....	E.31
4.6.2	Amount of traffic per day / acceptable duration of traffic interruptions .....	E.31
4.6.3	Frequency of flooding .....	E.31
4.6.4	Emergency / principal route .....	E.31
4.6.5	Availability of alternative route .....	E.32
4.6.6	Damage to land or property .....	E.32
4.6.7	Uncertainties in flood prediction .....	E.32
4.6.8	Bank elevation and bed material of the watercourse .....	E.32
4.6.9	Complexity of the structure .....	E.33
<b>5.</b>	<b>SITE SELECTION AND APPRAISAL .....</b>	<b>E.35</b>
5.1	General requirements .....	E.35
5.1.1	Road Alignment .....	E.36
5.1.2	Location .....	E.36
5.1.3	Existing Structure Assessment .....	E.36
5.1.4	Site Investigation .....	E.37
5.1.5	Bearing capacity .....	E.37
5.2	Specific requirements .....	E.40
5.2.1	Drifts .....	E.40
5.2.2	Culverts .....	E.40
5.2.3	Vented fords .....	E.44
5.2.4	Large bore culverts .....	E.45
5.2.5	Bridges .....	E.45
<b>6.</b>	<b>WATERCOURSE CHARACTERISTICS .....</b>	<b>E.47</b>
6.1	Maximum peak flow .....	E.47
6.1.1	Method 1 - Observation .....	E.49
6.1.2	Method 2 - Interviews .....	E.49
6.1.3	Method 3 - Rational Method .....	E.50
6.1.4	Method 4 - Estimation .....	E.50
6.2	Flood return period .....	E.50
6.3	Duration of peak flow .....	E.51
6.4	Flow velocity .....	E.51
6.4.1	Direct observation in flood conditions .....	E.51
6.4.2	Mannings formula .....	E.52
6.4.3	Flat terrain .....	E.52

6.5	Normal flow rate.....	E.53
6.6	Perennial / seasonal flow.....	E.53
6.7	Amount of debris in water.....	E.53
6.8	Type of river (incised or alluvial) .....	E.53
6.8.1	Incised .....	E.53
6.8.2	Alluvial .....	E.53
6.9	Watercourse bank and bed characteristics.....	E.53
6.10	Catchment area and shape .....	E.54
6.11	Cross-sections at crossing point.....	E.54
6.12	Hydraulic gradient upstream and downstream .....	E.55
6.13	Permeability of soil.....	E.55
6.14	Rainfall intensity.....	E.55
<b>7.</b>	<b>MATERIALS.....</b>	<b>E.56</b>
7.1	Stone and stone masonry.....	E.56
7.1.1	Stone sources and extraction .....	E.58
7.1.2	Properties of stone .....	E.60
7.1.3	Field Testing .....	E.61
7.1.4	Mortars .....	E.62
7.1.5	Stone walls.....	E.63
7.1.6	Dry stone walling .....	E.65
7.1.7	Hybrid walls .....	E.66
7.1.8	Masonry culverts.....	E.68
7.1.9	Gabion works.....	E.69
7.2	Brick and block masonry .....	E.71
7.2.1	Properties of bricks and blocks.....	E.73
7.2.2	Field testing.....	E.75
7.2.3	Mortars for brick and block masonry .....	E.76
7.3	Timber and organic materials.....	E.77
7.3.1	Characteristics and utilisation of timber .....	E.79
7.3.2	Properties of timber.....	E.82
7.3.3	Field testing.....	E.84
7.3.4	Uses of timber.....	E.86
7.4	Plain and reinforced concrete.....	E.87
7.4.1	Materials for concrete .....	E.88
7.4.2	Production and placement .....	E.91
7.4.3	Properties of concrete .....	E.94
7.4.4	Field testing.....	E.95
7.4.5	Uses of concrete .....	E.98
<b>8.</b>	<b>STRUCTURE DESIGN.....</b>	<b>E.100</b>



8.1	Scour .....	E.100
8.1.1	Rule 1 - Provide minimum foundation or cut-off wall depths .....	E.102
8.1.2	Rule 2 - Create a minimal constriction to the water flow .....	E.102
8.1.3	Rule 3 - Avoid the use of piers.....	E.105
8.2	Foundations.....	E.106
8.3	Structural Slabs.....	E.107
8.3.1	Drifts .....	E.107
8.3.2	Concrete slab.....	E.109
8.3.3	Cement mortar bonded stone paving .....	E.109
8.3.4	Hand pitched stone .....	E.109
8.3.5	Gabions and gravel .....	E.110
8.3.6	Slab construction (vented fords and large bore culverts) .....	E.111
8.4	Cut-off walls.....	E.111
8.5	Pipes.....	E.112
8.5.1	Vertical positioning of pipes .....	E.112
8.5.2	Pipe sizing.....	E.113
8.5.3	Pipe options.....	E.121
8.5.4	Pipe inlets .....	E.127
8.5.5	Pipe bedding and cover arrangements .....	E.128
8.5.6	Multiple culverts and vented fords .....	E.130
8.6	Headwalls and Wingwalls.....	E.131
8.6.1	Culverts.....	E.131
8.6.2	Wingwalls - Larger structures.....	E.133
8.6.3	Stone, brick and blockwork walls.....	E.134
8.6.4	Gabion baskets.....	E.136
8.6.5	Timber walls.....	E.137
8.7	Aprons.....	E.137
8.7.1	Drift aprons.....	E.137
8.7.2	Culvert aprons .....	E.137
8.7.3	Vented ford aprons.....	E.138
8.8	Approach ramps.....	E.138
8.9	Downstream Protection .....	E.141
8.9.1	Rip-rap .....	E.144
8.9.2	Masonry slabs .....	E.145
8.9.3	Gabions .....	E.145
8.9.4	Vegetation .....	E.147
8.9.5	Steep channels .....	E.148
8.9.6	Drain protection.....	E.149
8.10	Arches.....	E.149

8.10.1	Arch shape .....	E.150
8.10.2	Formwork reuse .....	E.150
8.10.3	Bridge/culvert layout .....	E.150
8.10.4	Construction sequence.....	E.151
8.10.5	Arch materials .....	E.151
8.10.6	Fill options .....	E.152
8.11	Bridge design .....	E.152
8.11.1	Choice of bridge site .....	E.153
8.11.2	Loading.....	E.153
8.11.3	Scour.....	E.154
8.11.4	Drainage .....	E.154
8.11.5	Maintenance .....	E.154
8.11.6	Choice of structure .....	E.155
8.11.7	Choice of materials and form of construction .....	E.155
8.11.8	Foundations.....	E.156
8.11.9	Arch bridges .....	E.156
8.11.10	Deck.....	E.159
8.11.11	Abutments .....	E.163
8.11.12	Piers .....	E.164
8.11.13	Bearings and joints .....	E.165
8.11.14	Parapets.....	E.166
8.12	Other design issues.....	E.167
8.12.1	Debris control .....	E.167
8.12.2	Road signage.....	E.167
8.12.3	Carbon footprint.....	E.167
8.12.4	Climate change.....	E.167
<b>9.</b>	<b>CONSTRUCTION .....</b>	<b>E.168</b>
9.1	Preparatory work .....	E.168
9.1.1	Planning of site works.....	E.169
9.2	Site works .....	E.172
9.2.1	Simple setting out techniques.....	E.173
9.2.2	Setting out culverts and drifts.....	E.173
9.2.3	Setting out bridges and large structures .....	E.179
9.2.4	Excavations .....	E.179
9.2.5	Temporary works.....	E.181
9.2.6	Shuttering/formwork and steel reinforcement for concrete work.....	E.181
9.2.7	Steel reinforcement .....	E.181
9.2.8	Concrete work .....	E.183



9.2.9	Precast concrete .....	E.185
9.2.10	Timber stave culverts (Plate E.9.4).....	E.185
9.2.11	Masonry work .....	E.186
9.2.12	Timber superstructure.....	E.187
9.2.13	Earthworks/Backfilling.....	E.189
9.2.14	Safety measures.....	E.190
9.3	Site administration.....	E.190
<b>10.</b>	<b>MAINTENANCE.....</b>	<b>E.192</b>
10.1	Managing the structure .....	E.192
10.2	Maintaining the structure .....	E.194
10.3	Common maintenance requirements.....	E.195
10.3.1	Drifts .....	E.195
10.3.2	Culverts.....	E.195
10.3.3	Vented drifts and large bore culverts.....	E.196
10.3.4	Bridge Maintenance .....	E.197
<b>11.</b>	<b>REFERENCES.....</b>	<b>E.199</b>

## E

## LIST OF TABLES

Table E.2.1: Data Requirements .....	E.10
Table E.3.1: Design storm return period (years) .....	E.15
Table E.3.2: Typical loaded weights and dimensions of vehicles that may use low volume roads .....	E.16
Table E.3.3: Safe Sight Stopping Distance (single lane) .....	E.20
Table E.4.1: Drifts advantages and disadvantages .....	E.23
Table E.4.2: Culvert advantages and disadvantages .....	E.24
Table E.4.3: Vented fords/causeways advantages and disadvantages .....	E.27
Table E.4.4: Large bore culverts advantages and disadvantages .....	E.29
Table E.4.5: Bridges advantages and disadvantages .....	E.30
Table E.4.6: Example comparison of timber and masonry bridge costs .....	E.31
Table E.4.7: Closure Times .....	E.33
Table E.5.1: Trial Pits: Requirements and Locations .....	E.38
Table E.5.2: Rock bearing capacity .....	E.38
Table E.5.3: Clays and silts bearing capacity .....	E.39
Table E.5.4: Sands and gravels bearing capacity .....	E.39
Table E.5.5: Minimum recommended relief culvert spacing .....	E.41
Table E.6.1: Hydraulic and watercourse data required to undertake design .....	E.48
Table E.6.2: Runoff coefficient: Humid catchment .....	E.50
Table E.6.3: Runoff coefficient: Semi-arid catchment .....	E.50
Table E.6.4: Flood Period Factors .....	E.51
Table E.6.5: Mannings formula .....	E.52
Table E.6.6: Roughness coefficient .....	E.52
Table E.7.1: Classes of rocks used for building .....	E.59
Table E.7.2: Durability Issues .....	E.61
Table E.7.3: Mortar Proportions by Volume .....	E.63
Table E.7.4: Heavy hardwoods .....	E.79
Table E.7.5: Lighter hardwoods .....	E.79
Table E.7.6: Softwoods .....	E.80
Table E.7.7: Design stresses for the three principal timber groups .....	E.83
Table E.7.8: Limits of visible defects for structural timber from tropical hardwoods .....	E.85
Table E.7.9: Concrete Types .....	E.91
Table E.7.10: Concrete grades, strengths and batching strengths .....	E.91
Table E.7.11: Recommendations for good quality concrete .....	E.93
Table E.7.12: Maximum slump values for particular uses .....	E.94
Table E.7.13: Agents of concrete deterioration .....	E.95
Table E.8.1: Guidance on design aspects .....	E.100



Table E.8.2: Foundation depths .....	E.102
Table E.8.3: Opening widths .....	E.102
Table E.8.4: Scour depth adjustment .....	E.105
Table E.8.5: Bearing safety factor .....	E.107
Table E.8.6: Cut-off wall locations .....	E.111
Table E.8.7: Maximum flow rates .....	E.114
Table E.8.8: Simplified Formulae for Calculation of Discharge Capacity .....	E.121
Table E.8.9: Masonry culverts .....	E.123
Table E.8.10: Timber barrel culverts .....	E.123
Table E.8.11: Timber log culverts .....	E.125
Table E.8.12: Cast in-situ concrete culverts .....	E.125
Table E.8.13: Precast unreinforced concrete culverts .....	E.126
Table E.8.14: Steel culverts .....	E.127
Table E.8.15: Pipe spacing and flow reduction factors .....	E.131
Table E.8.16: Wingwalls .....	E.133
Table E.8.17: Height of wingwall without surcharge .....	E.135
Table E.8.18: Height of wingwall with surcharge .....	E.136
Table E.8.19: Height and width of gabion walls .....	E.137
Table E.8.20: Fill material in the approach way .....	E.139
Table E.8.21: Maximum water velocities .....	E.144
Table E.8.22: Stone sizes for rip-rap bed protection .....	E.145
Table E.8.23: Small Versus Large arches? .....	E.150
Table E.8.24: Minimum arch ring thickness .....	E.152
Table E.8.25: Sawn timber girder bridge deck for 6 ton vehicles .....	E.161
Table E.8.26: Nailing requirements .....	E.162
Table E.8.27: Minimum deck clearances .....	E.167
Table E.9.1: Checklist of cost components for detailed costing of a structure .....	E.169
Table E.9.2: Checklist for planning site works .....	E.170
Table E.9.3: Checklist for preparing a construction programme .....	E.170
Table E.9.4: Recommended productivity standards .....	E.171
Table E.9.5: Checklist of handtools and site equipment .....	E.172
Table E.9.6: Supervision check box - Excavation .....	E.181
Table E.9.7: Supervision Check Box - Shuttering/formwork .....	E.182
Table E.9.8: Supervision check box - Reinforcement steel fixing .....	E.183
Table E.9.9: Supervision check box - Concreting .....	E.185
Table E.9.11: Supervision check box - Backfilling .....	E.190
Table E.9.12: Checklist of site administration tasks .....	E.190
Table E.10.1: Structure - Routine .....	E.194
Table E.10.2: Structure - Periodic .....	E.19

## E

## LIST OF FIGURES

Figure E.1.1: Flow diagram of the planning, design and construction process .....	E.6
Figure E.2.1: Example of a Structural Survey Format .....	E.13
Figure E.4.1: Key features of a stream drift .....	E.21
Figure E.4.2: Key features of a relief culvert .....	E.23
Figure E.4.3: A typical vented ford / causeway .....	E.25
Figure E.4.4: Key features of large bore culvert .....	E.27
Figure E.4.5: Key features of a simply supported deck bridge .....	E.29
Figure E.4.6: Large embankments required to prevent road flooding .....	E.32
Figure E.4.7: Complexity and Cost .....	E.33
Figure E.4.8: 'Route Map' for the selection of a suitable structure .....	E.34
Figure E.5.1 Suitable crossing points for larger structures .....	E.35
Figure E.5.2: Right angle crossings reduce the length and cost of structure required. ....	E.36
Figure E.5.3: Road alignment raised over culvert (Schematic) .....	E.42
Figure E.5.4: Culvert drop inlets .....	E.43
Figure E.5.5: Culvert alignment options .....	E.44
Figure E.5.6: Key design criteria for a vented ford .....	E.45
Figure E.6.1: Catchment characteristics .....	E.54
Figure E.6.2: Stream crossing point cross-sections .....	E.55
Figure E.7.1: Hammer test for stone .....	E.62
Figure E.7.2: Rubble masonry wall .....	E.64
Figure E.7.3: Squared masonry walling .....	E.64
Figure E.7.4: Dry stone retaining wall .....	E.65
Figure E.7.5: Hybrid wall .....	E.67
Figure E.7.6: Gabion details .....	E.69
Figure E.7.7: Brick types .....	E.73
Figure E.7.8: Saw cuts .....	E.80
Figure E.7.9: Natural defects in timber .....	E.82
Figure E.7.10: Timber shape criteria .....	E.85
Figure E.7.11: The constituents of concrete .....	E.88
Figure E.7.12: Cement stored in dry conditions .....	E.89
Figure E.7.13: Concrete mixes (guidance) .....	E.92
Figure E.7.14: Field fines test .....	E.95
Figure E.7.15: Slump test mould .....	E.96
Figure E.7.16: Slump test .....	E.97
Figure E.8.1: Scour allowances .....	E.103
Figure E.8.2: Scour – Fine silt .....	E.103



Figure E.8.3: Scour - Fine sand.....	E.104
Figure E.8.4: Scour – Coarse sand.....	E.104
Figure E.8.5: Depth of scour around piers (from TRL ORN9) .....	E.105
Table E.8.5: Bearing safety factor .....	E.107
Figure E.8.6: Construction on sloping bedrock.....	E.107
Figure E.8.7: Cut-off wall .....	E.112
Figure E.8.8: Culvert pipe requirements .....	E.113
Figure E.8.9: Pipe design cases.....	E.114
Figure E.8.10: Friction factor .....	E.116
Figure E.8.11: Flow Rate.....	E.116
Figure E.8.12: Restriction .....	E.117
Figure E.8.13: Headwater depth and capacity for corrugated metal pipe culverts with inlet control. (Adapted from FHWA, 1998).....	E.118
Figure E.8.14: Headwater depth and capacity for concrete pipe culverts with inlet control. (Adapted from FHWA, 1998).....	E.119
Figure E.8.15: Headwater depth and capacity for concrete box culverts with inlet control. (Adapted from FHWA, 1998).....	E.120
Figure E.8.16: Transportation issues.....	E.122
Figure E.8.17: Masonry Culverts.....	E.122
Figure E.8.18: Timber log culvert details.....	E.124
Figure E.8.19: Drop inlet on relief culvert .....	E.127
Figure E.8.20: L-shaped inlet.....	E.128
Figure E.8.21: Pipe granular bedding and cover .....	E.129
Figure E.8.22: Pipe arrangement with minimum cover .....	E.130
Figure E.8.23: Possible culvert headwall positions.....	E.131
Figure E.8.24: Position of culvert headwalls.....	E.132
Figure E.8.25: Headwall and wingwall arrangements .....	E.133
Figure E.8.26: Stone, brick or blockwork wall with and without sloping backfill (surcharge) .....	E.135
Figure E.8.27: Gabion baskets for walls .....	E.136
Figure E.8.28: Culvert apron .....	E.138
Figure E.8.29: Construction of approach ways.....	E.140
Figure E.8.30: Approach way cross section .....	E.140
Figure E.8.31: Energy dissipating apron .....	E.145
Figure E.8.32: Gabion protection on steep banks .....	E.146
Figure E.8.33: Gabion protection on shallow banks.....	E.146
Figure E.8.34: Gabion basket step waterfall .....	E.148
Figure E.8.35: Arch forces .....	E.150
Figure E.8.37: Two course arch.....	E.151
Figure E.8.36: Use of tyre in formwork.....	E.151

Figure E.8.38: Corrugated metal sheet arch .....	E.152
Figure E.8.39: Arch bridge details.....	E.157
Figure E.8.40: Abutment details.....	E.163
Figure E.8.41: Gabion Abutment Log Deck Bridge .....	E.164
Figure E.8.42: Pier shapes (Plan view) .....	E.165
Figure E.9.1: Levelling with a water hose .....	E.173
Figure E.9.2: Setting out a right angle .....	E.173
Figure E.9.3: Use of batter boards .....	E.173
Figure E.9.4: Culvert arrangement A (flat outfall).....	E.174
Figure E.9.5: Culvert arrangement B (intermediate outfall).....	E.174
Figure E.9.6: Culvert arrangement C (steep outfall).....	E.174
Figure E.9.7: Procedure for setting out a culvert .....	E.175
Figure E.9.8 (a) and (b): Setting out culvert profiles.....	E.177
Figure E.9.9: Basic setting out techniques for structures .....	E.179
Figure E.9.10: Safety issues .....	E.180
Figure E.9.11: Pumping arrangements.....	E.180
Figure E.9.12: Formwork detail .....	E.181
Figure E.9.13: Wall Formwork detail .....	E.182
Figure E.9.14: Reinforcement spacers.....	E.183
Figure E.9.15: Batch box .....	E.183
Figure E.9.16: Concrete hand mixing.....	E.184
Figure E.9.17: Masonry Templates .....	E.186
Figure E.9.18: Timber beam launching .....	E.187
Figure E.9.19: Log packing.....	E.187
Figure E.9.20: Fixing deck timbers.....	E.188
Figure E.9.21: Trimming running boards.....	E.188
Figure E.9.22: Kerb timber fixing .....	E.189
Figure E.9.23: Backfilling .....	E.189

## E

## LIST OF PLATES

Plate E.1.1:	Concrete arch bridge with masonry abutments and spandrels.....	E. 1
Plate E.1.2:	Modular steel panel bridge.....	E.4
Plate E.1.3:	Steel cable pedestrian bridge.....	E.4
Plate E.3.1:	Overloading and risk of related structures failure are important considerations for some routes .....	E.16
Plate E.3.2:	Robust width restrictions can be used in some instances to restrict heavy vehicles....	E.17
Plate E.3.3:	Culvert head stone outside main running lanes.....	E.17
Plate E.3.4:	Guide stones narrowing road width .....	E.18
Plate E.3.5:	Pedestrian guard rails (in need of repair) .....	E.20
Plate E.4.1:	A stream drift.....	E.22
Plate E.4.2:	A basic hand packed stone drift .....	E.22
Plate E.4.3:	A three barrel corrugated steel culvert with stepped outfall apron .....	E.25
Plate E.4.4:	A vented ford .....	E.26
Plate E.4.5:	Concrete vented causeway .....	E.26
Plate E.4.6:	Downstream protection to a vented ford.....	E.27
Plate E.4.7:	Large bore arch culverts.....	E.28
Plate E.4.8:	Guide stones on large bore culvert structure.....	E.28
Plate E.5.1:	Collapse due to settlement.....	E.37
Plate E.5.2:	Flat arid area location of the low point .....	E.40
Plate E.5.3:	Ponding at culvert outlet.....	E.41
Plate E.5.4:	Long culvert .....	E.43
Plate E.6.1:	Flood debris caught on vegetation.....	E.49
Plate E.7.1:	Dry jointed, multiple opening, cantilevered laterite stone culvert approximately 1,000 years old and still in service. ....	E.57
Plate E.7.2:	Dry jointed, laterite, stone viaduct, approximately 1,000 years old, still in service on a main road. ....	E.57
Plate E.7.3:	Examples of established Ethiopian techniques of dry stone walling .....	E.58
Plate E.7.4:	Hand dressed stone .....	E.60
Plate E.7.5:	Hand quarrying of stone .....	E.60
Plate E.7.6:	Hand quarried granite stone blocks.....	E.60
Plate E.7.7:	Manual quarry operations can create local employment, however good management is required to ensure a safe working environment.....	E.60
Plate E.7.8:	Rubble stone .....	E.63
Plate E.7.9:	Dry stone wall supporting embankment.....	E.65
Plate E.7.10:	Dressed dry stone wall .....	E.66
Plate E.7.11:	Hybrid retaining wall .....	E.67
Plate E.7.12:	Masonry culvert with steel former to be left insitu after construction.....	E.68



Plates E.7.13-15: Dry stone masonry culvert extension works - Dry stone Conservancy, USA .....	E.68
Plate E.7.16: Gabions supporting a road on a steep slope.....	E.69
Plate E.7.17: Filling gabion baskets .....	E.70
Plate E.7.18: Gabion retaining wall used as river bank protection.....	E.70
Plate E.7.19: Natural fibre matting inserted in gabion protection works to encourage rapid growth of vegetation cover.....	E.70
Plate E.7.20: Steel mesh gabions.....	E.70
Plate E.7.21: Gabion river crossing .....	E.70
Plate E.7.22: Fired clay brick is a very versatile material. This elliptical brick arch bridge over the River Thames at Maidenhead, UK was constructed in 1838 and has two main spans of 38 metres. It is still in use today (designer: Isambard Kingdom Brunel) photograph by Jon Combe.....	E.71
Plate E.7.23: Fired clay brick structures exist in many countries and still provide service for today's traffic after centuries of use .....	E.72
Plate E.7.24: High quality burnt clay bricks produced in small 'beehive' kilns fired by rice husk. Bricks can be fired using coal, wood or agricultural waste products .....	E.72
Plate E.7.25: Simple burnt clay brick clamp .....	E.72
Plate E.7.26: Bricks baked in a kiln.....	E.73
Plate E.7.27: Bricks in a bridge pier .....	E.77
Plate E.7.28: Steel beams being moved into position using labour methods, without the use of cranes; ready for completion with a timber deck.....	E.78
Plate E.7.29: Timber deck on recycled steel beams .....	E.78
Plate E.7.30: Completed timber deck.....	E.78
Plate E.7.31: Timber bridge deck, pier and abutments .....	E.78
Plate E.7.32: Timber poles for piles .....	E.81
Plate E.7.33: Timber poles as deck beams of a twin span bridge.....	E.81
Plate E.7.34: Timber decked bridge .....	E.86
Plate E.7.35: Log abutments & deck.....	E.87
Plate E.7.36: Treated timber culvert.....	E.87
Plate E.7.37: Aggregate crushed and screened by hand .....	E.89
Plate E.7.38: Steel reinforcement cage being assembled.....	E.90
Plate E.7.39: Concrete culvert rings .....	E.98
Plate E.7.40: Concrete drift under construction .....	E.98
Plate E.7.41: Reinforced concrete slab.....	E.99
Plate E.7.42: Flow spreader structure at the outlet of a mitre drain on a steep fragile slope. Bio-engineering planting should be established downhill of such structures.....	E.99
Plate E.7.43: A simple reinforced concrete walled box culvert ready to receive pre-cast top slab units (timber or reinforced concrete) .....	E.99
Plate E.8.1: Bridge damage due to scour of abutment.....	E.101
Plate E.8.2: Failure of structure due to a combination of constriction of the watercourse (structure too small), scour and inadequate protection of abutments. ....	E.106
Plate E.8.3: Guide stones at the edge of a drift.....	E.108

Plate E.8.4:	Concrete slab drift.....	E.109
Plate E.8.5:	Hand pitched stone drift.....	E.110
Plate E.8.6:	Gabion drift.....	E.110
Plate E.8.7:	Natural fibre matting inserted in the top and face of the gabion.....	E.111
Plate E.8.8:	Ponding at culvert outfall.....	E.115
Plate E.8.9:	Ponding in outfall channel.....	E.115
Plate E.8.10:	Timber barrel culvert.....	E.123
Plate E.8.11:	Timber pole culvert during reconstruction.....	E.124
Plate E.8.12:	Reusable steel mould for cast in-situ culvert.....	E.125
Plate E.8.13:	Cast in-situ culvert.....	E.125
Plate E.8.14:	Steel mould.....	E.126
Plate E.8.15:	Precast concrete culvert ring.....	E.126
Plate E.8.16:	Steel culvert.....	E.127
Plate E.8.17:	Drop inlet on stream culvert.....	E.128
Plate E.8.18:	Skew culvert crossing with splay wingwall to prevent water continuing in side drain.....	E.128
Plate E.8.19:	Poor quality jointing and bedding support for pipe culvert.....	E.129
Plate E.8.20:	Wingwall cascade.....	E.134
Plate E.8.21:	Masonry side drains at the edge of an approach way.....	E.141
Plate E.8.22:	Example of damage due to lack of downstream protection.....	E.141
Plate E.8.23:	Minor erosion in watercourse upstream from culvert.....	E.142
Plate E.8.24:	Serious erosion downstream from the same culvert due to concentration of flow and lack of appropriate protection measures.....	E.142
Plate E.8.25:	Severe erosion downstream of a relief culvert due to inadequate protection measures.....	E.143
Plate E.8.26:	Severe erosion downstream of a cross culvert due to inadequate protection measures.....	E.143
Plate E.8.27:	Gabion erosion control structure downstream of a culvert.....	E.147
Plate E.8.28:	Gabion basket step waterfall.....	E.148
Plate E.8.30:	Semi-circular Arch bridge.....	E.149
Plate E.8.29:	Masonry Arch.....	E.149
Plate E.8.31:	Two span concrete deck bridge with masonry pier and abutments.....	E.153
Plate E.8.32:	Reinforced concrete deck on masonry abutments and pier.....	E.155
Plate E.8.33:	Masonry arch under construction with wooden formwork.....	E.158
Plate E.8.34:	Completed masonry arch bridge with splayed wing walls on hard rock foundations.....	E.159
Plate E.8.35:	Timber deck with floor planking and edge beams in need of repair.....	E.161
Plate E.8.36:	Log stringers from underside of bridge deck.....	E.162
Plate E.8.37:	Brick pier.....	E.165
Plate E.8.38:	Raised kerbs on a vented causeway allow water to pass over the structure with minimum disturbance, but provide protection from vehicles driving off the structure.....	E.166
Plate E.8.39:	Timber bridge with handrails.....	E.166

Plate E.8.39:	Road narrows sign .....	E.167
Plate E.9.1:	Construction of culvert inlet apron with guide pegs and strings .....	E.178
Plate E.9.2:	Completed culvert inlet apron .....	E.178
Plate E.9.3:	Hand mixing mortar on a clean surface .....	E.184
Plate E.9.4:	Timber stave culvert .....	E.185
Plate E.9.5:	Example of Masonry works .....	E.186
Plate E.10.1 and Plate E.10.2:	Culvert cleaning tool.....	E.195
Plate E.10.3:	Box culvert partially blocked by vegetation.....	E.196
Plate E.10.4:	Cleaning the drop inlet and barrel of a large bore culvert .....	E.196
Plate E.10.5:	Serious vehicle impact damage to steel panel bridge.....	E.198





## 1.

## INTRODUCTION

Part E of the LVR Design Manual - 2011 deals with small drainage and watercourse crossing structures, typically up to 10 metres span (as shown in Plate E.1.1), and retaining structures. It provides detailed guidance on the processes involved with the planning, design, construction and maintenance of small drainage and other structures for low volume roads.

It is clear that road structures are an important aspect of road design and construction. 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 Ethiopia's main roads<sup>1</sup>. 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 Ethiopia for some time. It is certainly not advisable to blindly apply standards, practices and 'rules of thumb' derived from rich economies for use in Ethiopia 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.



**Plate E.1.1: Concrete arch bridge with masonry abutments and spandrels**



This LVR Design Manual - 2011 Part E on Small Structures aims particularly to satisfy the need 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, construction and maintenance 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. References are provided at the end of Part E for more complex structures or problems, where these issues were considered outside of the scope and objectives of the Manual.

Part E of this Manual has been written as a design guide, to complement existing national design codes and standards from the Ethiopian Roads Authority. It is also intended that this Part of the Manual will assist in the process of establishing more comprehensive and appropriate planning, design, construction 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.

## 1.1 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. In practical terms this manual deals with structures of span up to 10 metres. 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 Part D 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:

### 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.

### 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



Manual will be suitable for paved roads provided that possible increased loadings and higher design standards such as roadway widths are satisfied.

### **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.

### **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. The Manual deals with the construction aspects of structures which are of interest to supervisors and engineers. The construction chapter concentrates on the management and supervision of the construction that must be undertaken by the field officer/engineer overseeing the project.

### **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. The maintainability of structures will also be improved as the skills required will be established during the construction phase within the local community.

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 creation 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; 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:

1. Drifts
2. Simple culverts
3. Vented fords
4. Large bore culverts
5. 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 Bridge Design Manual - 2011.

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 (eg Bailey) as shown in Plate E.1.2. 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.



**Plate E.1.2: Modular steel panel bridge**

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 (Plate E.1.3) for pedestrian, animal and light motor traffic. Design and construction of such bridges are covered in specialist documentation developed for application in Ethiopia. (Ethiopian Suspended Trail Bridge Survey, Design and Construction Manual)



**Plate E.1.3: Steel cable pedestrian bridge**

Chapters E.1 to E.7 cover planning and initial design assessment of structures. Chapters E.8 to E.10 focus on detailed design, construction and maintenance. The separate Volume of LVR Standard Drawings contains some standard designs of appropriate structures in A3 format. It is intended that standardising these designs which have been independently checked technically, 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 ERA Bridge Design Manual - 2011 should be used.

## 1.4

### How to use Part E

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 E.1.1. The two initial tasks which should be carried out are to identify the problem or task (Chapter E.2) and determine the design criteria (Chapter E.3) for the structure. The initial design data may then be collected (Chapter E.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 E.4) is initially undertaken followed by an appraisal of a potential construction site (Chapter E.5). The water flow characteristics of the watercourse (Chapter E.6) should then be considered before a selection of the most appropriate structure is made (Chapter E.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 E.8) which will require further reference to be made to chapters covering site selection and appraisal (Chapter E.5) and watercourse characteristics (Chapter E.6). It will also be necessary to review the options for construction materials (Chapter E.7) that may be available.

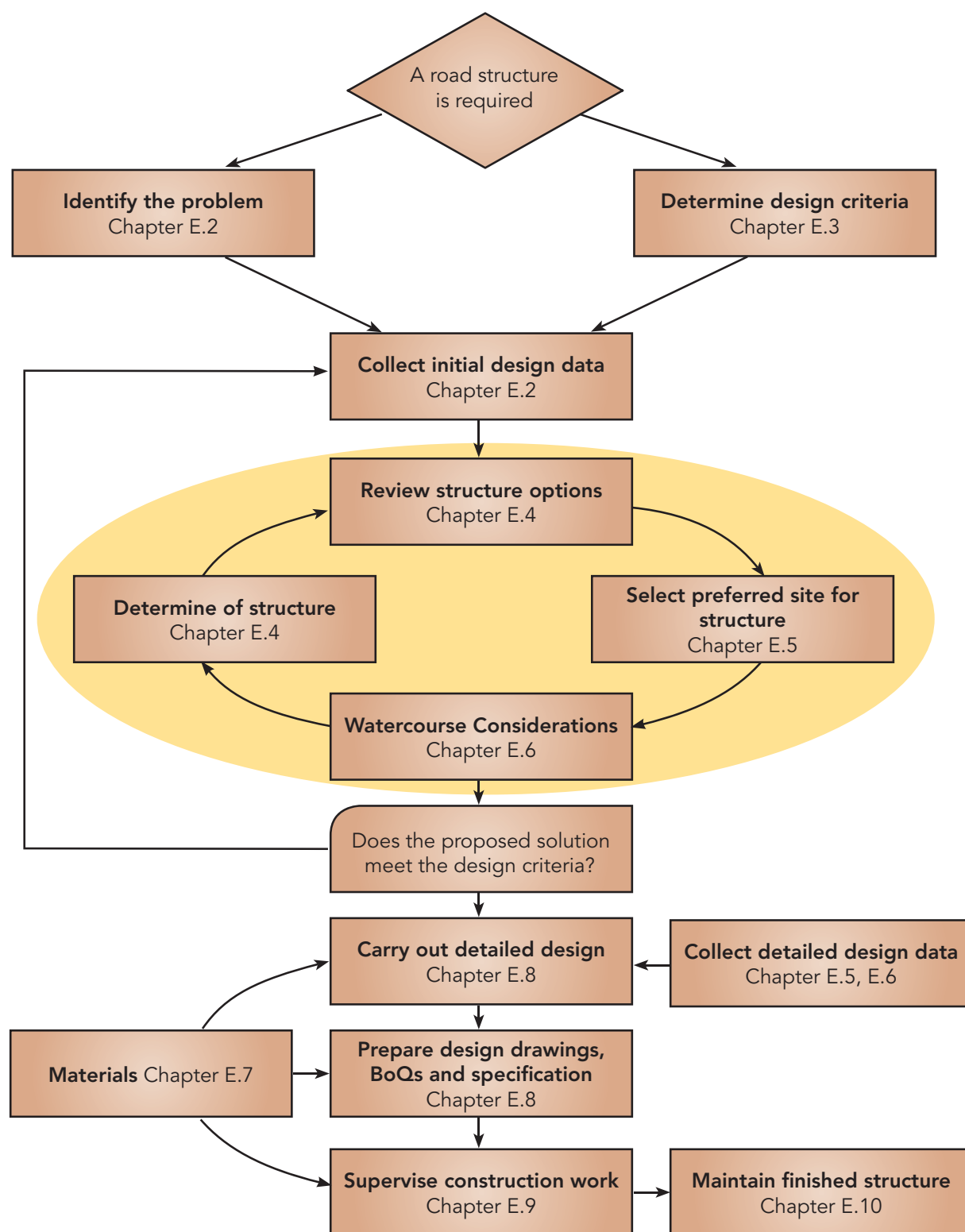
A separate Volume of the LVR Design Manual - 2011 contains standard design drawings that may be useful and contribute to the preparation of design drawings. During supervision of the construction work (Chapter E.9) it will be necessary to ensure materials used in the structure meet and are used according to the specifications. This may require additional reference to the materials chapter and the Specifications. Chapter E.10 covers the maintenance requirements of structures after they have been built and highlights the problems that may be encountered if maintenance is not carried out.

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 ERA Bridge Design Manual - 2011 should be used.

A qualified civil, highway or structural engineer should certify all bridge and completed structures as fit for purpose.





**Figure E.1.1 Flow diagram of the planning, design and construction process**

## 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.

##### 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.

##### Wereda 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.

For example, 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 Birr is available would the best option be to construct one structure which costs 200,000 Birr or provide 5 smaller structures around the road network, which only cost 40,000 Birr 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. 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

In order to set priorities it will be necessary to assess the general condition of the road network, highlighting which roads require improvement and where new or improved structures are required. 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 are 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.

## 2.3

### Assessment of potential structures

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

- Type of structure - Chapter E.4;
- Location of the structure - Chapter E.5;
- Size of structure - Chapter E.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, or **Site Investigation**.

### 2.3.1 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.

### 2.3.2 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 (See Part D, Chapter 5);
- 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 (See Part D, Chapter 6);
- Determine section and gradient near potential sites by surveying the watercourse;
- Determine area of the waterway for normal and flood flows;
- Check local resource availability;
- Cross check information with local community members regarding flood levels, frequency and 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.

## 2.4 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 E.2.1 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 E.2.1: Data Requirements**

Category	Item	Information required
Local Resources	Labour	<ul style="list-style-type: none"> <li>Is there an availability of trade skills in the locality eg carpentry, stone masons?</li> <li>What is the standard of workmanship available?</li> <li>Options of:               <ol style="list-style-type: none"> <li>Specialist skills vs. training local labour</li> <li>Time/cost vs. skills transfer and ongoing maintenance potential</li> </ol> </li> <li>Labour wage rates</li> </ul>
	Materials (Part E.7)	<ul style="list-style-type: none"> <li>What is the availability of local materials (eg masonry stone (rough/dressed), timber, locally manufactured brick and blockwork)?</li> <li>What is the strength, quality, durability and quantity of local materials?</li> <li>Steel: what are the imported and delivery costs to site, delays, welding, bending and fixing skills available?</li> <li>Cement: what are the strengths achievable, delivery/ import delays, types of concrete and experience, quality control and possible testing arrangements?</li> <li>What are the unit costs of materials?</li> </ul>
	Equipment	<ul style="list-style-type: none"> <li>What basic specialist equipment is available / would be required for construction AND maintenance (transport, production, loading unloading, mixing, placing, craneage etc.?)</li> <li>What are the costs of equipment (including transport and servicing costs)?</li> </ul>
Design Criteria (Chapter E.3)	General	<ul style="list-style-type: none"> <li>What is the reliability of the collected data?</li> <li>Is a separate structure needed to allow work to commence further along the road?</li> <li>What will be the cost for construction AND maintenance?</li> <li>Do pedestrians, animals or IMTs frequently travel along the road?</li> </ul>
	Traffic	<ul style="list-style-type: none"> <li>What is the class of road?</li> <li>Are local standards established for structures on this category of road?</li> <li>What is the largest type of vehicle that uses the road?</li> <li>Does vehicle and axle load data exist?</li> <li>If funds are severely constrained, is a one lane, alternate traffic flow option feasible?</li> <li>What is the traffic density, does it vary eg seasonally or on market days in the local wereda or kebele?</li> <li>Review standards used elsewhere &amp; recommend appropriate ones. Will the vehicle size or loading increase if the road or structure is improved (new or re-routed traffic)?</li> <li>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?</li> </ul>

Category	Item	Information required
<b>Type of Structure</b> (Chapter E.4)	New	<ul style="list-style-type: none"> <li>Which types of structure would be acceptable?</li> </ul>
	Existing Structure	<ul style="list-style-type: none"> <li>What is the general condition of the structure?</li> <li>What was the original design life?</li> <li>Do as-built records exist?</li> <li>Are there indications of maximum flood levels on structure?</li> <li>Are there any signs of post construction settlement?</li> <li>What are the main problems with the existing structure?</li> <li>Are there failures in any of the structural elements?</li> <li>What is the current level of scour around structure?</li> <li>Indications of excessive loading or abuse?</li> <li>Dimensions and any possibility of refurbishment or adaptation?</li> </ul>
<b>Site Selection</b> (Chapter E.5)	General	<ul style="list-style-type: none"> <li>Is the depth to firm strata or rock known?</li> <li>What type of material is available to build on for foundations?</li> <li>What is the level of the water table?</li> <li>What is the compressibility or strength of subsoil?</li> <li>What is the best location of trial pits - to provide the most valuable information?</li> <li>Is the water / soil chemistry aggressive to building materials? (specialist advice may be required)</li> </ul>
<b>Water Parameters</b> (Chapter E.6)	Watercourse Details	<ul style="list-style-type: none"> <li>Is the stream perennial or seasonal?</li> <li>What is the type of watercourse? (meandering, straight, bends, presence of weeds)</li> <li>Is the watercourse and bed stable, eg in rock?</li> <li>What is the low water level?</li> <li>What are the minimum or normal flow levels?</li> <li>What are the maximum flood levels (MFL)? (frequency of occurrence and duration)</li> <li>What are the watercourse cross sections at potential site?</li> <li>What is the gradient of watercourse upstream and downstream of the crossing point?</li> <li>Is there evidence of course/bank or level changes, erosion/deposition at the site, upstream or downstream? Consult with old maps and the community</li> <li>Is there sometimes floating debris in the water?</li> <li>What is the water velocity during floods?</li> <li>What is the longitudinal section or profile along the watercourse? Is the watercourse used for private or commercial traffic with headroom requirements?</li> <li>Size and amount of sediment supplied from catchment area.</li> </ul>
	Catchment Details	<ul style="list-style-type: none"> <li>Area of catchment?</li> <li>Are sudden floods encountered?</li> <li>Shape of catchment?</li> <li>Gradient of terrain?</li> <li>Permeability of soil?</li> <li>Vegetation coverage and type?</li> <li>Rainfall intensity?</li> <li>Is the vegetation coverage changing rapidly eg Deforestation?</li> </ul>



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.

## 2.5 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. Information about land use will also need to be collected from the whole catchment area upstream of the potential construction site.

**Always ask the question:  
What is the contribution of the information to the design process?**

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. An example of a Structural Survey form is shown in Table E.2.2. 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 & Reference Points										Preliminary Survey Recommendations			
No.	Chainage	Type	Principal Material	Culvert Length* or bridge width* (m)	Culvert? Bridge span (m)	Diameter/Height		Structural Condition	Remarks	Culvert Length* or bridge width* (m)	Culvert/ Bridge span (m)	Diameter/Height		Proposed solutions	
						Pipe Diam. (mm)	Height (m)					Pipe Diam. (m)	Height (m)		
1	0+260	PC	RC	6.00	0.60	1Ø600	0.60	Good	Sitted					Remove soil and debris. Check + Survey outlet conditions	
2	0+477	PC	RC	6.50	1.00	2Ø1000	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 LHS					Rebuild brick headwall	
6	2+750	Vented Drift	Masonry/ Concrete	6.00	8.50	1Ø600	0.60	Good	Channel erosion RHS downstream. Substantial erosion around structure			2Ø1000?		Prelim assessment indicates enlargement needed	
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	1Ø600	0.60	Fair	Severe 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			1Ø600		Provide new 1Ø600 culvert	
10	4+335	Drift	Masonry	5.50	6.40			Poor	In centre of village with steep eroded approaches	6.5m	~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	LHS Parapet rail damaged					Replace one section of parapet rail	

**Key**

\* Clear width across carriageway between headwalls or kerbs

PC = Pipe Culvert

BC = Box Culvert

AC = Arch Culvert

RC = Reinforced Concrete

RHS = Right hand side in direction of increasing chainage

LHS = Left hand side in direction of increasing chainage

Figure E.2.1: Example of a Structural Survey Format

## 3.

## DESIGN CRITERIA

### 3.1

#### Selecting design parameters

Ethiopia has national standards established for the design of road structures on the primary road network. However, these standards may be inappropriate 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 Ethiopia due to factors of 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? (eg 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 and weredas. 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 (eg 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 (ie 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 E.6 of this 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 E.3.1 therefore shows suggested return periods for design flood flows for different types of structures.

**Table E.3.1: Design storm return period (years)**

Structure type	Geometric design standard <sup>2</sup>			
	DC4	DC3	DC2	DC1
Gutters and inlets <sup>(1)</sup>	2	2	2	1
Side ditches <sup>(1)</sup>	10	5	5	2
Ford <sup>(1)</sup>	10	5	5	2
Drift <sup>(1)</sup>	10	5	5	2
Culvert diameter <2m <sup>(1)</sup>	15	10	10	5
Large culvert diameter 2 - 6m	25	15	10	5
Gabion abutment bridge	25	20	15	-
Short span bridge 6 - 10m	50	25	15	-

**Note**

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 D.5.1 and D.5.2 in Part D.

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, they are often ignored by drivers and operators. 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 E.3.2.

**Table E.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 <sup>(1)</sup>	60 000	18	2.5

**Note:**

- 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 E.3.2.

**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 as illustrated in Plate E.3.1.



**Plate E.3.1: Overloading and risk of related structures failure are important considerations for some routes**

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 E.3.2, it will be necessary to install a robust non-removable barrier each side of the structure to prevent overloaded vehicles crossing (Plate E.3.2).





**Plate E.3.2: Robust width restrictions can be used in some instances to restrict heavy vehicles**

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. 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 narrowings, 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 (Plate E.3.3). These requirements may be relaxed to provide only clear carriageway width in slow speed mountainous alignments.



**Plate E.3.3: Culvert head stone outside main running lanes**



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 (see Plate E.3.4).



**Plate E.3.4: Guide stones narrowing road width**

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 Part B.

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 ERA Bridge Design Manual - 2011 and selected vehicle loading.

### 3.6 Serviceability

**Vehicle Impact:** One of the most common causes of damage to structures is vehicle impact. It is therefore important that reinforcement be 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, according to the Ethiopian standards for the category of road.

**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 (ie 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 when compared to the ride from 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.

### 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.

Guard rails 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 guard rail to prevent pedestrian and child accidents. This guard rail will not normally be required to restrain vehicles from falling off the structure (Plate E.3.4). The provision of guard rails or kerbs to prevent vehicle accidents will depend on the level of vehicle traffic. It is unlikely that vehicle guard rails can be economically justified where the vehicle flows are less than 50 vpd. If vehicle guard rails are not provided it is imperative that clearly marked kerbs or kerb stones 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 the structure. Guard rails should not be used on structures that are designed to be overtopped as they will trap debris.

Sight distances: Drivers should always be able to see the road far enough ahead to be able to stop safely if required (eg when there is an obstruction on the road). It may not be possible to maintain a full sight distance over a cross drainage structure. However, the distances in Table E.3.3 provide a guide to the desirable minimum distance that should be provided.



**Plate E.3.5: Pedestrian guard rails (in need of repair)**

**Table E.3.3: Safe Sight Stopping Distance (single lane)**

Speed km/h	30	40	50	60
Distance m	50	70	100	130

(Source: TRL, 1984 Towards Safer Roads in Developing Countries - A Guide for Planners and Engineers)

### 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.

### 3.11 Funding

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 do 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 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.



## 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, explaining the characteristics of each and highlighting the conditions suitable for their use. The advantages and disadvantages associated with each structure are also discussed.

At the most basic level, a ford can be created in a stable sandy bed of an occasional watercourse by burying stones of 15 - 30 cm size just below the surface and re-covering them with sand. This substantially improves bearing capacity for vehicles. The Chapter deals with improved crossing structures from drifts to small bridges with spans of <10m.

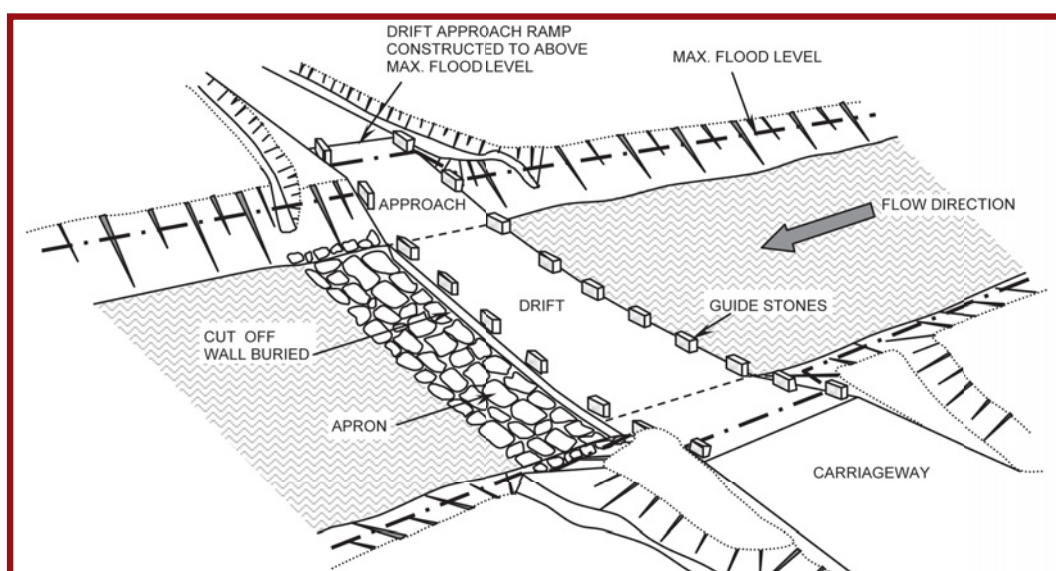
## 4.1

## Drifts

Drifts are the most basic structure and can be the lowest cost form of watercourse crossing construction. 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 (as five years flow  $6\text{m}^3 / \text{sec}$ ) or perennial, drifts may be used to allow the stream to cross the road (see Figure E.4.1 and Plate E.4.1).



**Figure E.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 eg a sandy river bed or level rock. A drift is a ford or splash with an improved running surface constructed from imported (or gathered) materials an example of which is shown in Plate E.4.2. A low water crossing is the collective term used to describe all drifts, fords, splashes and vented fords.



**Plate E.4.1: A stream drift**



**Plate E.4.2: A basic hand packed stone drift**

#### 4.1.1

##### Key features

The key features of drifts are:

- 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.
- Drifts are particularly useful in areas that are normally dry with occasional heavy rain causing short periods of flood water flow.
- 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.
- Alternative solutions may be preferable for small permanent watercourses to prevent vehicles having to drive through the water.
- Drifts are particularly suited to areas where material is difficult to excavate, thus making culverts difficult to construct.
- Drifts are also particularly suited in flat areas where culverts cannot be buried because of lack of gradient.
- The drift approaches must extend above the maximum design flood level flow to prevent erosion of the road material.
- 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.
- Buried cut off walls are required upstream and downstream of the drift to prevent under cutting by water flow or seepage.



- 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% (7% for roads with large numbers of heavy trucks).
- Drifts should not be located near or at a bend in the river.
- 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 E.4.1.

**Table E.4.1: Drifts advantages and disadvantages**

Advantages	Disadvantages
<ul style="list-style-type: none"> <li>■ Low cost: at the most basic level, can be constructed and maintained entirely with local labour and materials</li> <li>■ Ease of maintenance and repair</li> <li>■ Volume of excavated material in most cases is minimal</li> <li>■ Do not block with silt or other debris carried by flood water.</li> <li>■ Can accommodate much larger flows than culverts</li> <li>■ Easier to repair than culverts</li> <li>■ Water flows over a wide area, resulting in less water concentration and erosion downstream than piped culverts</li> </ul>	<ul style="list-style-type: none"> <li>■ Drifts require vehicles to slow down when crossing</li> <li>■ The crossing can be impassable to traffic during flood periods</li> <li>■ Foot passage can be inconvenient or hazardous when water is flowing</li> </ul>

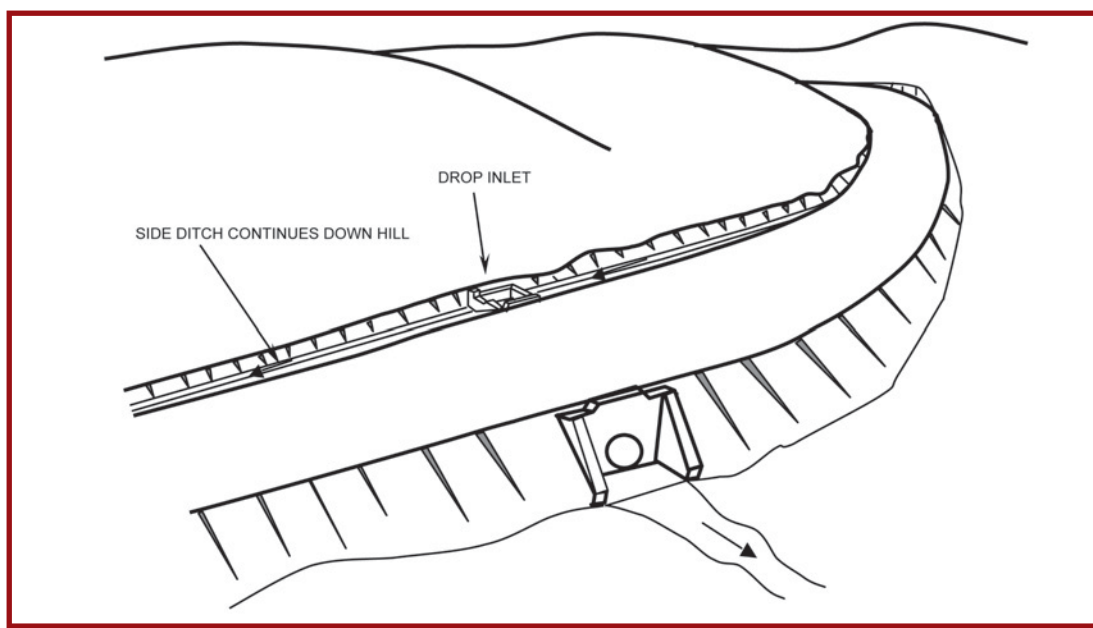
## 4.2

### Culverts

Culverts are the next step upwards from drifts in terms of cost and complexity of structure. There are two types of culvert:

**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 E.4.2).

**Stream culverts:** which allow a watercourse to pass under the roadway.



**Figure E.4.2: Key features of a relief culvert**



4.2.1 Key features

The key features of culverts are:

- 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 high rainfall, flat areas the frequency may also increase to allow water to cross the road alignment in manageable quantities.
- Culverts channel water under the road, avoiding the need for vehicles to drive through the watercourse.
- In addition to well defined water crossing points culverts should normally be located at low points or dips in the road alignment.
- 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.
- Culverts can be pipe, box, slab or arch type.
- 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.
- Aprons with buried cut off walls are also required at the inlet and outlet to prevent water seepage, scouring and undercutting.
- Culvert alignment should follow the watercourse both horizontally and vertically where possible.
- Gradient of the culvert invert should be between 2 and 5%. Shallower gradients could results in silting whereas steeper gradients result in scour.
- Culvert invert levels should be approximately in line with the water flow in the stream bed, otherwise drop inlet and/or long outfall excavations may be required.
- Common culvert diameters are 600mm and 900mm.
- Cross culverts smaller than 600mm in diameter should not be installed as they are very difficult to clean.
- 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.
- It is necessary to protect the watercourse from erosion downstream from the structure.
- 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 is shown in Plate E.4.3.
- When silt supply is high, pipe culverts shall not be used.

The advantages and disadvantages of using culverts are shown in Table E.4.2.

Table E.4.2: Culvert advantages and disadvantages

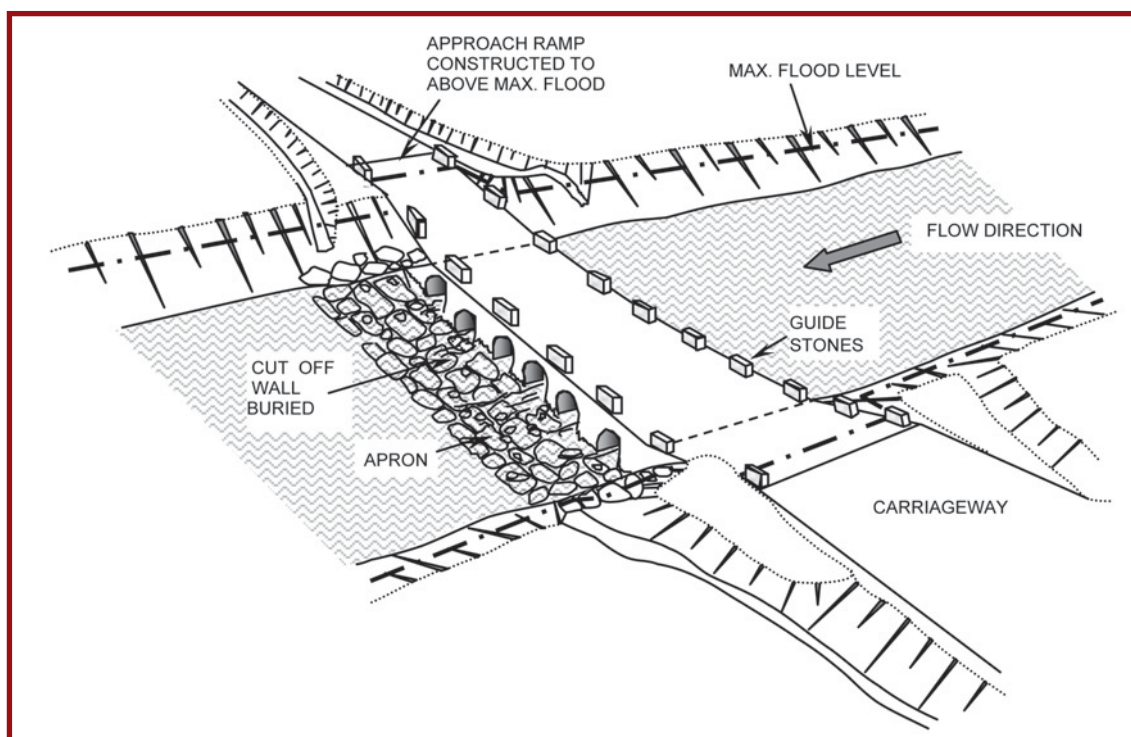
Advantages	Disadvantages
<ul style="list-style-type: none"><li>■ Culverts provide a relatively cheap and efficient way of transferring water across a road</li><li>■ Can be constructed and maintained primarily with local labour and local materials</li><li>■ Culverts allow vehicle and foot passage at all times</li><li>■ Culverts do not require traffic to slow down when they are crossed</li><li>■ Culverts allow water to cross the road at various angles to the road direction for a relatively small increase in costs</li></ul>	<ul style="list-style-type: none"><li>■ Regular maintenance is often required to prevent the culvert silting up, or to remove debris blockage</li><li>■ Culverts act as a channel, forcing water flow to be concentrated, so there is a greater potential for downstream erosion compared with drifts</li><li>■ Culverts are not suited to occasional high volume flows</li></ul>



**Plate E.4.3: A three barrel corrugated steel culvert with stepped outfall apron**

### 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 E.4.3.



**Figure E.4.3: A typical vented ford / causeway**



## 4.3.1

**Key features**

The key features of vented fords and causeways are:

- These structures are designed to pass the normal dry weather flow of the river through pipes below the road (see Plate E.4.4 and E.4.5). Occasional larger floods pass through the pipes and over the road, which may make the road impassable for short periods of time.
- Vented causeways are the same concept as vented drifts but are longer with more pipes, to cross wider watercourse beds.
- The level of the road on the vented drift should be high enough to prevent overtopping except at times of peak flows.
- 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.
- Vented fords should be built across the whole width of the water- course.
- A vented ford requires approach ramps, which must be surfaced with a non erodible material and extend above the maximum flood level.
- Watercourse bank protection will be required to prevent erosion and eventually damaging the entire structure
- The approach ramps should not have a steeper grade than 10% (7% where there is significant heavy vehicle traffic).
- 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.
- 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.
- There is also a requirement to protect the watercourse from erosion downstream from the structure (see Plate E.4.6). There will be considerable turbulence immediately downstream of the structure in flood conditions.
- 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.
- 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.
- Vented fords can also be known as piped drifts



**Plate E.4.4: A vented ford**



**Plate E.4.5: Concrete vented causeway**

The advantages and disadvantages of using vented fords and causeways are shown in Table E.4.3.



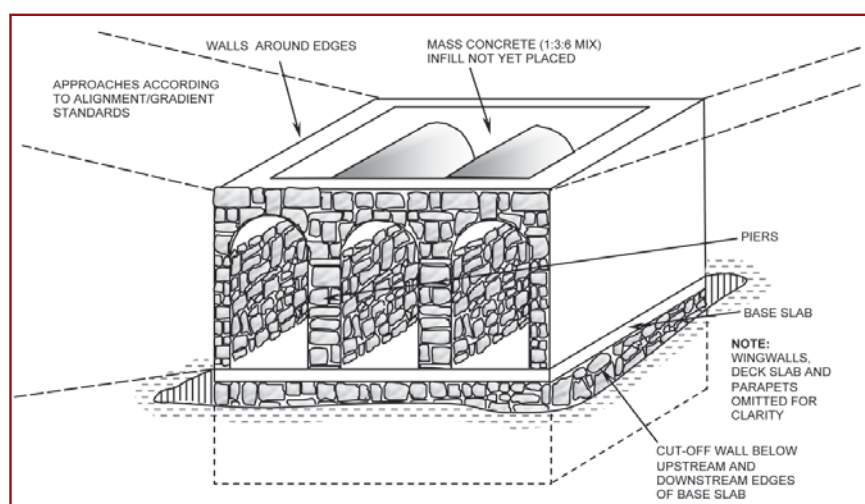
**Table E.4.3: Vented fords/causeways advantages and disadvantages**

Advantages	Disadvantages
<ul style="list-style-type: none"> <li>▪ Vented fords can allow a large amount of water to pass without overtopping</li> <li>▪ They are cheaper to construct and maintain than bridges</li> <li>▪ Construction of vented fords is fairly straightforward compared with bridges</li> <li>▪ Vented fords are well suited to cope with short high volume flows</li> <li>▪ Can be constructed and maintained primarily with local labour and local materials</li> </ul>	<ul style="list-style-type: none"> <li>▪ Vented fords can be closed for short periods during periods of flooding and high flow</li> <li>▪ Floating debris can lodge against the upstream side of the structure and block pipes</li> <li>▪ Foot passage can be inconvenient or hazardous when water is flowing</li> </ul>

**Plate E.4.6: Downstream protection to a vented ford**

## 4.4 Large Bore Arch Culverts

Large bore arch culverts are illustrated in Figure E.4.4 with typical examples shown in Plate E.4.7 and E.4.8.

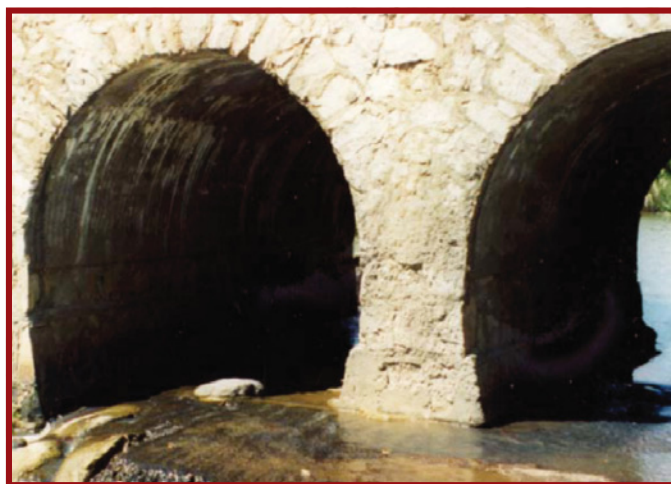
**Figure E.4.4: Key features of large bore culvert**

## 4.4.1

**Key features**

The key features of large bore arch culverts are:

- 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.
- Very large bore arch culverts may also be called arch bridges.
- 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.
- Although these structures are not in generally designed to be overtopped, they can be designed and constructed to cope with an occasional overtopping flood flow.
- The road alignment needs to be a minimum of 2 metres above the bottom of the watercourse.
- Approach embankments are required at each end of the structure.
- 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.
- These structures require large amounts of internal fill material during construction.
- Guide stones or kerbs should be placed at the edge of the carriageway to increase vehicle safety.
- If the crossing is to be used by pedestrians, consideration should be given to installing guard rails and central refuges for long crossings where pedestrians can move off the roadway to allow traffic to pass.
- Water from the road side drains should be carefully channelled into the watercourse away from the structure to prevent erosion of the bank or scour of the culvert structure.



***Plate E.4.7: Large bore arch culverts***



***Plate E.4.8: Guide stones on large bore culvert structure***



The advantages and disadvantages of large bore arch culverts are shown in Table E.4.4.

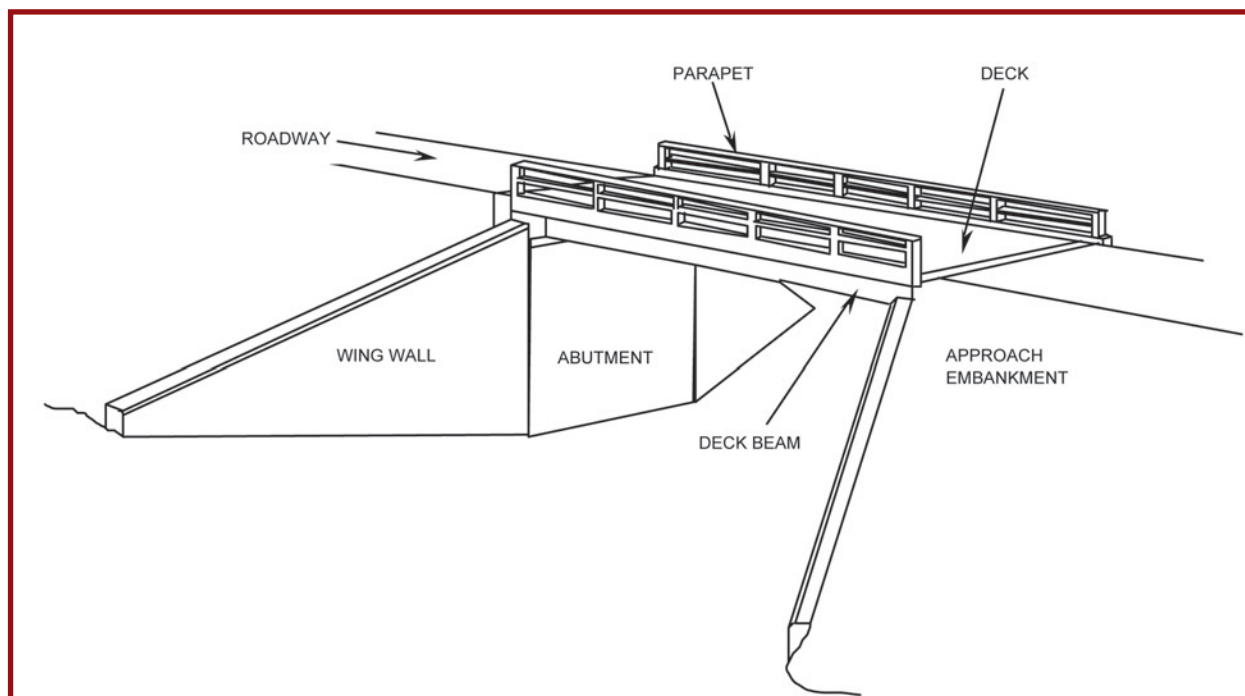
**Table E.4.4: Large bore culverts advantages and disadvantages**

Advantages	Disadvantages
<ul style="list-style-type: none"> <li>Large bore culverts are usually easier and cheaper to construct than bridges</li> <li>They can accommodate flows significantly higher than smaller culverts and vented fords</li> <li>Can be constructed and maintained primarily with local labour and materials, without the need for craneage</li> <li>They may easily be designed and constructed for occasional overtopping</li> <li>Central 'piers' are not so susceptible to damage by scour and erosion when compared with bridge piers</li> <li>They generally require less maintenance than conventional bridges</li> </ul>	<ul style="list-style-type: none"> <li>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</li> <li>Large bore culverts can require a significant amount of internal fill material</li> </ul>

An alternative to a large or multi-bore culvert is a reinforced concrete box culvert. This type of structure is not covered by the Manual. For guidance on such structures refer to the ERA Bridge Design Manual - 2011 and publications such as TRL Overseas Road Note 9.

## 4.5 Bridges (arch or simply supported deck)

These 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 ERA Bridge Design Manual - 2011. Simply supported bridge decks are illustrated in Figure E.4.5.



**Figure E.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:

- The arch is the simplest form of bridge.
- There are a number of different elements to a simply supported deck bridge, which will comprise of a superstructure (deck, parapets, guide stones and other road furniture) and substructure (abutments, wingwalls, foundations, piers and cut off walls).
- Bridges are generally the most expensive type of road structure, requiring specialist engineering advice and technically approved designs.
- Bridges can be single span or multi span, with a number of openings for water flow and intermediate piers to support the superstructure.
- The main structure is always above flood level, so the road will always be passable.
- Abutments support the superstructure and retain the soil of the approach embankments.
- Wingwalls are needed to provide support and protect the road embankment from erosion.
- 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.
- 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.
- Bridges should not significantly affect the flow of water (ie the openings must be large enough to prevent water backing up and flooding or over topping the bridge).
- The shape of the abutments and piers will affect the volume of flow through the structure and also the amount of scouring.
- 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.
- Water from the road side drains should be channelled into the watercourse to prevent erosion of the bank or scour of the abutment structure.
- Guide stones or kerbs should be placed at the edge of the carriageway to increase vehicle safety.
- If the crossing is to be used by pedestrians, consideration should be given to installing guard rails 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 E.4.5.

**Table E.4.5: Bridges advantages and disadvantages**

Advantages	Disadvantages
<ul style="list-style-type: none"> <li>■ The road is always passable as the structure should not be overtopped</li> <li>■ 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)</li> </ul>	<ul style="list-style-type: none"> <li>■ Bridges are normally significantly more expensive than other road structures</li> <li>■ They are more complex than other structures and will require specialist engineering support for design and construction</li> <li>■ Additional height of and earthworks in approach embankments</li> <li>■ Bridges may require heavy duty lifting cranes for the deck components</li> <li>■ Although all structures should be inspected for defects, bridges require regular detailed checks</li> <li>■ Bridges are likely to fail if flood flow predictions are incorrect and they are over topped</li> <li>■ A small amount of scour and erosion can often result in major damage to the structure</li> </ul>

## 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 which 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 E.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.

**Table E.4.6: Example comparison of timber and masonry bridge costs**

Year	Timber Bridge		Masonry vented ford	
	Work Undertaken	Cost	Work undertaken	Cost
1	Construction	10000	Construction	15000
4	Inspection and replacement of running boards	1000	Repair of downstream protection	300
8	Inspection, replacement of running boards and 2 deck members	2000	Replacement of downstream protection	700
12	Inspection and replacement of decayed structural members	4000	Repair of downstream protection	300
15	Inspection replacement of running boards	1000	Replacement of downstream protection	700
	Total Cost	18 000		17 000

### 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 length of time that the road could be closed due to overtopping during periods of peak flood. 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, as 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.

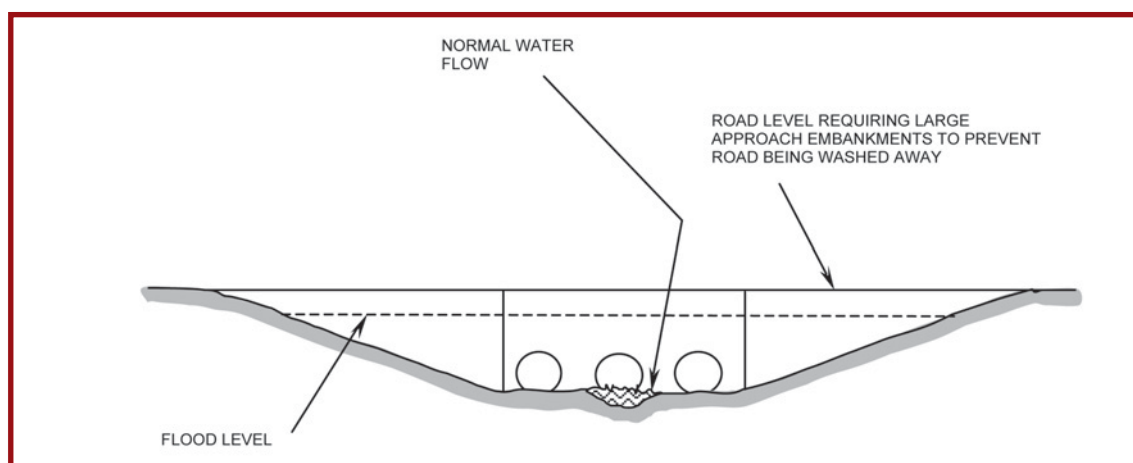
#### 4.6.7 Uncertainties in flood prediction

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 river bed it may be difficult to construct a structure that will not be overtopped without large approach ramps/embankments as illustrated in Figure E.4.6.



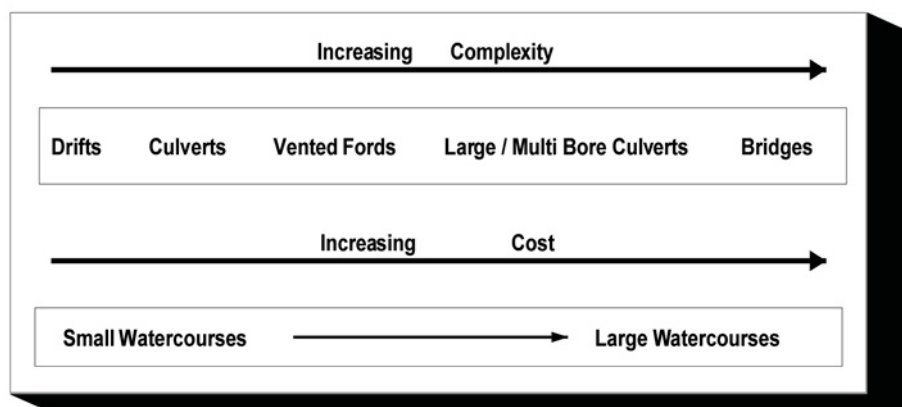
**Figure E.4.6: Large embankments required to prevent road flooding**



## 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 a bridge (see Figure E.4.7).



**Figure E.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 E.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 E.4.8 only highlights the key issues and it should only be used as a guide when determining the most appropriate structure.

Figure E.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 its particular circumstances. In the absence of any local guidelines Table E.4.7, gives suggested upper and lower bounds for closure times.

**Table E.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

When the problem is ‘beyond the scope of this Manual’, specialist bridge engineering skills should be mobilised.

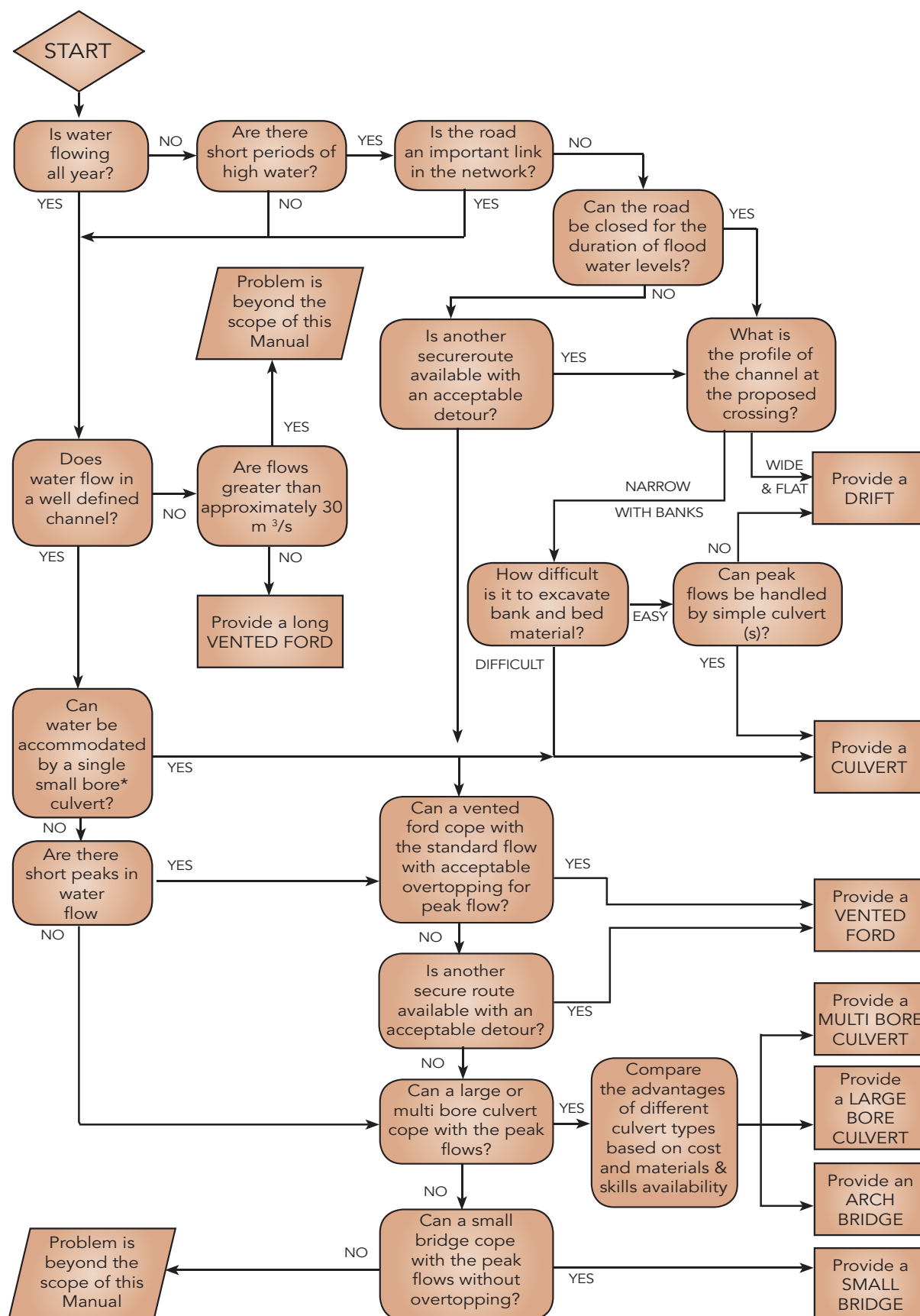


Figure E.4.8: 'Route Map' for the selection of a suitable structure

## 5.

## SITE SELECTION AND APPRAISAL

## 5.1

## General requirements

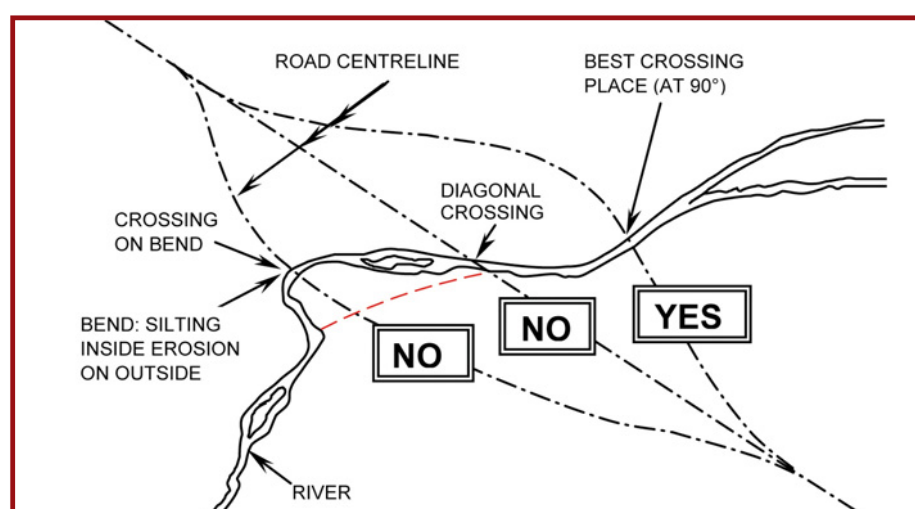
For minor structures such as drifts or culverts on existing routes there may be little choice available in site selection. Changing the existing road alignment could incur substantial additional road works costs.

For relief drifts or culverts that are necessary to allow the build up 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 minimize the risk of damage or erosion downstream. If not, provide some mitigation works (eg drop structures or gabions)

For larger structures and watercourses the selection of site location requires more attention (See Figure E.5.1). Adjustment of the road alignment is often justifiable to minimize the cost of structures and risk of damage or erosion.

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 to be constructed 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):

- The crossing should be located away from horizontal curves in the watercourse, as 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 E.5.1)
- 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 reducing there is the potential for silt and other debris to be deposited near or inside the structure;
- The crossing should ideally be at an area of the channel with a non-erodible bed. These areas have a reduced scour potential, reducing the amount of watercourse protection required;
- The road should cross the watercourse at a point with well defined banks, where the stream will generally be narrower;
- The watercourse should not be prone to flooding at the crossing point;
- The skew angle shall be  $<15^\circ$ .



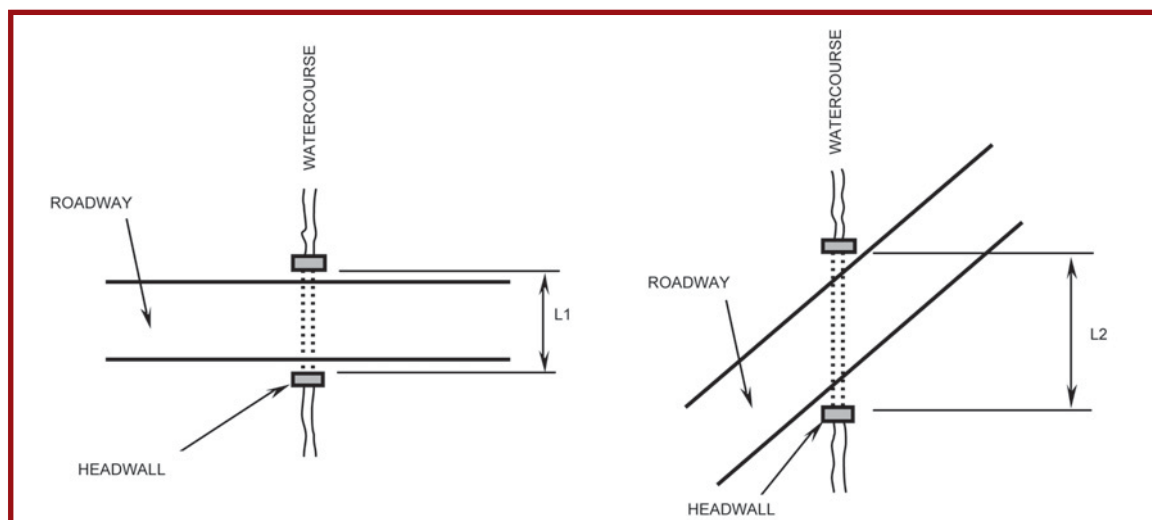
**Figure E.5.1 Suitable crossing points for larger structures**



### 5.1.1 Road Alignment

In addition to the watercourse requirements noted in Section E.5.1, the road should:

- Cross the watercourse at 90 degrees as 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 E.5.2.



**Figure E.5.2: Right angle crossings reduce the length and cost of structure required.**

- 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 will be 6m.
- 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.
- Be centred above the centre line of the substructure.

### 5.1.2 Location

In locating a structure, the following criteria should be considered:

- A site with a natural narrow channel width rather than a wide one should be used.
- The crossing should be constructed at a straight stretch of river or watercourse, rather than a curved one where the stream is likely to cause erosion of the bank on the outside of the curve.
- Alignment should be at right angles to the water flow to avoid additional scouring. A skew crossing may channel the water towards one of the river banks. This channelling may erode the approach way and/or the bank eventually resulting in the river flowing around the bridge rather than under it.
- The approach roads should preferably be straight on each side to ensure sufficient sight distances and prevent traffic hazards;
- The site of the river crossing should be away from waterfalls and confluence zones.

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 an inadequate structure has been provided 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; and 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:

- Small gullies exist on the road due to water flowing across the running surface;
- Existing culverts are damaged due to:
  - standing water softening the soil around the culvert;
  - insufficient capacity.
- Sand and silt has been deposited on the road in patches due to standing water;
- Culverts, inlets or outlets are silted due to incorrect design or installation;
- Evidence of erosion around the structure or culvert;
- Debris trapped at inlet due to incorrect type, sizing or lack of protection.

#### 5.1.4 Site Investigation

The objective of 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, it is advisable to refer to the Site Investigation Manual (2011) for foundations investigations. A site investigation will involve taking samples of the ground material to determine its bearing capacity. These samples can either be obtained through digging trial pits or by using a hand auger.

#### 5.1.5 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 (see Plate E.5.1).

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, (eg bridge abutments and piers) as the soil must have a high bearing capacity to support these loads.



**Plate E.5.1: Collapse due to settlement**

The number of trial pits that should be dug will depend on the complexity of the structure and the uniformity of the soil. Table E.5.1 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 E.5.1: 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)

The only accurate method for determining the bearing capacity of any soil is through detailed field and laboratory investigations. If soils testing facilities are not available, Tables E.5.2, E.5.3 and E.5.4 may be used for determining an approximate bearing capacity of the in situ rock and soil material. A Dynamic Cone Penetrometer (DCP) is a low cost, portable device that can also provide an approximation for in situ soil strength for some materials. However, care must be taken in interpreting results, particularly with regard to possible variations of in-service moisture conditions.

The engineer should take samples of the soil from the trial pits and compare its properties with the descriptions in the tables. As different materials have different strength criteria, the three tables are applicable to rocks, clays and silts, and sands and gravels. The soils used for bearing capacity estimation should be in the same condition and state as they would be found at the proposed site. As a general guideline, the more complex and expensive the structure, the more extensive the soil and foundation investigation should be to minimise initial and whole life costs and the risk of later damage or failure of the structure.

**Table E.5.2: Rock bearing capacity**

Soil description	Rock strength	Allowable bearing capacity (kN/m <sup>2</sup> )	Uniaxial compressive strength (mN/m <sup>2</sup> )
A hammer blow required to break specimen, can be scratched with firm pressure from knife	Strong	10 000	50 - 100+
Easily broken with hammer, can be easily scratched with knife and pick end indents approx. 5mm	Moderately strong	2000	12.5 - 50
Broken in hand by hitting with hammer, can be grooved 2mm deep with a knife	Moderately weak	1000	5.0 - 12.5
Broken by leaning on sample with a hammer, can be grooved or gouged easily with a knife	Weak	750	1.25 - 5.0
Can be broken by hand and knife will penetrate approx. 5mm	Very weak	250	0.6 - 1.25

**Note:**

1. The uniaxial compressive strength will normally be determined from laboratory tests. It has been included in this Table for comparison against laboratory soil data where available.



**Table E.5.3: Clays and silts bearing capacity**

Soil description	Strength	Allowable bearing capacity (kN/m <sup>2</sup> )	Undrained shear strength
A thumb nail will not indent the soil	Hard	600	300+
Indented by a thumb nail, penetrated about 15mm with a knife	Very stiff	300	150 - 300
Indented by a thumb with effort, cannot be moulded by fingers	Stiff	150	75 - 150
Penetrated by thumb with pressure, moulded with strong finger pressure	Firm	75	40 - 75
Easily penetrated by thumb, moulded by light finger pressure	Soft	25 (should not be used as a foundation soil)	20 - 40
Extrudes between fingers when squeezed in hand	Very soft	0	< 20

**Note:**

1. The undrained shear strength will normally be determined from laboratory tests. It has been included in this Table for comparison against laboratory soil data where available. It is important to appreciate that clay soils in particular vary enormously in strength with moisture content. Dry weather visual assessment is certainly no indication of likely wet season performance.

Soft or very soft clay/silt soils at the level of proposed foundations will indicate the likely requirement for special arrangements such as piling. This would require specialist expertise and designs for such conditions are beyond the scope of this Manual.

**Table E.5.4: Sands and gravels bearing capacity**

Soil sample description	Strength	Allowable bearing capacity (kN/ m <sup>2</sup> )	Standard penetration test N-Value
High resistance to repeated blows with a pick	Very dense	500	>50
Requires pick for excavation, a 50mm diameter peg is hard to drive in	Dense	300	30 - 50
Considerable resistance to penetration by sharp end of pick	Medium dense	100	10 - 30
Can be excavated by spade, a 50mm peg is easily driven, can be crushed between fingers	Loose	50	5 - 10
Crumbles very easily when scraped with a pick	Very loose	Negligible	<5

**Note:**

1. The standard penetration test N-value will normally be determined from in situ tests. It has been included in this Table for comparison against laboratory soil data where available.

## 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:

- Avoid areas with steep banks (greater than 1.5m) as these require a large amount of excavation to achieve acceptable approach gradients, and can cause erosion/siltation problems at the banks.
- The level of the drift should be as close as possible to the existing river bed level. This is most important as it will affect the amount of water turbulence and erosion that may occur around the drift.
- The normal depth of water should be a maximum of 150mm and the maximum 5 years flow should be 6m<sup>3</sup>/second on the drift to allow traffic to pass.
- 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.
- In flat arid areas the exact location of the low point in the alignment or occasional watercourse may not be possible to determine without a detailed level survey (Plate E.5.2).



**Plate E.5.2: Flat arid area location of the low point**

### 5.2.2 Culverts

Culverts (or drifts) are usually required at every low point in the road alignment when run-off should be cross-drained or when it is not possible to be drained forward, backward or with turn of, in addition to actual water crossing points. Exceptions to this are for an alignment along a hill or mountain ridge and where drifts or other structures are more suitable for a particular location. The culverts also allow water from the side drains to cross the road. In areas of sloping ground with little vegetation water will tend to run down the surface of a hill side and collect in the side drains. In these areas further culverts may be required to transfer this water across the road. On long continuous gradients without turnout possibilities it may also be necessary to provide additional intermediate culverts to transfer water across the road to avoid large quantities of water building up and causing erosion to the drain, road or land downhill of the road. In such circumstances, these 'relief' culverts will normally be expected to be required at intervals of no more than about 400m.

It is impossible to define the number of culverts required per km as this will vary according to the topography, catchment and weather characteristics and must be determined by an investigation of the proposed route. However, as a guide there will typically be 1-3 culverts per km in arid flat or undulating land and up to 6 culverts per km in more severe terrain, high rainfall areas.

In hilly areas on long steep gradients relief culverts will be required at regular intervals to transfer water from the uphill side drain to the downhill side of the road to prevent erosion from a large build up of water in the side drain. Table E.5.5 suggests intervals between relief culverts on long grades. 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: E.5.5: Minimum recommended relief culvert spacing**

Road gradient (%)	Culvert intervals (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. The next concern will be the level at which the culvert should be installed. On rural roads there is often insufficient attention paid to the alignment and forces related to the water flow, even when this is infrequent. This often causes problems for the performance and maintenance of the culvert (see Plate E.5.3).



**Plate E.5.3: Ponding at culvert outlet**

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 water course but should never be less than 1% to prevent siltation.

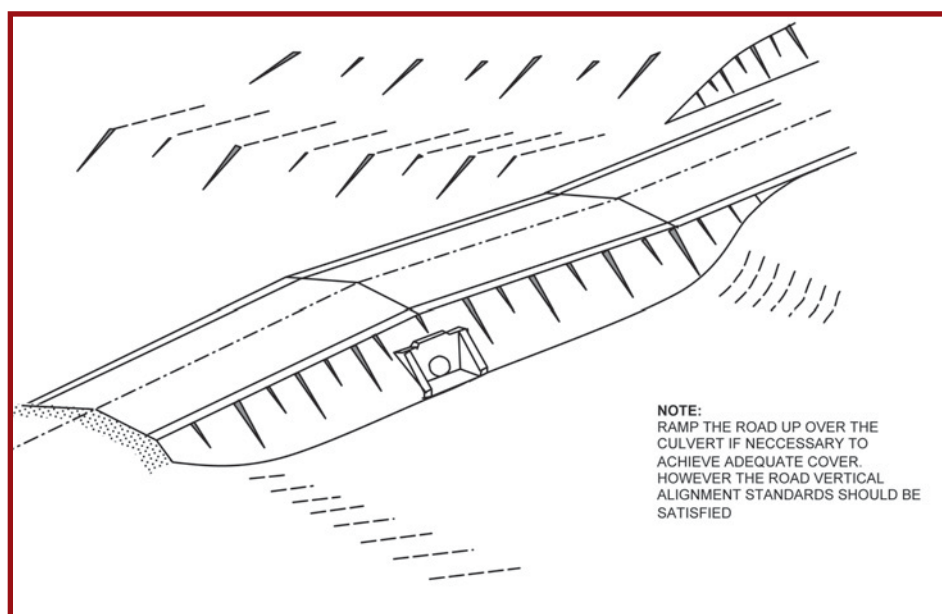
For relief cross culverts, where sediment loads are low to moderate, the combination of a nominally 1m deep catch-pit inlet, a moderately sloping culvert long-section, and sufficient energy dissipation and



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:

- In flat ground, the invert of the culvert outfall should be determined by the level of the surrounding ground. Box culverts and arch culverts are preferable in these circumstances as 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 (Plate E.5.3) 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 stream line 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.
- Where the road is on ground sloping across the alignment, a frequently observed mistake is to leave the road vertical alignment unchanged and 'bury' the culvert so that the outlet discharges in a long trench with a flat grade. 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 E.5.3). Long culvert (Plate E.5.4) outfall ditches should be avoided and their grade should not be less than 2% under normal conditions.

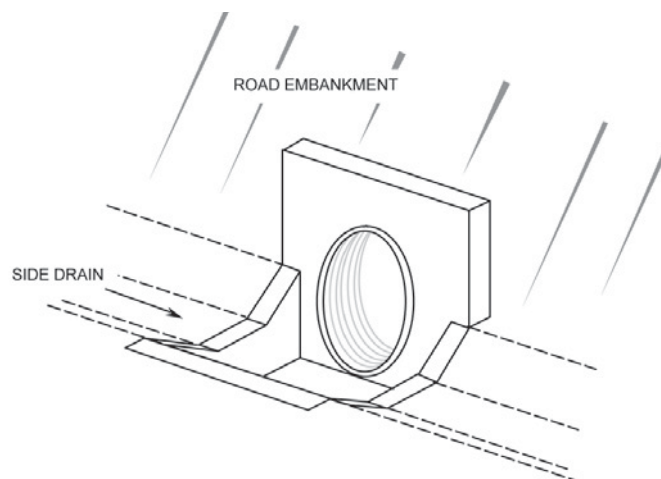


**Figure E.5.3: Road alignment raised over culvert (Schematic)**



**Plate E.5.4: Long culvert**

- 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 (See Plate E.5.5 and Figure E.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.



**Plate E.5.5 and Figure E.5.4: Culvert drop inlets**

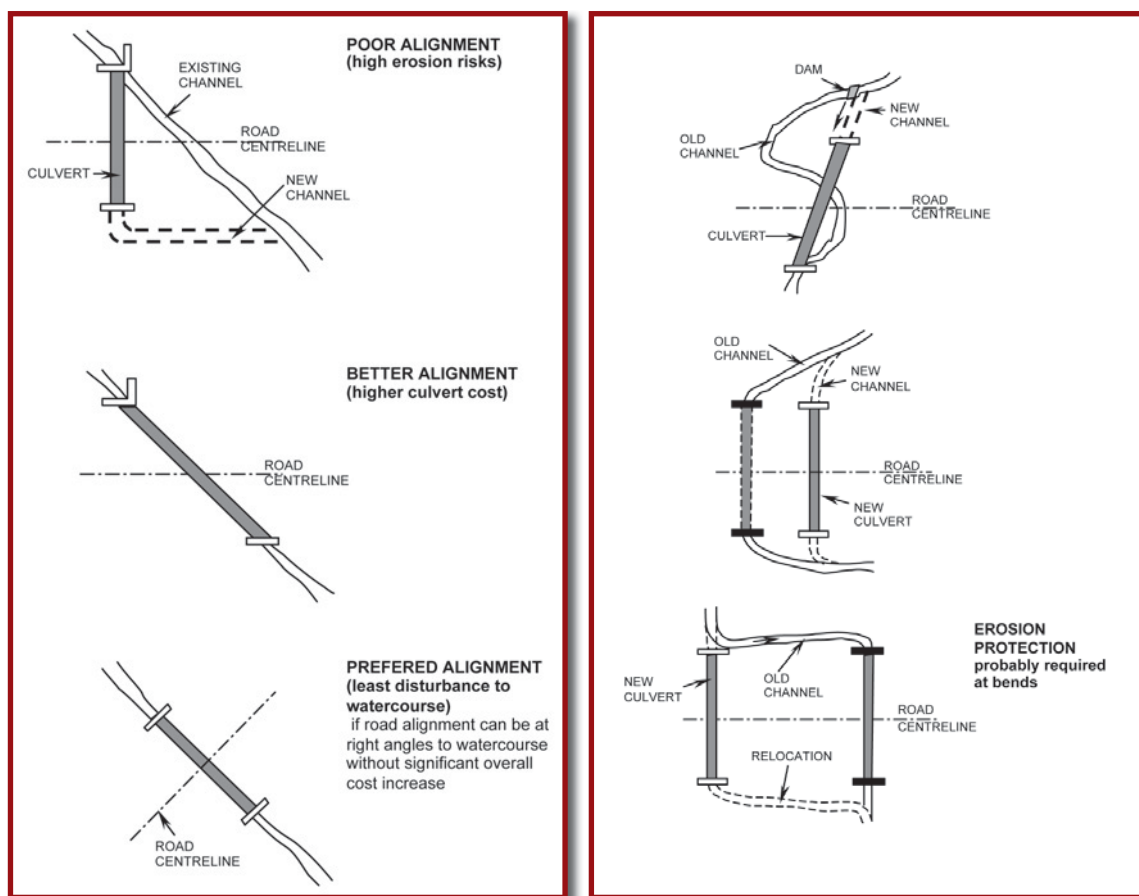
In all situations the road alignment standards and structure protection cover requirements should be complied with. Erosion, silting potential and maintenance implications should be seriously considered in all cases. Further guidance on culvert setting out is provided in Chapter E.9.

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 E.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 E.8.



**Figure E.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 E.5.6).

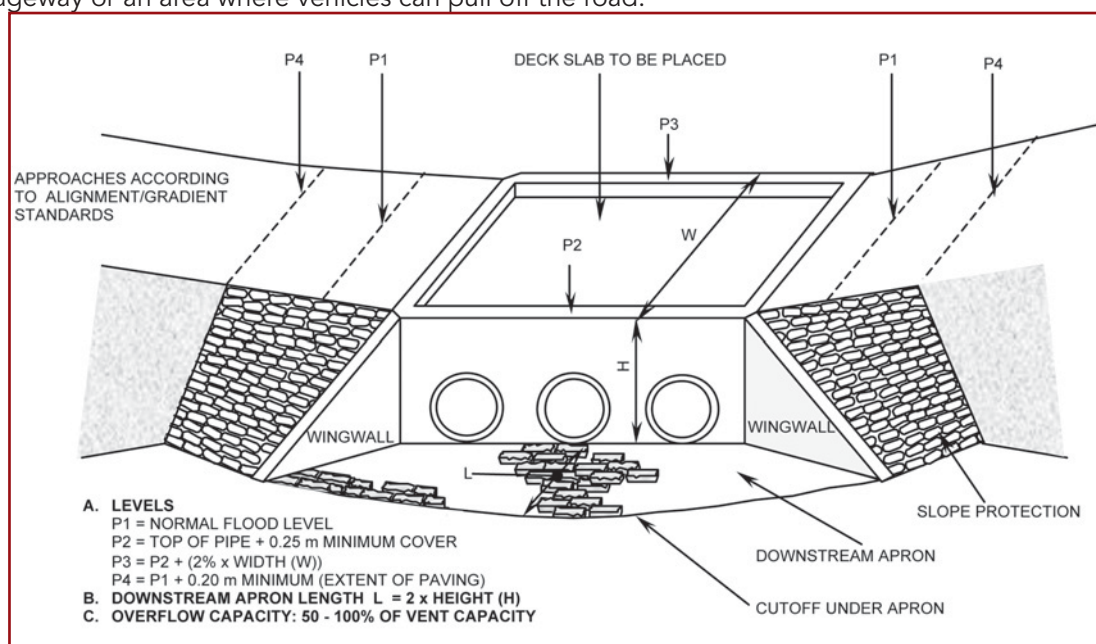
A vented ford provides a constriction to the water flow, due to the solid fill between the pipes. The proposed location should allow sufficient pipes to be constructed to prevent normal flows overtopping the structure. In areas where the flow level regularly varies, it is desirable that there are sufficient 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 enough 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 E.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 metres below the proposed road level, to allow sufficient cover over the culvert barrel. Proposed sites for these culverts should have watercourse banks higher than two metres to prevent the need for long approach embankments which increase the cost of the structure.

If the crossing site will require 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 the 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 ERA Bridge Design Manual - 2011 or publications such as 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 (ie 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.

## WATERCOURSE CHARACTERISTICS

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 metres 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
  - Annual and seasonal variations
  - Extent and duration of the rainfall
  - Intensity and distribution
- Geological features
  - Type and permeability of the soil
  - Natural water storage characteristics of the catchment area
  - Size of the catchment
  - Intense rainfall only occurs over a small area at any point in time so runoff is not proportional to size of catchment
  - Fan shaped catchment will give higher peak flows as runoff will generally arrive at the confluence of all streams at the same time. Long and thin catchment areas have the discharge spread over a longer period and have relatively smaller peak flows for a similar area.
- 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 E.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.

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.

## 6.1

**Maximum peak flow**

The maximum peak flow is the most important information to be collected as it is used to determine the size of the chosen structure. 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 to be constructed.



**Table: E.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 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 area & 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 down-stream	50m above & 25m below crossing 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	_____	_____

## 6.1.1

**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 (Plate E.6.1).

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 have been removed by natural weathering. This method will therefore give an indication of a recent high flood level but will not be guaranteed to be the highest expected flood level. The information gathered by observation may be supplemented by interviews with local residents.



**Plate E.6.1: Flood debris caught on vegetation**

## 6.1.2

**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, as these occurrences tend to intimately affect their activities. If this method is adopted a number of people should be questioned as 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 flood water. 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 cross check between the data obtained for each method.

The interviews shall also acquire changes to the upstream line such as diversion, overtopping, floods from adjacent streams, land use change and irrigation projects.

### 6.1.3 Method 3 - Rational Method

This method is accurate for smaller catchments up to 10 km<sup>2</sup>. The rational method may be used for larger catchments but the results obtained will tend to be larger than the actual floods encountered.

$q = 0.278 \ c \ i \ A$	where			
	q	=	flood flow in m <sup>3</sup> /s	
	c	=	runoff coefficient (Table E.6.2 or E.6.3)	
	i	=	rainfall in mm/hr (rainfall intensity)	
	A	=	drainage area contributing to runoff in km <sup>2</sup>	

**Table: E.6.2: Runoff coefficient: Humid catchment**

Average Ground Slope	Soil Permeability			
	very low (rock & hard clay)	low (clay loam)	medium (sandy loam)	high (sand & gravel)
Flat 0 - 1 %	0.55	0.40	0.20	0.05
Gentle 1 - 4 %	0.75	0.55	0.35	0.20
Rolling 4 - 10 %	0.85	0.65	0.45	0.30
Steep > 10 %	0.95	0.75	0.55	0.40

**Table: E.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 & gravel)
Flat 0 - 1 %	0.75	0.40	0.05	0.05
Gentle 1 - 4 %	0.85	0.55	0.20	0.05
Rolling 4 - 10 %	0.95	0.70	0.30	0.05
Steep > 10 %	1.00	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.

### 6.1.4 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 this data may not exist or be incomplete. For catchments up to 15km<sup>2</sup> an approximate maximum flood flow can be calculated by assuming a discharge of 1 - 2 m<sup>3</sup>/s per 25 hectares of catchment area.

## 6.2 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 E.6.4 provides factors to adjust the size of a given storm period to another period based on a 12.5 year flood.

**Table E.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 E.6.4, the 5 year flood factor is 0.5. Therefore rainfall intensity =  $35 \times 0.5 = 18$  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<sup>3</sup>/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 =  $12 \times 0.9 / 1.5 = 7$  m<sup>3</sup>/s.

## 6.3

### 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 this 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 this data is 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<sup>2</sup> the designer can assume that the duration of peak flow will last no longer than twice the length of rainfall periods.

## 6.4

### Flow velocity

The velocity of the water flow during peak floods is important to determine as 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.

### 6.4.1

#### 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 get 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.

### 6.4.2 Mannings formula

Table E.6.5 shows Mannings formula for calculating flow velocity.

**Table E.6.5: Mannings formula**

$V = \frac{1}{n} R^{\frac{2}{3}} S^{\frac{1}{2}}$ <p> V = velocity in m/s  R = hydraulic depth (the area for the stream flow divided by the wetted perimeter)  S = hydraulic gradient ( the slope of the river bed over a reasonable distance either side of the crossing point)  n = roughness coefficient (see Table E.6.6) </p>	<p>WATER COURSE CROSS SECTION</p> <p>A = WATER AREA</p> <p>P = PERIMETER OF WATERCOURSE = CROSS SECTIONAL LENGTH OF BANKS AND BED</p> <p><math>R = \frac{A}{P}</math> = HYDRAULIC DEPTH</p> <p>Definition of hydraulic depth</p>
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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 E.6.6: Roughness coefficient**

Stream characteristics	Ranges of values of n
<ul style="list-style-type: none"> <li>Streams in upland areas <ul style="list-style-type: none"> <li>Gravels, cobbles and boulders with no vegetation</li> <li>Cobbles and large boulders</li> </ul> </li> <li>Streams on plains <ul style="list-style-type: none"> <li>Clean straight bank with no rifts or pools</li> <li>Same as 1 but with some weeds and stones</li> <li>Winding watercourse, some pools and shoals but clean banks</li> <li>As 3 but straighter river with less clearly defined banks</li> <li>As 3 but with some weeds and stones</li> <li>As 4 but with stony sections</li> <li>River reaches with weeds and deep pools</li> <li>Very weedy river reaches</li> <li>Stream out of channel flowing across grass</li> <li>Stream out of channel flowing through light bush</li> </ul> </li> </ul>	0.030 - 0.050 0.040 - 0.070 0.025 - 0.033 0.030 - 0.040 0.035 - 0.050 0.040 - 0.055 0.035 - 0.045 0.045 - 0.060 0.050 - 0.080 0.080 - 0.150 0.030 - 0.050 0.040 - 0.080

### 6.4.3 Flat terrain

In flat terrain where obtaining such a slope may not be possible and where water flow at the 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 than 1% 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 flood water 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 Table E.8.20 is then straightforward.

## 6.5 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. As the design of structures is primarily based on the peak flow rate it is necessary to know the normal flow rate for two reasons:

- 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.
- 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.

## 6.6 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, such as a vented ford, 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.

## 6.7 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.

## 6.8 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:

### 6.8.1 Incised

This section of the river is particularly prone to scour, especially around piers and abutments, which requires careful consideration to protection measures.

### 6.8.2 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.

## 6.9 Watercourse bank and bed characteristics

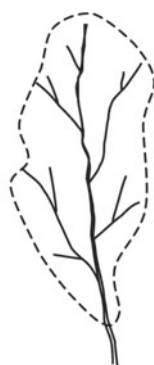
Visual inspections of the watercourse bank and bed should be carried out to determine the type of soil and depth to a firm stratum or rock. The ground conditions will determine the size, depth and shape



of the structures foundations. Watercourse characteristics will also determine the amount of protection required to the river bank downstream of the structure. It is not necessary to dig trial pits in the actual river bed 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.

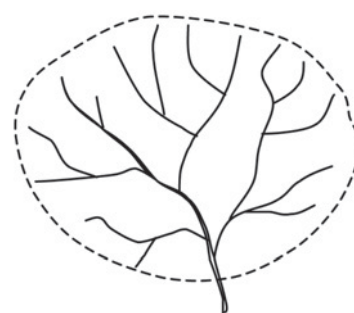
## 6.10 Catchment area and shape

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 E.6.1).



**LONG THIN CATCHMENT**  
- RELATIVELY LONGER  
FLOOD PERIODS AND  
SMALLER PEAK FLOWS

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.



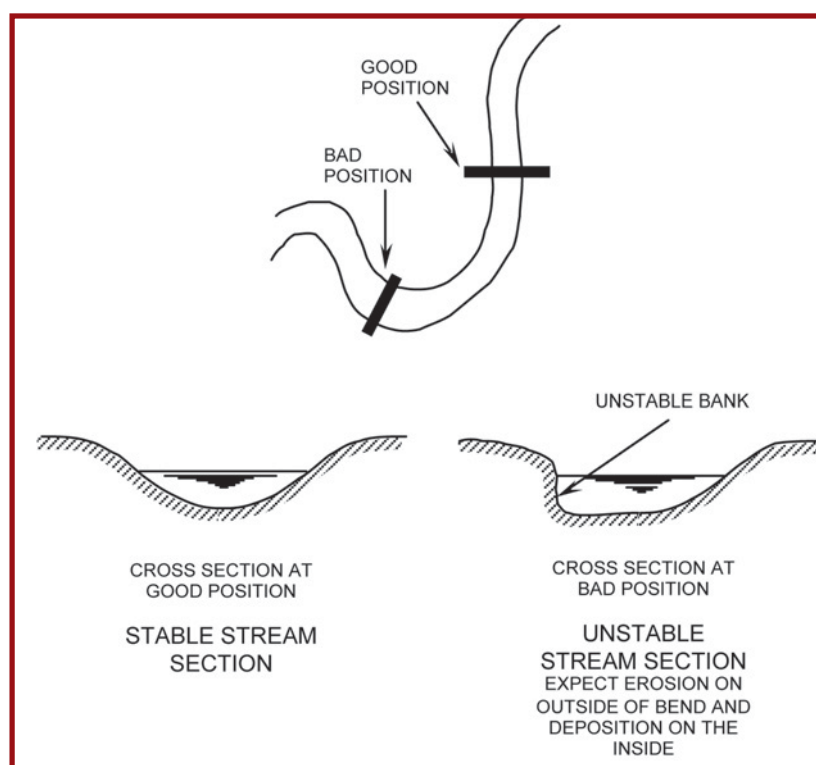
**BROAD CATCHMENT**  
- RELATIVELY HIGHER  
PEAK FLOWS OVER A  
SHORTER PERIOD

A round or square catchment area will tend to have shorter but higher peak flows when compared against 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 E.6.1: Catchment characteristics**

## 6.11 Cross-sections at crossing point

The cross-section of the watercourse at the crossing point will affect the design of the structure (Figure E.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, as 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 E.6.2: Stream crossing point cross-sections**

## 6.12 Hydraulic gradient upstream and downstream

The hydraulic gradient is the slope of the river bed 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 river bed. 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.

## 6.13 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.

## 6.14 Rainfall intensity

The rainfall intensity in the whole catchment area will affect the peak water flow after heavy rain (see Section E.6.1 on peak flow rate).

## 7.

## MATERIALS

This chapter aims to provide sufficient information to enable road designers and builders:

- to identify potentially suitable materials;
- to know what materials' properties will be required for various uses;
- to know how testing for these properties can simply be conducted;
- to know something about 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.

A particular aim of this chapter is to enable road builders to make more extensive use of local materials and existing craft skills in the construction of road structures. These are particularly suitable for use by small local enterprises and community implementation. Where manufactured materials such as steel and cement are used, initial costs tend to be high; special training in the correct procedures for construction are required. This Manual focuses particularly on materials such as brick, stone masonry and timber, which have until now been comparatively neglected both in guidelines for road construction and in the training of the designers and builders of roads. These materials usually allow lower cost durable solutions to structure requirements by making better use of locally available materials, skills and labour resources. They can also have more favourable carbon footprint characteristics and reduce foreign exchange and national importation requirements.

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.

It is recommended that consideration be given to all locally available construction materials. 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 make it an ideal material for road structures, where it is available. 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. In addition, 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. Examples of stone and stone masonry structures are shown in Plates E.7.1 and E.7.2 with examples of established Ethiopian dry stone walling expertise shown in Plate E.7.3





***Plate E.7.1: Dry jointed, multiple opening, cantilevered laterite stone culvert approximately 1,000 years old and still in service.***



***Plate E.7.2: Dry jointed, laterite, stone viaduct, approximately 1,000 years old, still in service on a main road.***





**Plate E.7.3: Examples of established Ethiopian techniques of dry stone walling**

### 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 E.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. Examples of this approach are shown in Plates E.7.4, E.7.5, E.7.6 and E.7.7.

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.

**Table E.7.1: Classes of rocks used for building**

<b>Igneous rocks</b>	Granite, Basalt, Pumice or Tuff. These are of volcanic origin and form as a result of cooling of molten material either within the earth's crust or at its surface. Granites and basalts are hard, dense, strong and impermeable, and can form excellent rubble 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.
<b>Sedimentary rocks</b>	Sandstones, Limestones. These are formed by deposition (usually under water) of particles from older rocks and organic materials, and chemical precipitation. They show natural stratification with separate layers having 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.
<b>Metamorphic rocks</b>	Slates, Quartzite, Marble. These are rocks which can be either igneous or sedimentary in origin, but which have been subsequently altered due to movements in the earth's crust causing them to experience enormous heat and pressure. As a result they are often hard and durable, and they tend to have a foliated structure with layers of stratification. Slates are metamorphosed clay and shale which quarry easily and are frequently suitable for walling and roofing stones. Marbles are metamorphosed limestones which have been crystallised by heat and pressure. They are hard and durable, and suitable for sawing and carving and can often take a high polish.
<b>Laterite</b>	This is strictly a form of soil rather than a rock. It 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 on hardening it becomes weather resistant, and has a 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.
<b>Field stone</b>	Stone which 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. It is usually of a durable type. Field stone can be a useful source of stone for small road projects, but should be subjected to tests as described below to determine its suitability.

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.





**Plate E.7.4:** *Hand dressed stone*



**Plate E.7.5:** *Hand quarrying of stone*



**Plate E.7.6:** *Hand quarried granite stone blocks*



**Plate E.7.7:** *Manual quarry operations can create local employment, however good management is required to ensure a safe working environment*

### 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. The structure of the stone is the most important aspect of its resistance to decay. 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 tests are sufficient to assess its durability characteristics. Other durability issues are shown in Table E.7.2.

**Table E.7.2: Durability Issues**

<b>Frost Action</b>	Some types of stone are seriously affected by frost, and in cold climates must not be used in positions where they can become saturated. The remedy is to detail the wall to protect the stone from becoming saturated, by means of a coping, and providing protection for the base from upward percolating water by means of a damp-proof course.
<b>Soluble salts</b>	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.
<b>Thermal and moisture movement</b>	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 soft 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**

Certain stones, notably soft limestones, sandstones and laterites, 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. It is a potential problem mostly where there is frost.

**Porosity**

Porosity is not in itself a disadvantage in most cases, but some stones are capable of absorbing substantial amounts of water; this can reduce the strength and also, in cold climates, freezing can cause disintegration of the stone. 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.

**Structure test**

The structure 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:

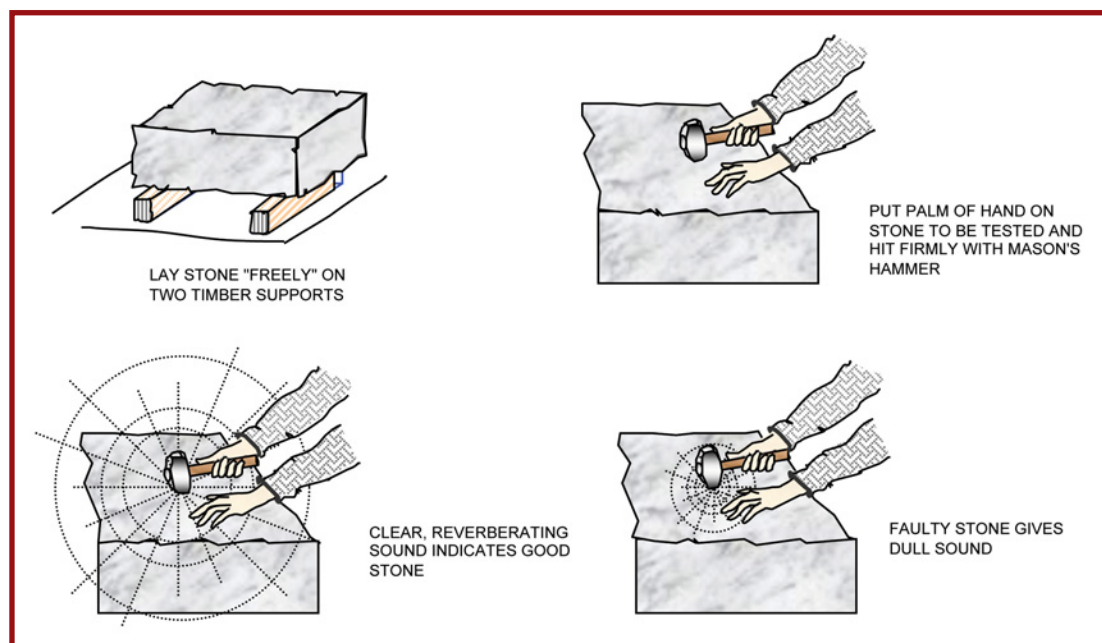
- Weighing it when dry (stored in a dry environment for at least 5 days);
- Immersing it in water for 24 hours at ambient temperature;
- Weighing it again after removing excess surface moisture.



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 E.7.1).



**Figure E.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

There is no adequate field test for compressive strength. 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 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 2 mm 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 plasticizer) 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 plasticizer 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. Plasticizers 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 E.7.3 below shows typical mortar mixes using cement-sand or cement-lime-sand.

**Table E.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

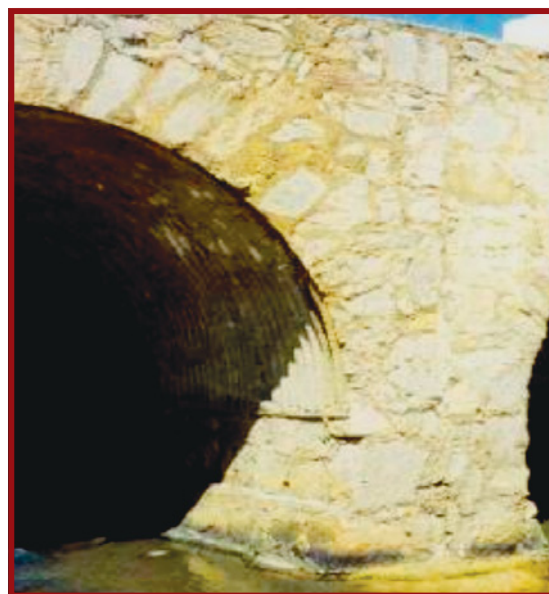
Commonly used mixes are 1:4 cement:sand for structural use, or where there is contact with water, and 1:6 in other cases. For a good quality mortar, water content should be low (typically 0.4 water/cement ratio). The quantity mixed in any one batch should not be more than can be used in about one hour; during that time unused mix should be covered to protect it from excessive evaporation.

### 7.1.5

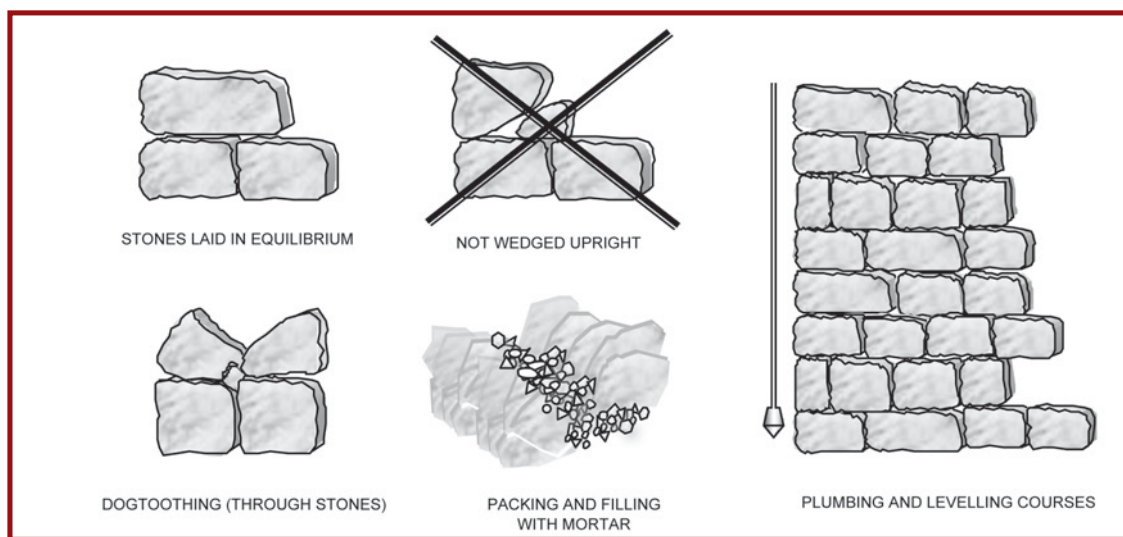
#### Stone walls

Random stone masonry is constructed from stones as they came from the quarry or source with minimal dressing. The laying skill is 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<sup>2</sup> 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 stone walls may be constructed without any courses, or brought to level courses for example every 600 or 900mm.

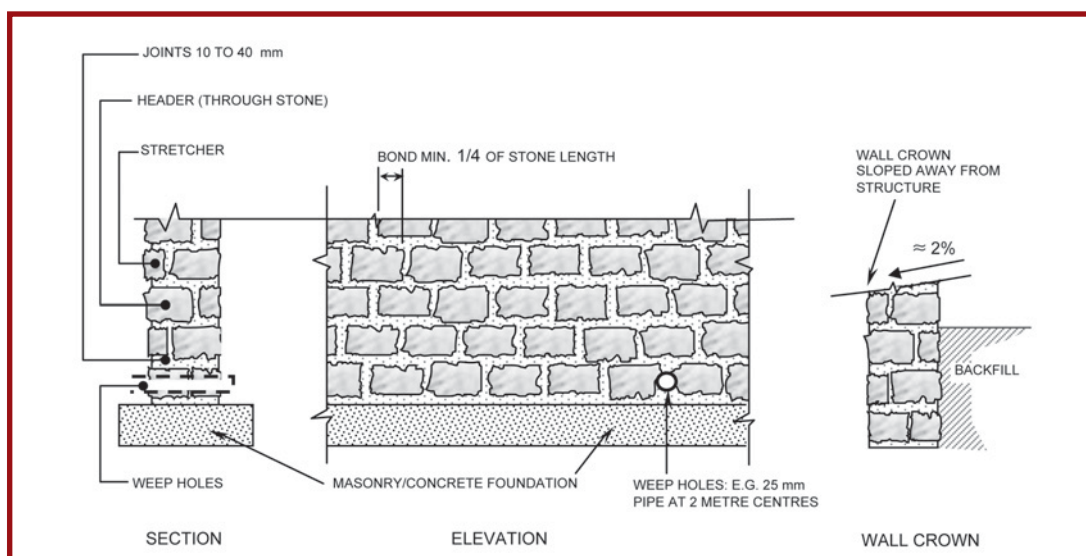


**Plate E.7.8: Rubble stone large bore culvert**



**Figure E.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 Plate E.7.8 and in Figures E.7.2 and E.7.3.



**Figure E.7.3: Squared masonry walling**

Some general requirements for stone walls 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 may be 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 E.7.3 above. A common mortar is 1:4 cement:sand.



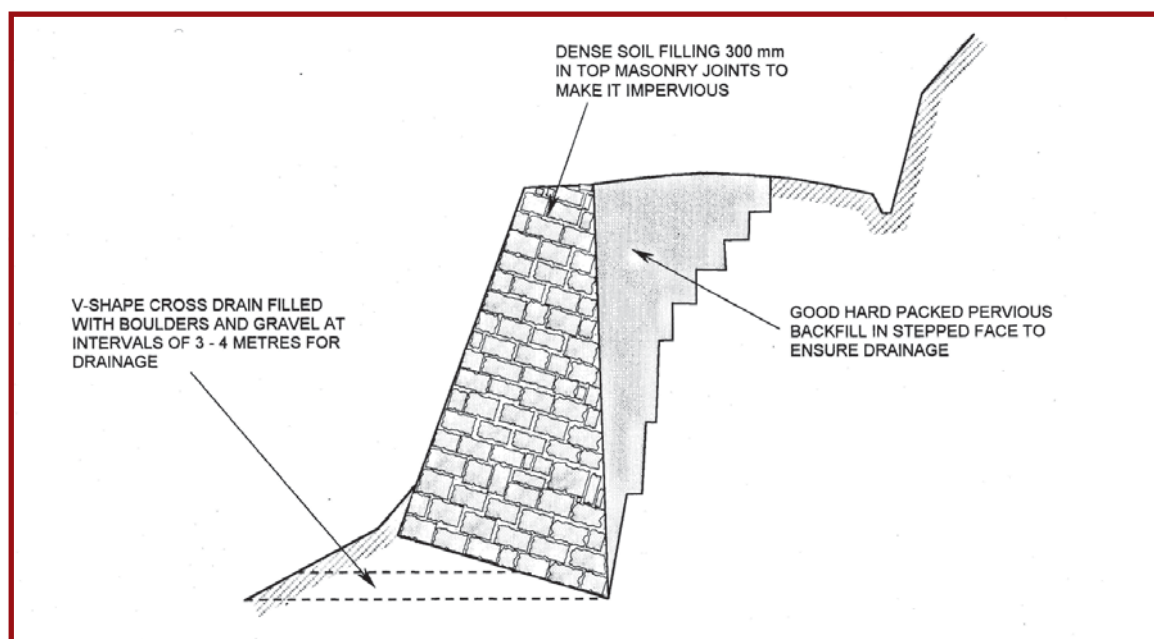
Some additional requirements for retaining walls are:

- 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. A dry stone wall costs substantially less than a mortared wall, but calls for considerable skill in choosing and laying stones if instability and rapid deterioration is 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. Typical arrangements are shown in Figure E.7.4. Undressed stone may be suitable for retaining walls (Plate E.7.9) where stone is available locally and the ground beneath is firm. Walls should not exceed 5m in height.



**Figure E.7.4: Dry stone retaining wall**



**Plate E.7.9: Dry stone wall supporting embankment**



Some guidelines for the construction of dry masonry walls are as follows:

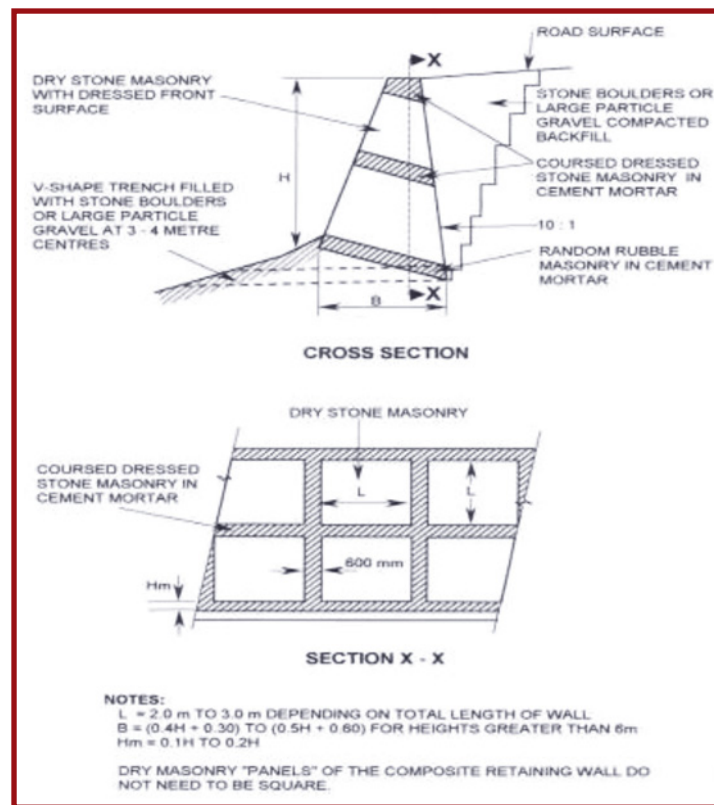
- All front-side inclinations should be in the range of 3:1 to 4:1 (vertical:horizontal);
- All back-side inclinations should be 1:10;
- The top width of the wall should be 1m;
- The tilt of the bottom of the foundation should be at right angle to the front inclination of the wall and hence fixed in 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 E.7.4 and Plate E.7.10);
- All other construction details can be considered analogous to the rules applicable to gabion wall construction.



**Plate E.7.10: Dressed dry stone wall**

### 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 stone wall 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. Examples are shown in Figure E.7.5 and Plate E.7.11



**Figure E.7.5: Hybrid wall**



**Plate E.7.11: Hybrid retaining wall**



## 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 (Plate E.7.12), timber or reusable steel formwork (Plates E.7.13,14 and 15). 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 commonly available with local building contractors. Dressed stone skills are required for dry stone masonry culverts.



**Plate E.7.12:**  
**Masonry culvert with**  
**steel former to be left**  
**insitu after construction**



**Plates E.7.13-15:** **Dry stone masonry culvert**  
**extension works - Dry stone Conservancy, USA**



## 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 E.7.16). Gabion boxes may be made from purpose made gabion cages, welded steel mesh sheets or galvanised chain link fencing.

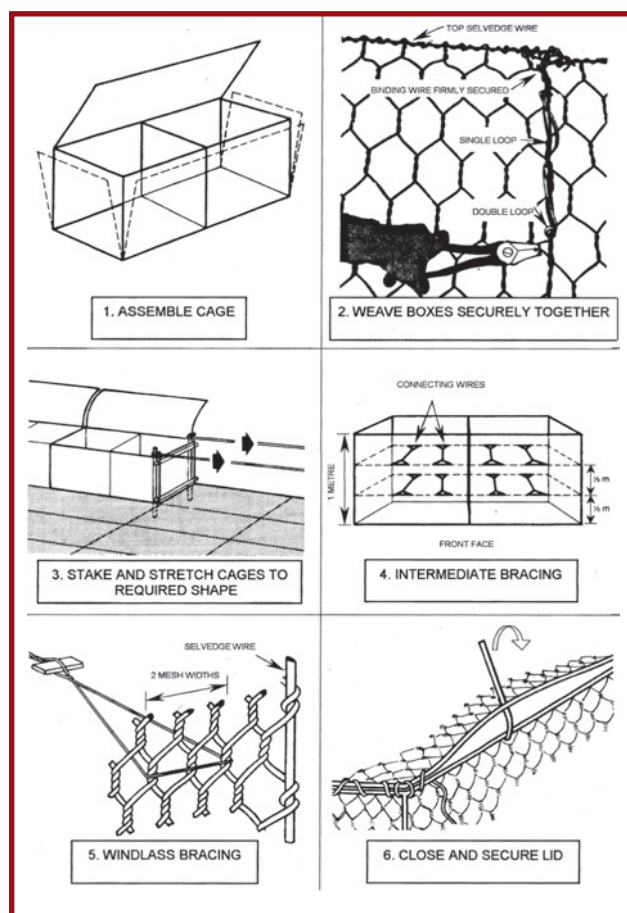
Gabions are used as a substitute for concrete or masonry, and gabion structures should be built with the same principles of good foundation, stability and quality control. The advantages of gabions are their simplicity of construction (requiring low levels of skill), use of local materials (stones), 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.



**Plate E.7.16:**  
**Gabions supporting a road on a steep slope**

The process of gabion construction (illustrated in Figure E.7.6) is as follows:

- 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 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;
- The connected baskets should be stretched and staked with wires and pegs to achieve the required shape;
- 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;
- 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;
- Further bracing should be fixed after filling to two-thirds height. 500mm height boxes should be braced at mid height only. 250 - 330mm gabions do not require internal bracing;
- Where water falls directly onto the top of the gabion, vertical bracing wire should also be fitted to secure the gabion lid when closed;
- 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;



**Figure E.7.6: Gabion details**



- 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.

Further illustrations of the construction and use of gabions are shown in Plates E.7.17 to E.7.21.



**Plate E.7.17: Filling gabion baskets**



**Plate E.7.18: Gabion retaining wall used as river bank protection**



**Plate E.7.19: Natural fibre matting inserted in gabion protection works to encourage rapid growth of vegetation cover**



**Plate E.7.20: Steel mesh gabions**



**Plate E.7.21: Gabion river crossing**



## 7.2

**Brick and block masonry**

Brick and block masonry materials are made in almost every Part of the world, and are frequently the standard materials used for walling in building construction.

Fired clay bricks have been used for centuries for bridges (see Plates E.7.22 and E.7.23) and are one the most flexible general building materials; their small and regular size make 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 however not as strong as the bricks themselves;
- Bricks should be laid bonded, to similar principles as stone masonry;
- Bricks should be protected from the possible incidence of soaking in frost susceptible climates;
- Abrasion situations such as drift surfaces should be avoided.

This makes fired clay bricks suitable for use in foundations, bridge piers, abutments, wing walls, arches, culverts and retaining walls. Bricks can be a particularly important construction material in regions and locations with shortages of hard stone resources.

Local brick making skills are established in many areas, and could be developed in new ones 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 (Plate E.7.24) as described in the gTKP report on practices established in Vietnam (Reference: Dzung).



**Plate E.7.22: Fired clay brick is a very versatile material. This elliptical brick arch bridge over the River Thames at Maidenhead, UK was constructed in 1838 and has two main spans of 38 metres. It is still in use today (designer: Isambard Kingdom Brunel) photograph by Jon Combe**





**Plate E.7.23: Fired clay brick structures exist in many countries and still provide service for today's traffic after centuries of use**



**Plate E.7.24: High quality burnt clay bricks produced in small 'beehive' kilns fired by rice husk. Bricks can be fired using coal, wood or agricultural waste products**

The range of masonry materials which are manufactured is wide. Burnt clay bricks (Plate E.7.25) are still in many places the most widely available manufactured masonry materials. However, 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 are found in different places, and may be suitable for less demanding applications such as culvert headwalls and low retaining walls. Where natural stone is locally available, this may be better to use than any manufactured material on environmental and transport costs grounds. The requirements, properties and testing recommendations described for bricks and blocks need to be adapted for other masonry materials.



**Plate E.7.25: Simple burnt clay brick clamp**

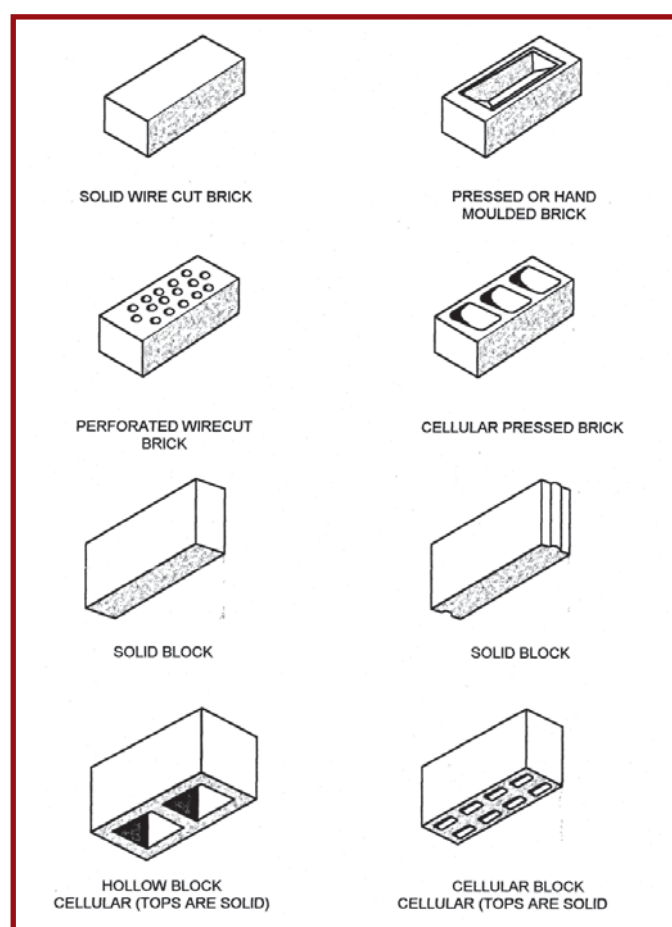
A wide range of soils is suitable for brick and block making. To make bricks, a suitable soil (called clay or brick-earth) is mixed with water, formed into the desired shape in a mould, dried, and then set in a kiln and fired at a sufficient temperature (usually 850-1000°C) to create permanent ceramic bonds between the soil particles (Plate E.7.26).

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 E.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.



**Plate E.7.26: Bricks baked in a kiln**



**Figure E.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 Ethiopia 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 Ethiopia 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.

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 of individual bricks and blocks is usually much higher than is needed, but the strength of panels is affected by their shape, how they are supported, and by the mortar used. The compressive strength requirement depends on the loading on the wall. A minimum unit compressive strength of 3.5N/mm<sup>2</sup> 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 50N/mm<sup>2</sup> 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 - parapets, piers and abutment walls. A water absorption not greater than 15% by weight of the dry brick weight 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. A key consideration is whether the site may be exposed to frosts. 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. Specific actions to limit susceptibility to frost and chemical action for clay bricks are discussed below.



### **Frost resistance**

Water expands on freezing; where walls can become saturated with water which subsequently freezes, the expansion can be very damaging to masonry work. Well-made bricks or blocks of low porosity are generally able to withstand regular freeze-thaw cycles: but more porous and lower strength masonry units may be damaged. Where frosts may occur, bricks or blocks which are not of the highest quality should be protected from conditions in which they may become saturated. The use of damp-proof courses to protect the base of the wall from rising damp, copings to protect the top, and weathering details to prevent water from running down the face of the wall form the best protection from frost damage. All mortar joints should also be well pointed to ensure that the finished face of the joints is dense.

### **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, obtain information 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 around 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 finger nail.

**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  $\pm 4\%$  (length and width) or  $\pm 3\%$  (height) from the standard size.

**Water absorption test for clay bricks**

Take a sample of 5 bricks at random. Dry and weigh each brick ( $W_1$ ); then submerge in clean water at ambient temperature for 24 hours. Wipe surface and weigh again ( $W_2$ ).

The water absorption (%) is the ratio:  
 $100 \times (W_2 - W_1) / W_1$

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 (eg 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.

Brick and block masonry may be used for bridge piers (Plate E.7.27) abutments and wing walls, arch culverts and wing walls, and small bridges.



**Plate E.7.27: Bricks in a bridge pier**

### 7.3 Timber and organic materials

Timber, in the form of sawn sections or poles, is in many areas 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 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. Sustainably produced timber can have attractive carbon footprint attributes.

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 (Plate E.7.28), masonry or concrete. Trussed or girder bridge decks can be made from cut sections of timber or from timber poles (Plates E.7.29 and E.7.30). Timber has also been used for both bridge, piers and abutments (Plate E.7.31) and for retaining structures, though in these uses a relatively shorter lifetime must be expected; and in Tanzania, a successful programme to use timber for culvert linings has been in progress for some years.





***Plate E.7.28: Steel beams being moved into position using labour methods, without the use of cranes; ready for completion with a timber deck***



***Plate E.7.29: Timber deck on recycled steel beams***



***Plate E.7.30: Completed timber deck***



***Plate E.7.31: Timber bridge deck, pier and abutments***

## 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 than 500 kg/m<sup>3</sup>) and 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<sup>3</sup>), 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 E.7.4, E.7.5 and E.7.6 (with their scientific and common name), which divide them into heavier and lighter hardwoods and softwoods.

**Table E.7.4: Heavy hardwoods**

Density >650kg/m <sup>3</sup> when dried to 18% moisture content	
Afrormosia	(Pericopsis elata)
Ekki	(Lophira elata)
Greenheart	(Ocotea rodiaei)
Iroko	(Chlorophora excelsa, regia)
Jarrah	(Eucalyptus marginata)
Karri	(Eucalyptus diversicolor)
Keruing (gurjun)	(Dipterocarpus spp)
Opepe	(Nauclea diderrichii)
Sapele	(Entandrophragma cylindricum)
Teak	(Tectona grandis)

**Table E.7.5: Lighter hardwoods**

Density <650kg/m <sup>3</sup> when dried to 18% moisture content	
African Mahogany	(Khaya ivorensis, anthotheca)
Afzelia	(Afzelia spp.)
Dahoma	(Piptadeniastrum africanum)
Gum	(Eucalyptus saligna)
Jacareuba	(Calophyllum brasiliense)
Meranti	(Shorea spp.)
Muminga	(Pterocarpus anyolensis)



Table E.7.6: Softwoods

Softwoods for bridge construction should generally have density >420kg/m <sup>3</sup> when dried to 18% moisture content	
Cedar	(Cedrus spp.)
Cypress	(Cuppressus spp.)
Douglas fir	(Pseudotsuga taxifora)
Kauri, East African	(Agathis alba)
Parana Pine	(Araucaria angustifolia)
Pine, Caribbean Pitch	(Pinus Caribaea)
Pine, Scots or Redwood	(Pinus sylvestries)

### 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 practised 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 E.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, is in the form of round poles as illustrated in Plates E.7.32 and E.7.33.

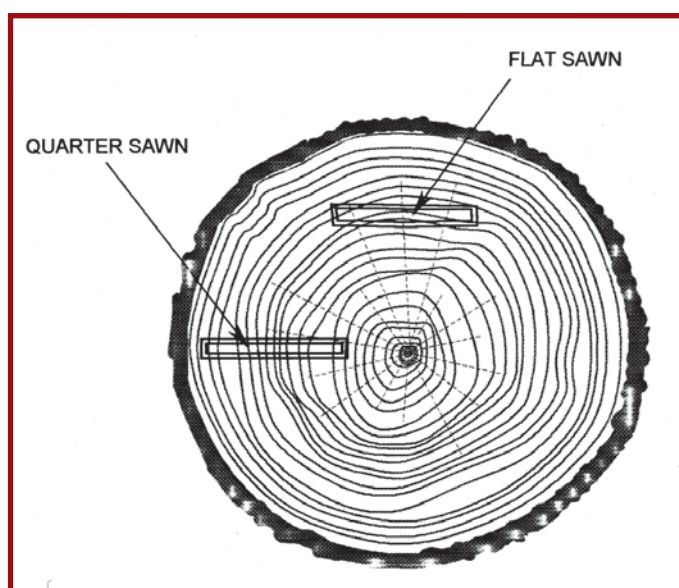


Figure E.7.8:

Saw cuts





**Plate E.7.32: Timber poles for piles  
(not covered by this Manual) for a concrete  
box culvert in very soft ground**



**Plate E.7.33: Timber poles as deck  
beams of a twin span bridge**

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, and 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.

### 7.3.2 Properties of timber

#### Natural defects

Natural defects shown in Figure E.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; can reduce strength in tension, 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.

#### 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 the Table 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<sup>3</sup>, but for bridge construction those suitable have densities above 420 kg/m<sup>3</sup> at 18% moisture content are required. Tropical hardwoods typically have densities in the range 500 to 800 kg/m<sup>3</sup> 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<sup>3</sup> when dried to a moisture content of 18%; and lighter hardwoods with densities less than 650 kg/m<sup>3</sup>.

#### 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 higher modulus of elasticity.

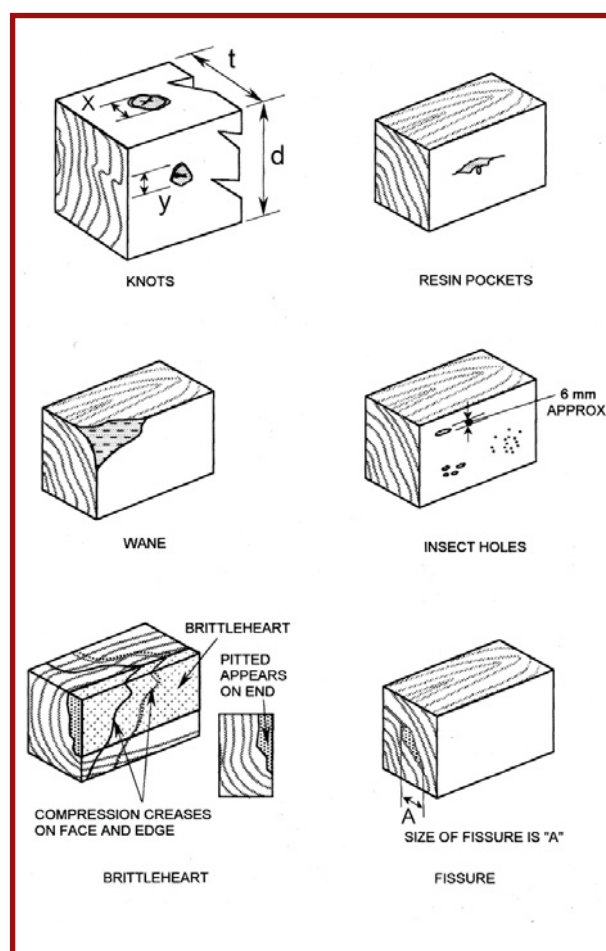


Figure E.7.9: Natural defects in timber



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 E.7.7.

**Table E.7.7: Design stresses for the three principal timber groups**

	Heavy Hardwoods (N/mm <sup>2</sup> )	Lighter Hardwoods (N/mm <sup>2</sup> )	Softwoods (N/mm <sup>2</sup> )
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 and 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.

The natural resistance of wood to decay can be increased by ensuring that its moisture content is below 18% (based on the oven-dry weight of the wood). 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.

Damage above ground may be prevented by ensuring that all means of access are eliminated. 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 waterborn 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  $30-60 \times 10^{-6}$  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.

## **7.3.3**

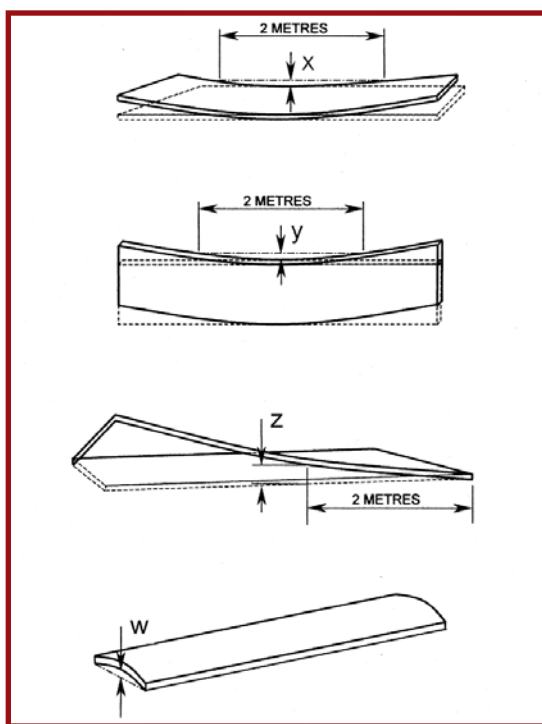
### **Field testing**

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 E.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 E.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 E.7.8. Other visible defects including bark pockets, compression failures, fungal decay, and brittleheart should not be permitted in any structural timber.

**Table E.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 °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 to be used 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

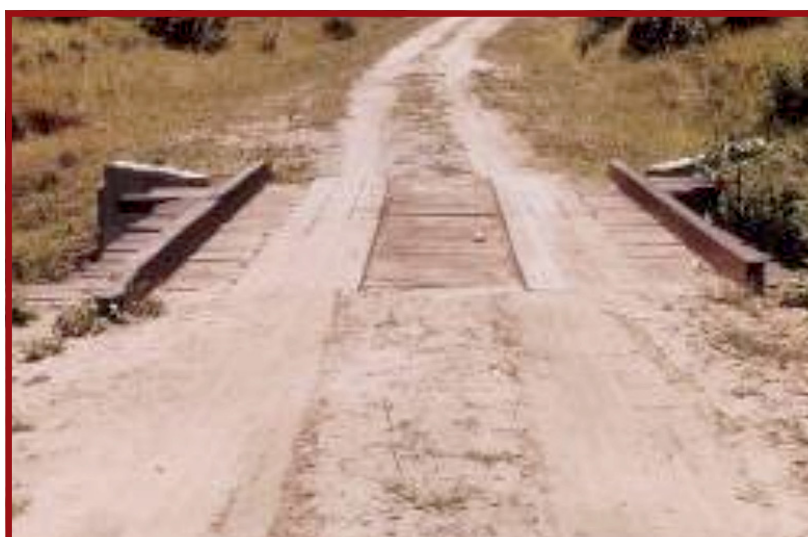
The suitability of the structural properties of a timber are normally determined by the use of standard tables of properties for the species to be used, coupled with stress grading to determine the classification of the sections available. However, in certain circumstances, the structural properties 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.

#### 7.3.4

### Uses of timber

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. Timber can also be used for bridge abutments and retaining structures (though in these uses a relatively shorter lifetime must be expected), and for culverts. Examples of the use of timber in structures are illustrated in plates E.7.34, E.7.35 and E.7.36.



**Plate E.7.34: Timber decked bridge**





**Plate E.7.35: Log abutments & deck**



**Plate E.7.36: Treated timber culvert**

## 7.4

### Plain and reinforced concrete

Plain and reinforced concrete are the widely used choices of material for a range of uses 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 able to resist the action of water.

Reinforced concrete is suitable for bridge decks, piers and abutments, 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.

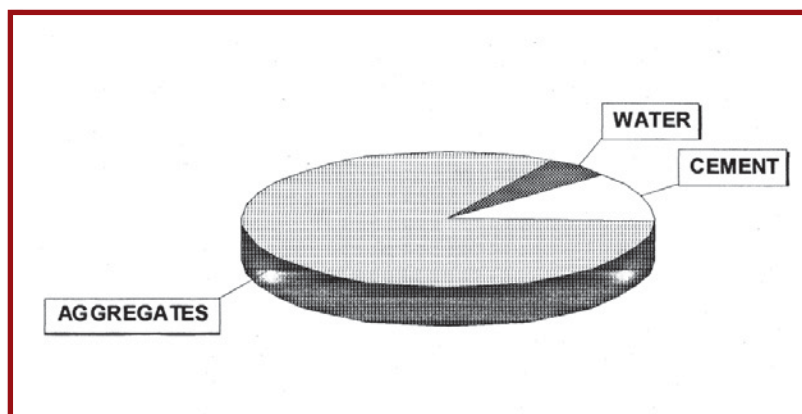
Because concrete, unlike other structural materials, is generally made on site from its raw materials, an important requirement for the use of concrete in structures is that both designers and builders, as well as those responsible for long-term maintenance, understand its essential properties and characteristics.

## 7.4.1

**Materials for concrete**

There are three essential constituents of concrete as illustrated in Figure E.7.11:

- 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;
- 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 moulded. Over time, the water combines chemically with the cement in a process called hydration, which causes the concrete to set and develop strength;



**Figure E.7.11: The constituents of concrete**

- 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.

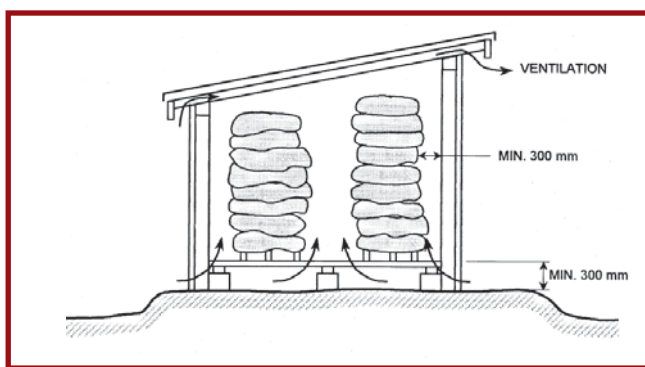
Plain concrete is relatively weak in tension, therefore steel reinforcement is used where tensile stresses are expected. When reinforced concrete is being made, the reinforcement is formed into a cage or grid, which is placed in the formwork before the concrete is placed. The following sections describe 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 paper bags. The cement must be kept totally dry until it is to be 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 E.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 E.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. Salty 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 a 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 a 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, 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 (Plate E.7.37) or by machine.

Aggregates should be stored in such a way that they do not become contaminated by soil, and that rainwater can drain easily.



**Plate E.7.37: Aggregate crushed and screened by hand**



### 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; and 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, while 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. An example of a steel reinforcement cage being assembled on site for the construction of a cut-off wall in a drift is shown in Plate E.7.38.



**Plate E.7.38: Steel reinforcement cage being assembled**

### 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 E.7.9.

**Table E.7.9: Concrete Types**

<b>Structural concrete</b>	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 <sup>2</sup> ) 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.
<b>Mass concrete</b>	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.
<b>Lean concrete</b>	This is a meagre mix with a 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.

The nominal mixes shown in Table E.7.10 should achieve the strengths indicated, with good quality graded aggregates, and water content just sufficient to give adequate workability. 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 E.7.10: Concrete grades, strengths and batching strengths**

Class of concrete	Expected 28 day strength N/mm <sup>2</sup>	Cement/ fine agg./ coarse agg. (guidance)	Material required for 1m <sup>3</sup> finished concrete (guidance)		
			50kg Cement bags (kg)	Fine (m <sup>3</sup> )	Coarse (m <sup>3</sup> )
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 E.7.13. The gauge box has a volume of 0.036 m<sup>3</sup>, equivalent to one 50kg bag of cement.

Class of Concrete	Batch with 1 bag cement		
	Number of boxes of aggregates		Yield per batch
	Fine	Coarse	(m <sup>3</sup> )
Lean	4	4	0.30
Mass	3	6	0.24
Grade 20	2	4	0.16
Grade 25	1.5	3	0.14

CONCRETE CAN BE BATCHED BY VOLUME.  
GAUGE BOXES MADE FROM STEEL, WOOD OR PLYWOOD ARE USED FOR THIS.

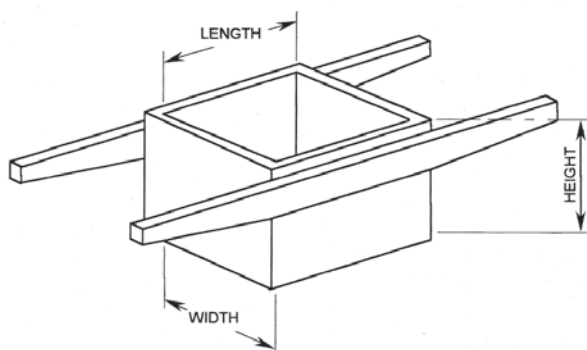
**BOX DIMENSIONS - INSIDE MEASUREMENTS**

LENGTH = 400 mm, WIDTH = 300 mm, HEIGHT = 300 mm

**VOLUME**

0.036 m<sup>3</sup> OR 36 LITRES

36 LITRES ARE EQUAL TO 1 (50 kg) BAG OF CEMENT



**Figure E.7.13: Concrete mixes (guidance)**

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.

### Transporting

Concrete should be mixed as near as possible to the site of placement and may be transported using trucks, wheelbarrows, or even using headpans for sites with difficult access. The wet mix should be transported within 30 minutes to allow placing before setting commences.

### Placing

The formwork or shuttering for the concrete must be clean, smooth faced, and secure from movement or leakage when the concrete is poured. Formwork is normally constructed from timber and plywood, especially where shapes are complex. Where the same shape is repeated (eg 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 as 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 (eg 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, as these can take account of local raw materials, site practices and climate. Protection of the workforce from injury is a vital element of good concreting practice.

Table E.7.11 provides guidelines for the placing, compacting and curing of concrete to assist in the attainment of a quality material.

**Table E.7.11: Recommendations for good quality concrete**

Activity	Recommendations of good practice
Placing concrete	<ul style="list-style-type: none"> <li>Forms and the shutters should be cleaned before placing the concrete</li> <li>Concrete should be placed in layers of 300mm depth</li> <li>Concrete should not be placed in heaps, as this causes separation of the stones from sand and cement</li> <li>Concrete should not be dropped from a height of more than 1.5m, as this also causes separation of the stone from the sand and cement</li> <li>Reinforcement bars are to be placed inside the shuttering before placing the concrete</li> </ul>
Compacting concrete	<ul style="list-style-type: none"> <li>Compacting is undertaken by tamping with a steel or wooden rod. It is important to remove all the air in the concrete as entrained air reduces the strength of the concrete.</li> </ul>
Curing concrete	<ul style="list-style-type: none"> <li>Curing means keeping the outside of the concrete moist (wet) during the setting (hardening) of the concrete by:               <ul style="list-style-type: none"> <li>Wetting the concrete surface frequently</li> <li>Covering the surface with wet material (cloth, paper bags, sand etc)</li> </ul> </li> <li>Hardening of concrete requires at least seven days. Curing prevents cracks in the surface layer of the concrete.</li> <li>As cement is normally one of the most expensive items in the construction process, it should not be wasted.</li> </ul>
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 E.7.12 indicates the maximum workability suitable for different situations.

**Table E.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

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, and this is the age at which the strength is specified for use in design. Concrete mixes are designed to achieve a given 28 day strength in compression, as measured by crushing tests on cubes or cylinders. Typical structural concretes have strengths in the range 25 to 40N/mm<sup>2</sup>. For high quality control 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 E.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 E.7.13: Agents of concrete deterioration**

<b>Corrosion (rusting) of the reinforcement</b>	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 either through inadequate concrete cover to the reinforcement, or because of poorly mixed or poorly compacted concrete, or as a result of cracking.
<b>Frost attack</b>	Frost attack is caused by expansion of water in the cement paste pores resulting in reduction of the strength of the cement paste - concrete is particularly vulnerable at early ages (up to 3 days) when its strength has not developed.
<b>Sulphate attack</b>	Sulphates in soil, sea water and some aggregates will react with the hydrated cement resulting in expansion and damage of the concrete.
<b>Alkali-silica reaction</b>	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**

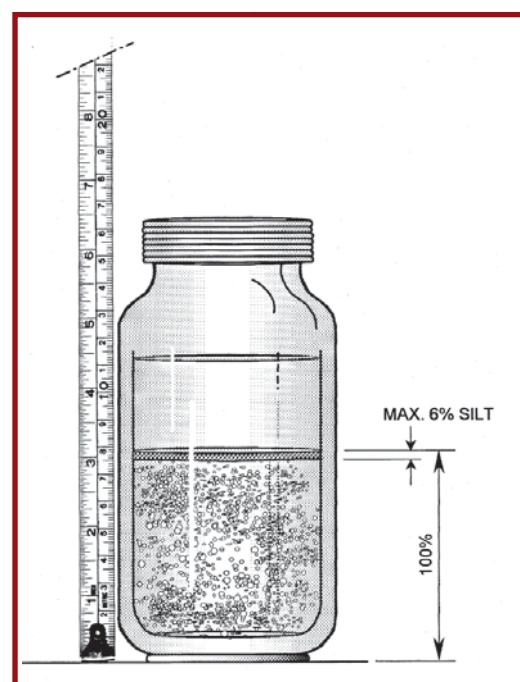
The coefficient of thermal expansion of concrete is about  $10 \text{ to } 14 \times 10^{-6} \text{ mm/mm}$ , ie about 3mm per m for a  $30^\circ\text{C}$  temperature rise, about the same as for structural steels ( $12 \times 10^{-6}$ ). Thus, for long concrete structures such as multi-span bridges, expansion joints are needed to allow for seasonal temperature changes.

**7.4.4****Field testing****Presence of silt and clay in sand and coarse aggregates: visual test**

Rub a sample of the sand between damp hands, and note the discolouration caused. Clean materials will leave the hands only slightly stained. If the hands remain dirty after the sand has been thrown away, it indicated the presence of too much silt and clay.

**Presence of silt and clay in sand and coarse aggregates: bottle test**

Half fill a clear bottle or tumbler with aggregates (Figure E.7.14); add water until it almost reaches the top, shake vigorously and then allow the aggregates to settle. After about 30 minutes there should be no fine material deposited on top of the aggregates and the water should be clear. Salt may be added to the water (one teaspoon per 0.5 litre) to speed the settlement. If the height of the silt layer is more than 6%, the sand should be washed.

**Figure E.7.14: Field fines test**



**Quality of reinforcement**

Reinforcement to be used should be supplied to comply with the national standards. Before use it should be checked to ensure that all bars are straight and free from loose scale, loose rust, oil, grease and dirt.

**Quality of cement**

Cement to be used should be supplied to the national standards. To check that it has not deteriorated in storage, it should be tested by hand for hardened lumps. A small proportion of lumpy cement may be removed by sieving.

**Test for workability of fresh concrete: the slump test**

The slump test is the standard way of making sure that concrete does not vary in consistency due to variations in the water:cement ratio. To make the test the standard cone-shaped mould is required, and a steel rod described in Figure E.7.15.

Mould shall be made of a metal not readily attacked by cement paste and not thinner than 1.5mm (eg galvanised steel). The interior of the mould shall be smooth and free from projections such as protruding rivets and shall be free from dents.

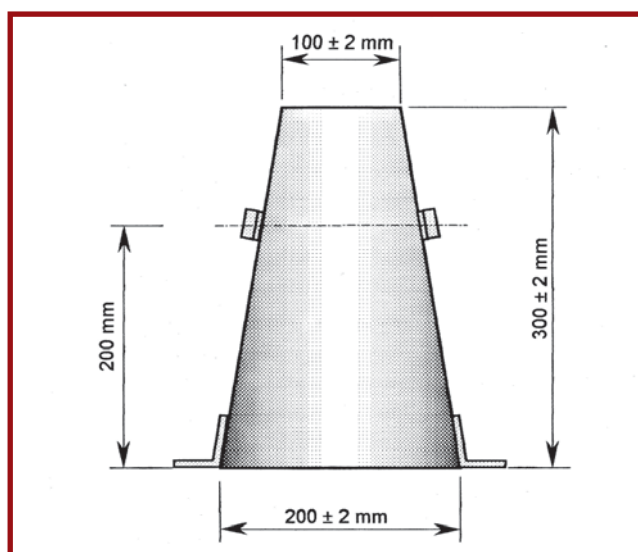
The mould shall be in the form of a hollow Part of a cone having the following internal dimensions:

diameter of base:  $200 \pm 2\text{mm}$

diameter of top:  $100 \pm 2\text{mm}$

height  $300 \pm 2\text{mm}$ .

Tamping rod: Made out of straight steel bar of circular cross section, 16mm diameter, 600mm long with both ends hemispherical.

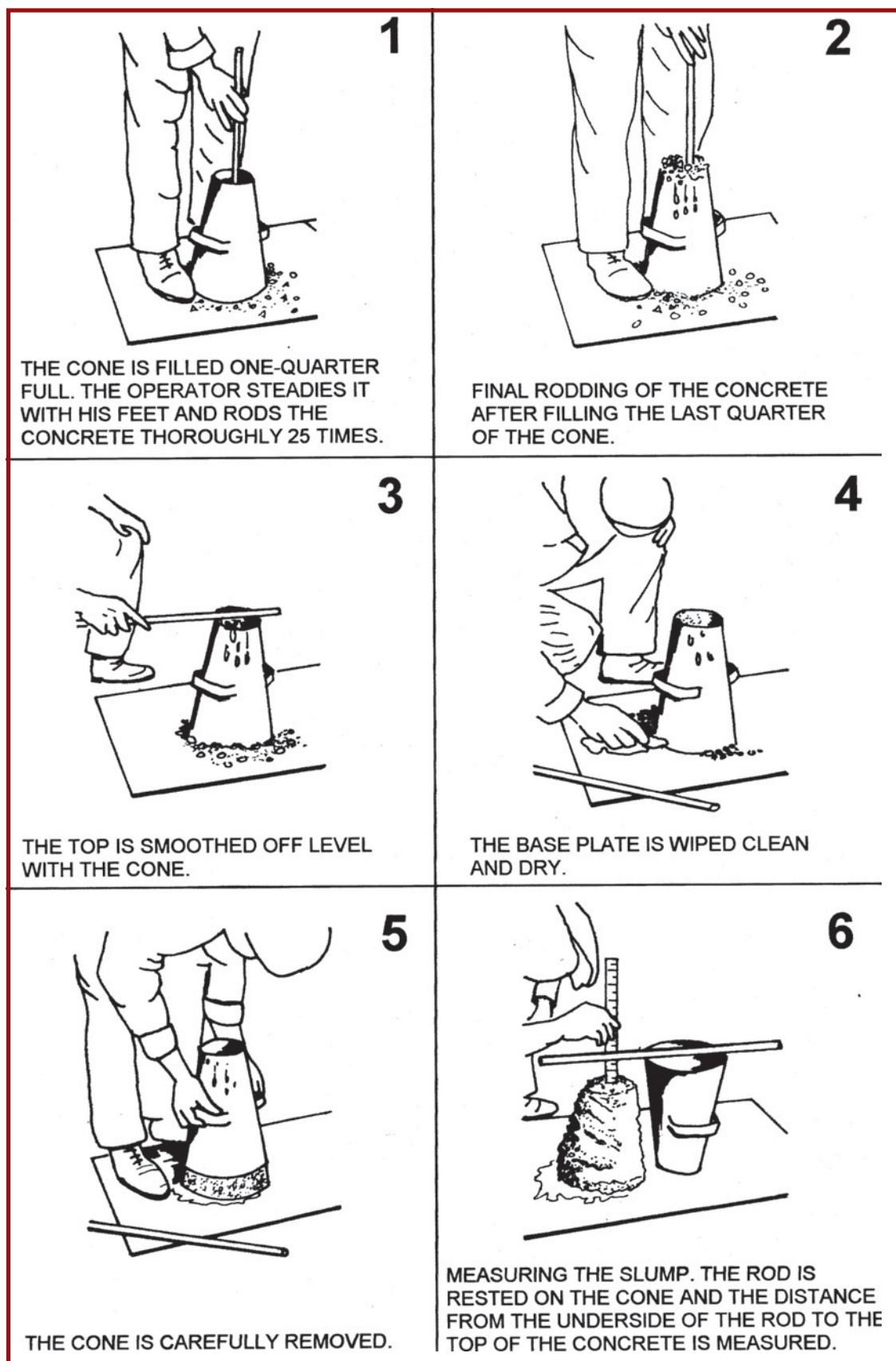


**Figure E.7.15: Slump test mould**

The procedure for the test is illustrated in Figure E.7.16. The cone has to be clean and dry inside and is put on a smooth, hard surface. The cone is filled one-quarter full. Holding it firmly in place with the metal feet, rod the concrete thoroughly 25 times. Then add more concrete to about half-way and rod it another 25 times, taking care to take the rod just through into the first layer. Next add the third layer filling the cone three-quarters full, and rod again 25 times, going through into the layer below. Finally fill the cone up, rod 25 times again, going well down into the third layer and smooth off the top. The top is smoothed off level with the cone.

Wipe the metal plate it stands on clean and dry and wipe round the base of the cone. Then, carefully and keeping it quite straight, lift the cone off and put it down beside the concrete. The concrete will collapse to some extent - very dry concrete hardly at all, very wet concrete completely. Test it by measuring how far it has collapsed.

To measure the slump, rest the rod across the top of the empty cone, so that it reaches over the concrete. With a rule measure down from the underside of the rod to the top of the concrete always measuring from the highest point on the concrete.



**Figure E.7.16: Slump test**



**Concrete strength: cube tests**

Test cubes may be made on the site to check whether the concrete used on a job has the required strength. The cubes are used to find the crushing strength of the concrete. It is essential that the cubes are made with great care. They are generally sent away to a laboratory for testing. This test is only recommended for structural concrete with a design strength of 20 N/mm<sup>2</sup> or above. Cast cubes should be cured as the constructed concrete by immersion in a tank of clean water for the initial period after casting and tested 28 days after casting. In some cases additional cubes are cast and crushed after 7 days to indicate whether the concrete is on track to achieve the required specification strength.

**Strength: impact test**

For a rough strength assessment for concrete of mass concrete grade, make a set of 10 briquettes from plain concrete of dimensions 100 x 200 x 50mm. Place each brick in turn with its largest face downwards, resting on timber battens 150mm apart. Drop a mason's 2 kg hammer from a height of exactly 0.5 m so that it strikes the upper face midway between the battens. The briquette should not break. If more than 1 in a sample of 10 bricks break in this test, the concrete is not of adequate strength and should not be used.

**7.4.5****Uses of concrete**

Reinforced concrete is used for bridge decks, piers and abutments, as well as for box culverts and culvert rings; and plain concrete may be used for drifts and causeways, and for the foundations of masonry and timber walls, piers and abutments. Typical examples of where concrete can be used in small drainage structures for low volume roads are shown in Plates E.7.39 to E.7.43.



**Plate E.7.39: Concrete culvert rings**





**Plate E.7.40: Concrete drift under construction**



**Plate E.7.41: Reinforced concrete slab**



**Plate E.7.42: Flow spreader structure at the outlet of a mitre drain on a steep fragile slope. Bio-engineering planting should be established downhill of such structures**



**Plate E.7.43: A simple reinforced concrete walled box culvert ready to receive pre-cast top slab units (timber or reinforced concrete)**

## 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 E.8.1 shows the aspects which must be consulted for the design of different structural elements for water crossing structures.

**Table E.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 <ul style="list-style-type: none"> <li>▪ general</li> <li>▪ deck</li> <li>▪ abutments</li> <li>▪ piers</li> <li>▪ bearings &amp; joints</li> </ul>				✓ (arch bridges)	

## 8.1

## Scour

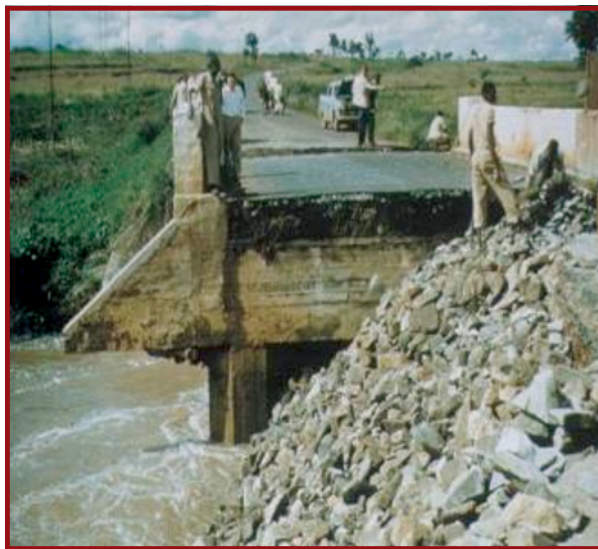
Scour is the erosion of material from the river sides and bed due to water flow. Damage due to scour is the most likely cause of structural failure (see Plate E.8.1). Minimising or eliminating the effects of scour should therefore receive the most attention when designing any structure. Scour can occur during any flow but the risk is generally greater during floods.

There are three major types of scour to be considered:

- **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.



- **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.
- **Local scour:** occurs around abutments and piers due to the increased velocity of the water and vortices around these obstructions.



**Plate E.8.1: Bridge damage due to scour of abutment**

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. Higher water velocities result in more scour.
- **Vegetation in the stream:** any vegetation growing permanently in the stream can improve the strength of the river bed, reducing scour. The vegetation can also reduce the speed of the water.
- **Depth, velocity and alignment of the flow through the bridge:** the faster the flow, the more scour will occur. If the flow is not parallel to the constriction more scour will occur on one side of the constriction.
- **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.

Inspect the proposed structure site and the watercourse upstream and downstream 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 minimum 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 E.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 E.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 E.8.3 should be provided to eliminate the effects of scour.

**Table E.8.3: Opening widths**

Peak flood flow rate	0.5	1	2	4	6	8	10	15	20	25	30	m <sup>3</sup> /s
Minimum width (W)	3.5	5	7	10	12	14	15	19	21	24	26	m

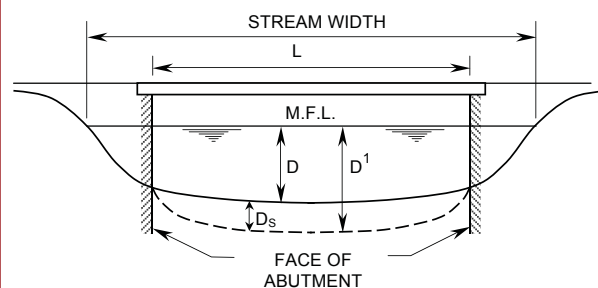
In some cases, particularly for bridges and larger flows, it will not be possible to provide the opening widths shown in Table E.8.3 above. The design, particularly the level of foundations, should allow for a lowering of the river bed level due to scour. The amount/depth of scour (as shown in Figure E.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

$$D_s = D_1 - D$$



W = THE ORIGINAL WIDTH OF THE STREAM

L = THE DESIGNED WATERWAY. WHEN THE BRIDGE IS ASSUMED TO CAUSE CONTRACTION, L IS LESS THAN W

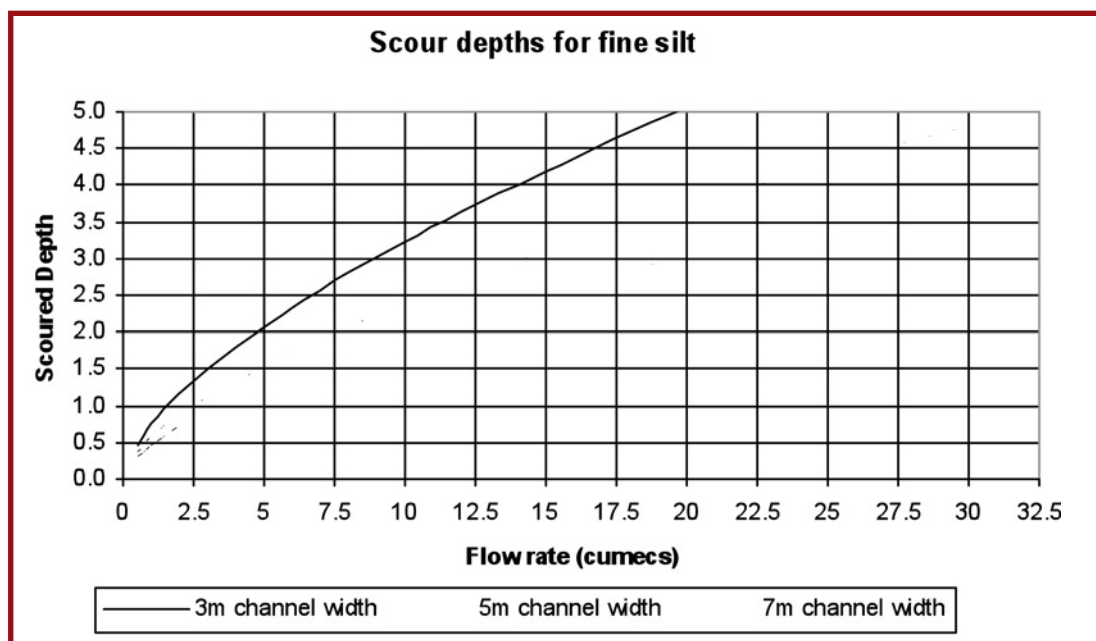
D = THE ORIGINAL DEPTH OF STREAM

D<sup>1</sup> = THE EXPECTED SCOUR DEPTH UNDER THE BRIDGE DUE TO ITS CONSTRICTION

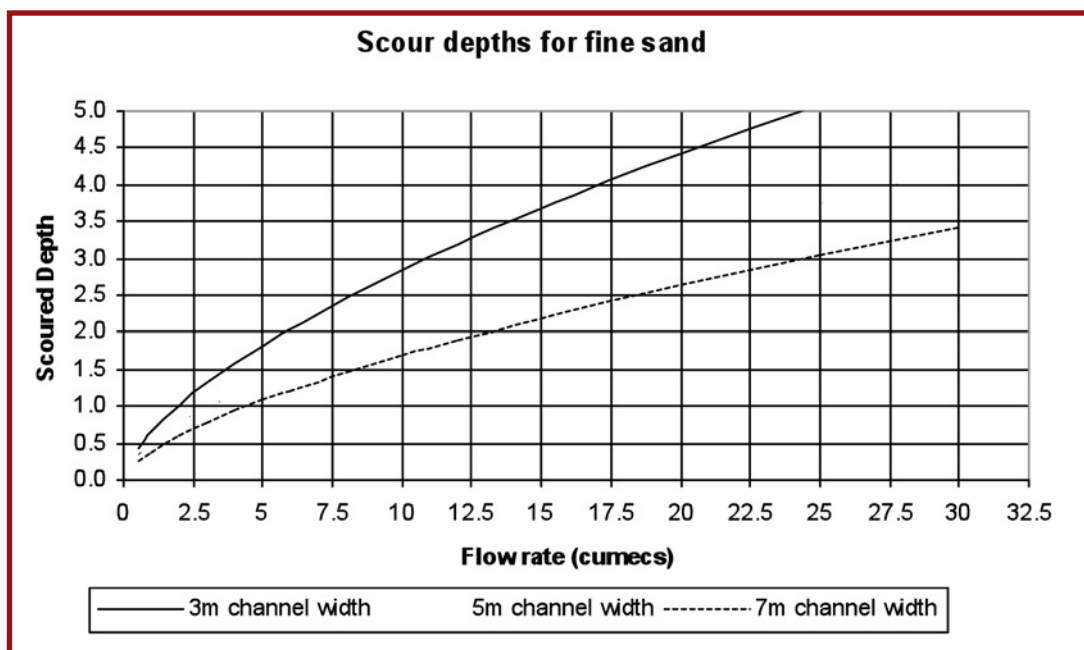
D<sub>s</sub> = ADDITIONAL DEPTH OF SCOUR DUE TO CONSTRICTION OF BRIDGE

**Figure: E.8.1: Scour allowances**

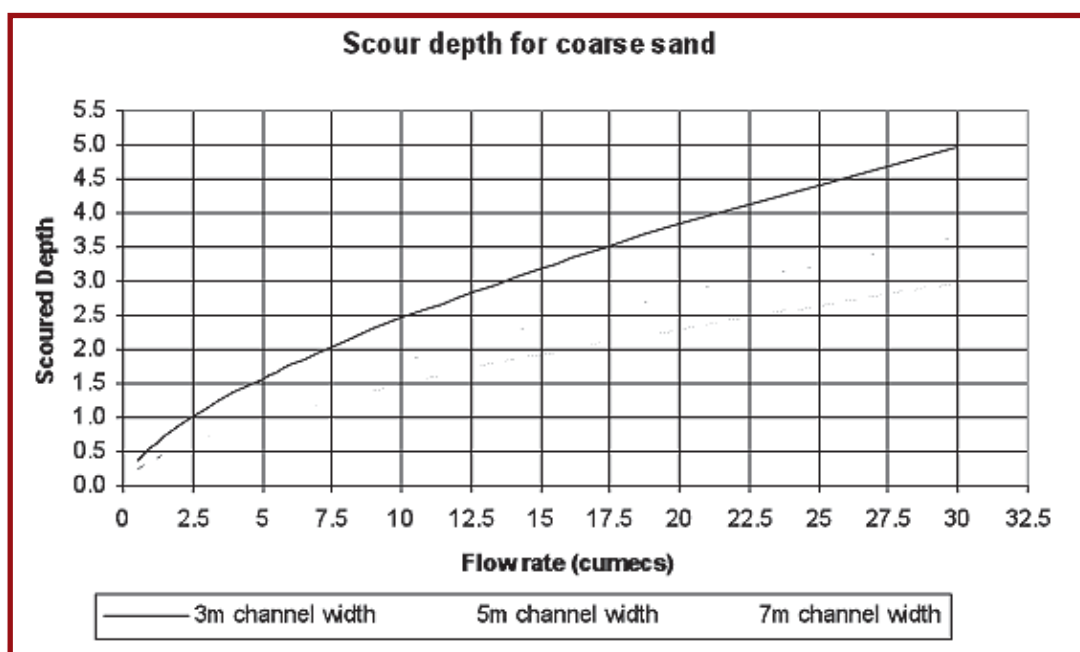
The three following graphs (Figures E.8.2, E.8.3 and E.8.4) allow the prediction of the water depth in the channel, which will allow the depth of scour to be calculated.



**Figure E.8.2: Scour – Fine silt**



**Figure E.8.3: Scour - Fine sand**



**Figure E.8.4: Scour - Coarse sand**

The depth of scour indicates the general level of erosion that will occur in the river bed. Additional local scour will occur near bridge abutments and wingwalls and also at the edges of aprons. Table E.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.



**Table E.8.4: Scour depth adjustment**

All foundations should be constructed below the predicted depth of scour.  
 Predicted maximum depth of scour = depth of general scour x local scour multiplier

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 E.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° away from the direction of water flow.

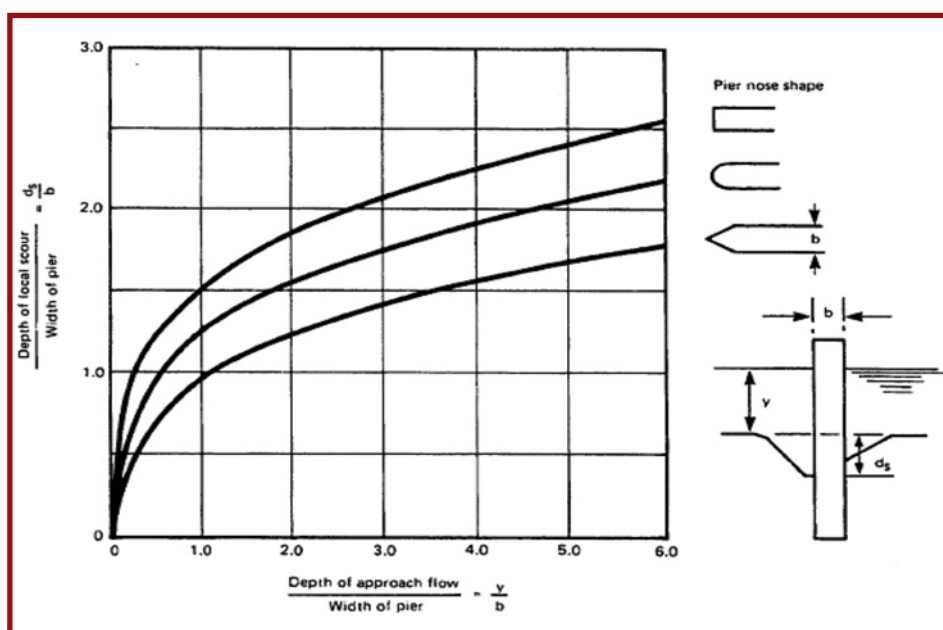
**Figure E.8.5: Depth of scour around piers (from TRL ORN9)**

Plate E.8.2 shows an example of the consequences of constricting a watercourse with a structure that is too small leading to excessive scour allied to inadequate protection of the abutments



***Plate E.8.2: Failure of structure due to a combination of constriction of the watercourse (structure too small), scour and inadequate protection of abutments.***

## 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 E.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 E.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 then will 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 (eg 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 10 cm of lean concrete blinding should be laid to provide a firm clean working platform.

A rough method for calculating the load exerted by the foundations of a vented ford or large bore culvert on the ground will be to calculate the load of the structural fill material and multiply by a safety factor shown in Table E.8.5.

**Table E.8.5: Bearing safety factor**

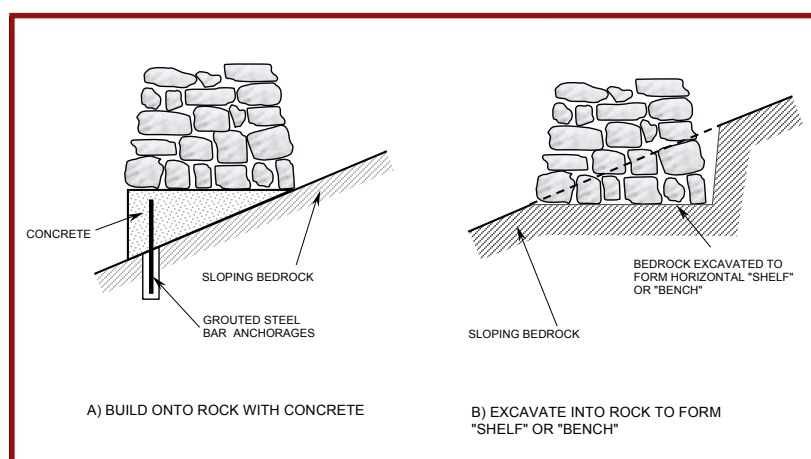
Material	Load per metre of fill	Safety factor
Concrete/gravel	25kN	1.5
Earth	20kN	1.5

For example:

The central section of a vented ford is 2m high (from its foundation level) and has masonry walls with an earth fill inside. What is the foundation loading?

The load exerted on the soil below the structure will be:  $2 \times 20 \times 1.5 = 60 \text{ kN/m}^2$

Where a foundation is to be built on rock which may be sloping down to the watercourse (see figure E.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, will be 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. The face may be cut in steps to increase bond between the structure and rock foundation.

**Figure E.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 river bed. 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 river bed. 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 river bed. 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 river bed. 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 of 10% 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 river banks 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 (see Plate E.8.3).



**Plate E.8.3: Guide stones at the edge of a 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. Drifts should be constructed with the central flat sections of the following length:

<b>River crossings</b>	<b>width of the watercourse</b>
<b>Relief and perennial stream drifts</b>	<b>width of the dry bed: minimum dimension of 2m</b>

#### **Drift slab construction**

There are four possible solutions for constructing the drift slab, in descending cost:

- 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 as 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 (Plate E.8.4) 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.



**Plate E.8.4: Concrete slab drift**

### 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 which 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 pitched stone

In areas where masonry stone is widely available this option is likely to be cheaper than constructing a concrete slab (see Plate E.8.5). 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, as this weakens the remaining structure. Larger stones are better than smaller ones as 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.





**Plate E.8.5: Hand pitched stone drift**

### 8.3.5

#### Gabions and gravel

This option 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 down stream side which acts as a dam to prevent the gravel being washed away (see Plate E.8.6). (note that the sand has been washed out on Plate E.8.6 but severe erosion has not occurred).



**Plate E.8.6: Gabion drift**

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 encourage vegetation growth for improved stabilisation (see Plate E.8.7).





**Plate E.8.7: Natural fibre matting inserted in the top and face of the gabion**

### 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 E.8.6.

**Table E.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 E.8.7.

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.

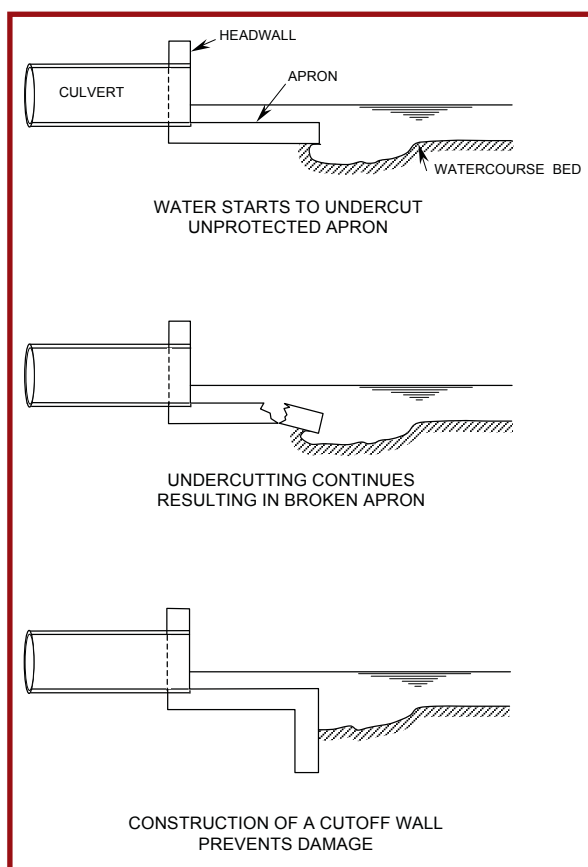


Figure E.8.7:

Cut-off wall

## 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. See also the section on setting out in Chapter E.9.

- **Type 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 outlet of the culvert will be below the existing ground level and will require an outfall ditch to be dug with a gradient of approximately 4%. 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 (see

below) 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.

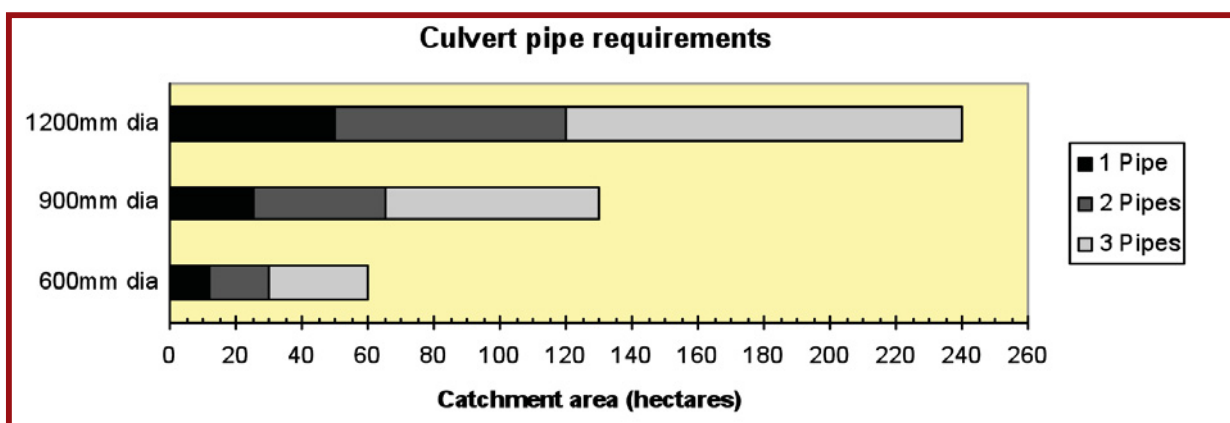
### 8.5.2

#### 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 E.8.8 following suggests the size and number of pipes that are required to give a suitable culvert capacity for the recommended storm return period. Figure E.8.8 is based on gentle/rolling ground with medium soil permeability.



**Figure E.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 E.8.9. 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 E.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, as the culvert size is determined by the requirements of minimum diameter for cleaning. Table E.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 E.8.7: Maximum flow rates**

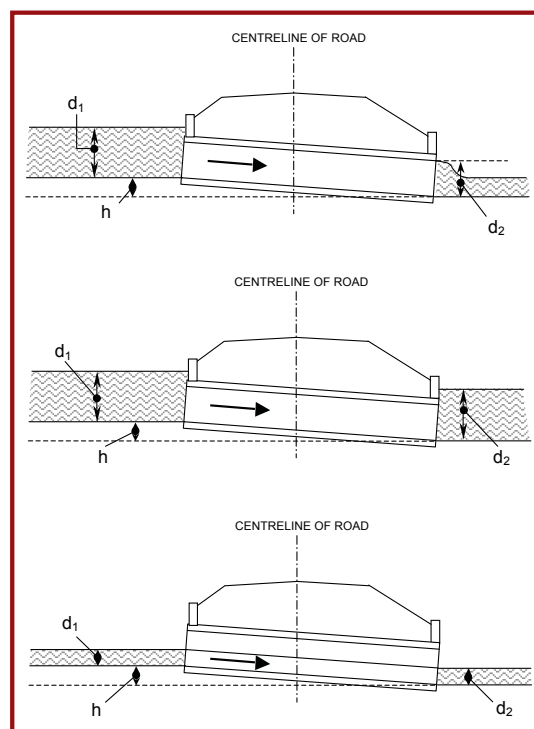
Maximum flow rates for 600mm diameter case 3 culverts	
Invert slope	Max flow rate
1%	20 l/s
2%	40 l/s
3%	50 l/s
4%	60 l/s
5%	70 l/s

- **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 down stream 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) as the water backed up downstream reduces the flow. This situation will exist in flat areas where the water in the culvert outfall flows slowly 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.

**Figure E.8.9: Pipe design cases****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 stream bed and is shown as  $d_1$  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 (see plates E.8.8 and E.8.9). Ponding will depend on the slope of the channel.



**Plate E.8.8: Ponding at culvert outfall**



**Plate E.8.9: Ponding in outfall channel**

**Step 6: Driving head**

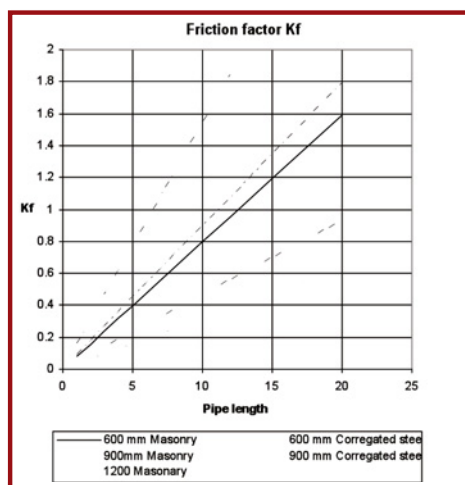
The driving head is the potential energy which causes the water to flow through the pipe.

<p><b>Driving head = H</b></p> <p><b><math>H = d1 + h - d2</math></b></p>	<p>where</p> <p>H is the driving head</p> <p>d1 is the upstream water depth</p> <p>d2 is the downstream water depth</p> <p>h is the drop in culvert invert level</p> <p>as shown in the previous design cases above</p>
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It is the difference between the water levels each side of the culvert.

**Step 7: Friction factor**

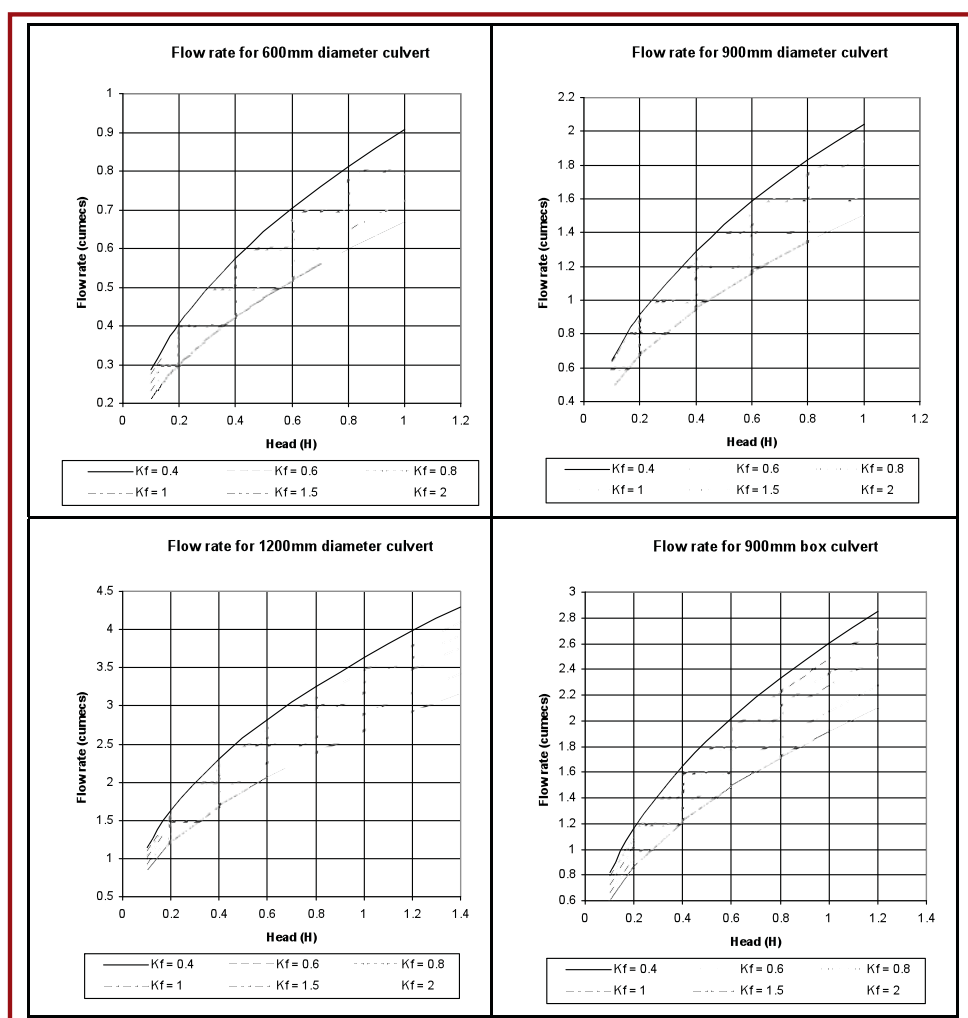
The length and roughness of the pipe will affect the flow rate. The friction factor determined from the graph (in Figure E.8.10) is an indication of the resistance to flow due to the pipe's characteristics and is required to calculate the maximum flow in the pipe.



**Figure E.8.10: Friction factor**

**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 E.8.11.

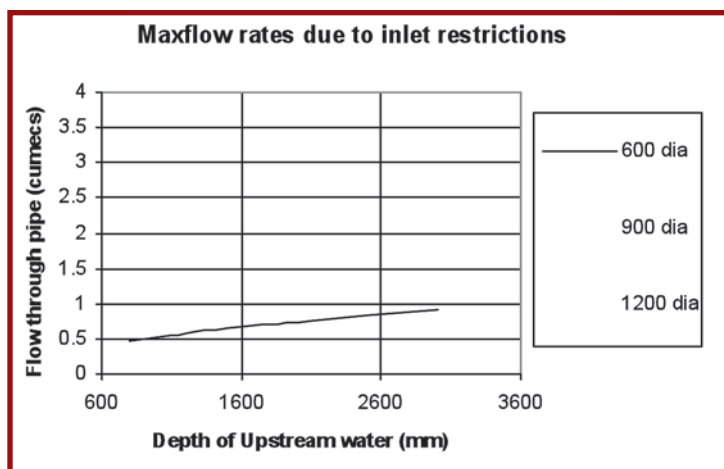


**Figure E.8.11: Flow Rate**



**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 E.8.12 and compare it with the flow rate obtained from step 8.



**Figure E.8.12: Restriction**

**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.

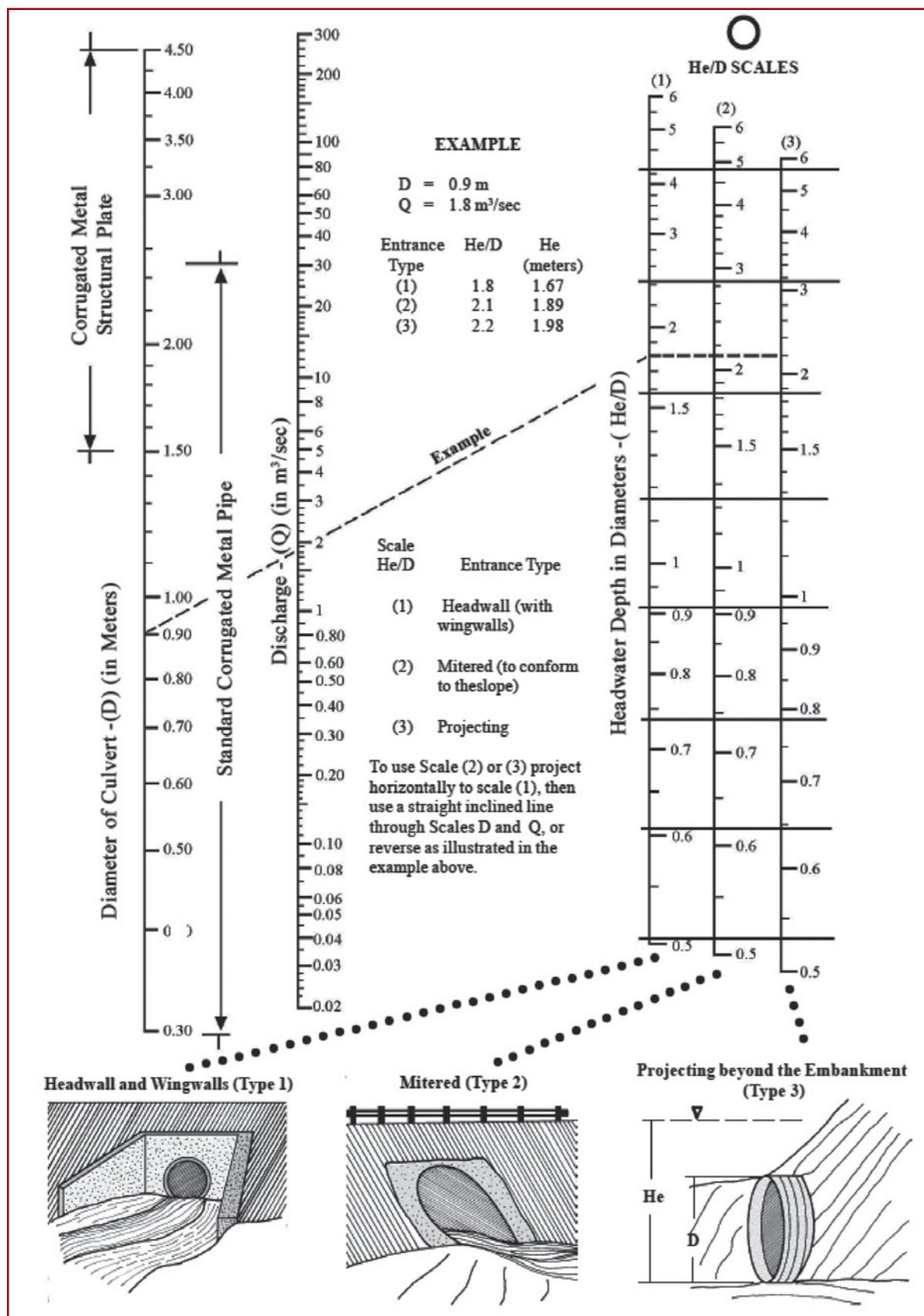
Where the maximum flow rate is larger than the predicted flow rate, the culvert design is acceptable. The next design stages for the culvert should be carried out; selecting appropriate inlet and outlet arrangements and confirming the type of pipe based on the assumptions made in the design steps.

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 flood water 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:

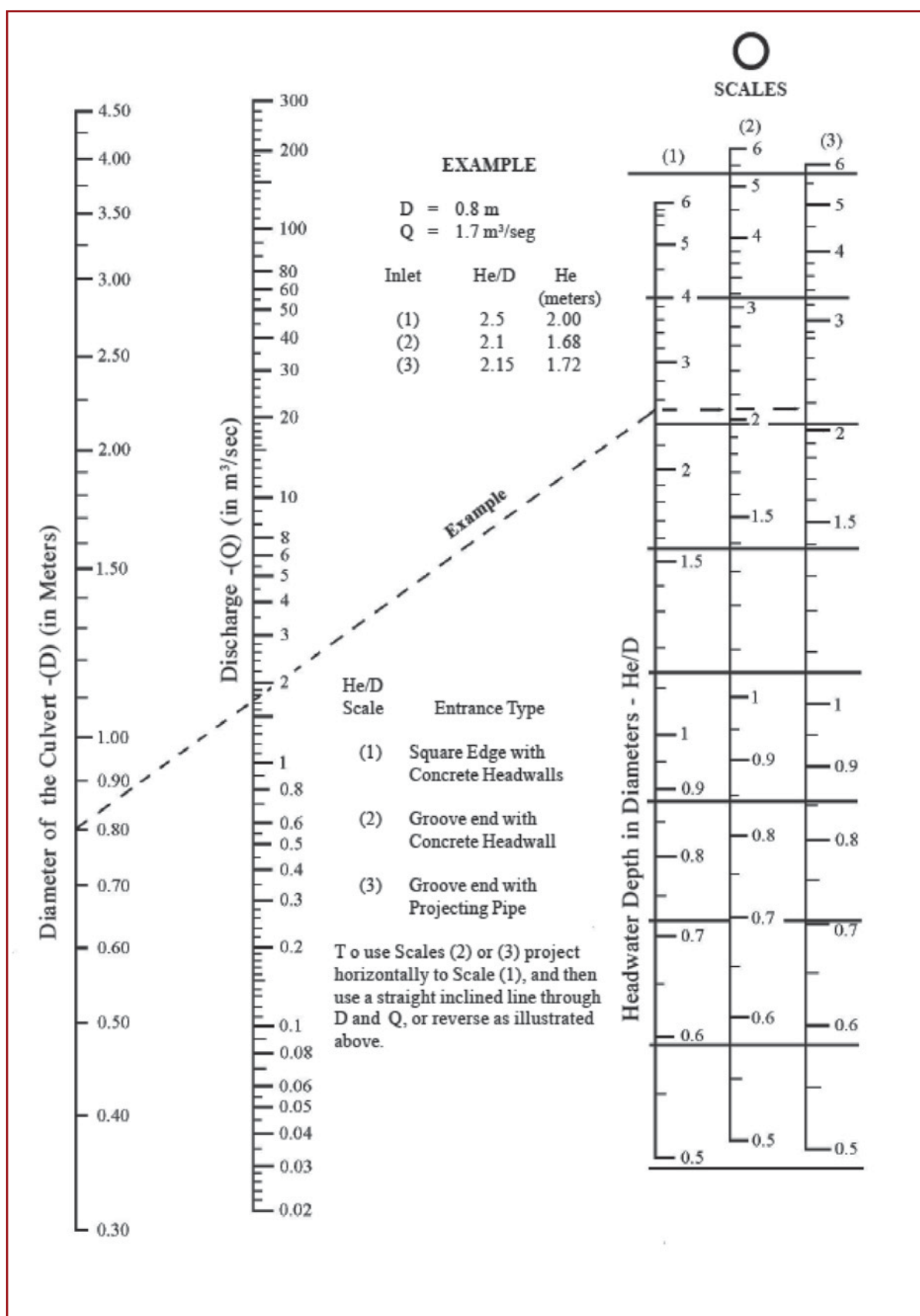
- Adding another pipe of the same diameter;
- Increasing the size of the pipe.

**Nomogram Method**

Pipe size, as a function of anticipated design flow (capacity) and headwater depth, can be determined using the Nomograms shown in E.8.13, E.8.14 and E.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 minimize the likelihood of the pipe plugging from floating debris.

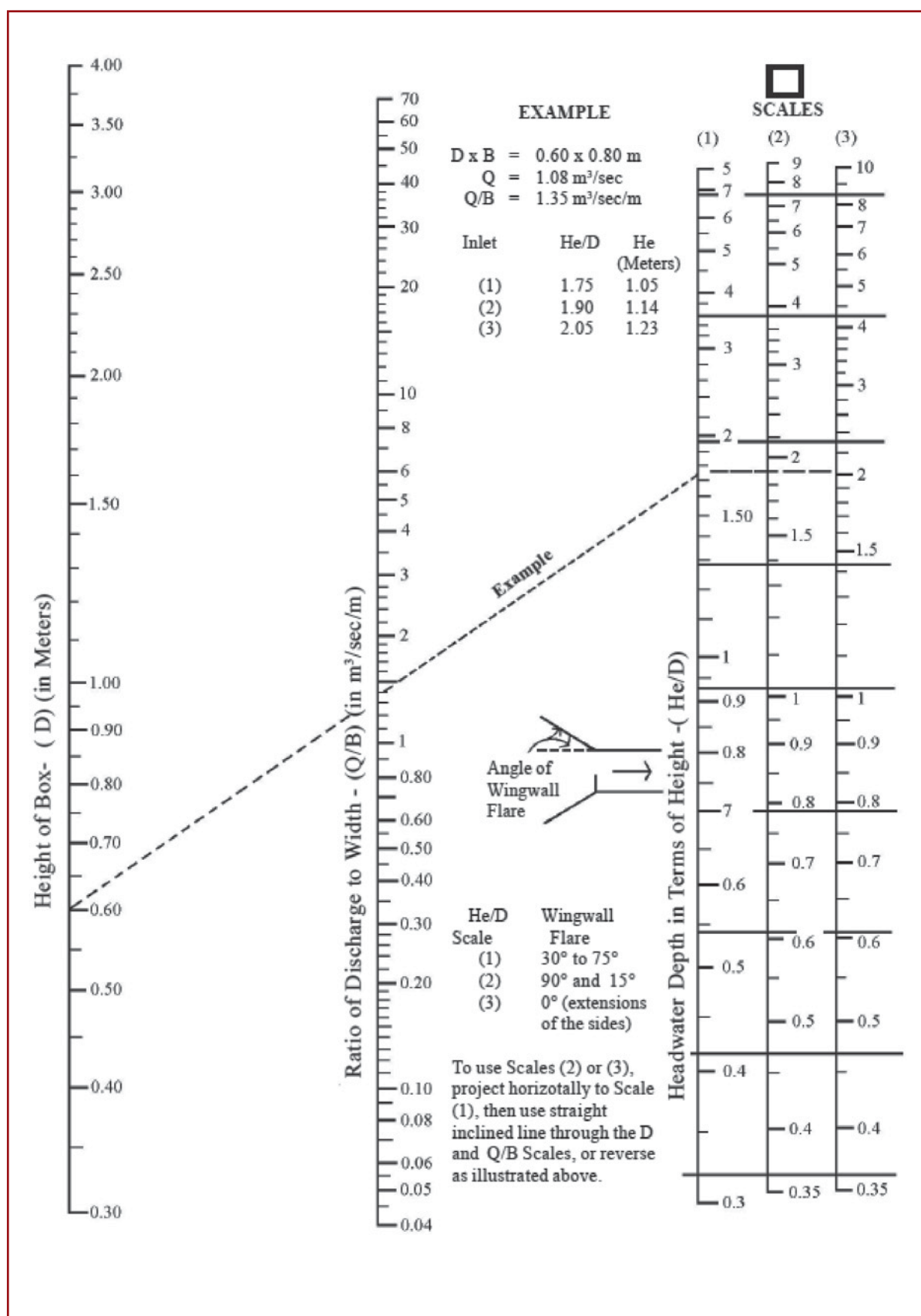


**Figure E.8.13: Headwater depth and capacity for corrugated metal pipe culverts with inlet control. (Adapted from FHWA, 1998)**



**Figure E.8.14: Headwater depth and capacity for concrete pipe culverts with inlet control. (Adapted from FHWA, 1998)**





**Figure E.8.15: Headwater depth and capacity for concrete box culverts with inlet control. (Adapted from FHWA, 1998)**

### Simplified Formulae Method

The use of formulas (Table E8.8) is preferred by some designers to the use of the Nomograms shown previous. The formulas are based on the following assumptions:

- Inlet Control
- Wingwall Angle =  $45^\circ$
- Vertical Headwall

**Table E.8.8: Simplified Formulae for Calculation of Discharge Capacity**

Type	Discharge Capacity Q (m <sup>3</sup> /s) (with inlet control)		
	H <sub>w</sub> /D=1.00	H <sub>w</sub> /D=1.25	H <sub>w</sub> /D=1.50
Concrete Pipe	$1.3 \times D^{2.5}$	$1.9 \times D^{2.5}$	$2.2 \times D^{2.5}$
Corrugated Metal Pipe	$1.1 \times D^{2.5}$	$1.6 \times D^{2.5}$	$1.8 \times D^{2.5}$
Arch Culvert (semi-circular)	$2.3 \times H^{2.5}$	$3.4 \times H^{2.5}$	$4.0 \times H^{2.5}$
Box Culvert	$1.5 \times B \times H^{1.5}$	$2.1 \times B \times H^{1.5}$	$2.5 \times B \times H^{1.5}$
D :diameter of a pipe culvert (m)		B :width of a box culvert (m)	
H <sub>w</sub> :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).

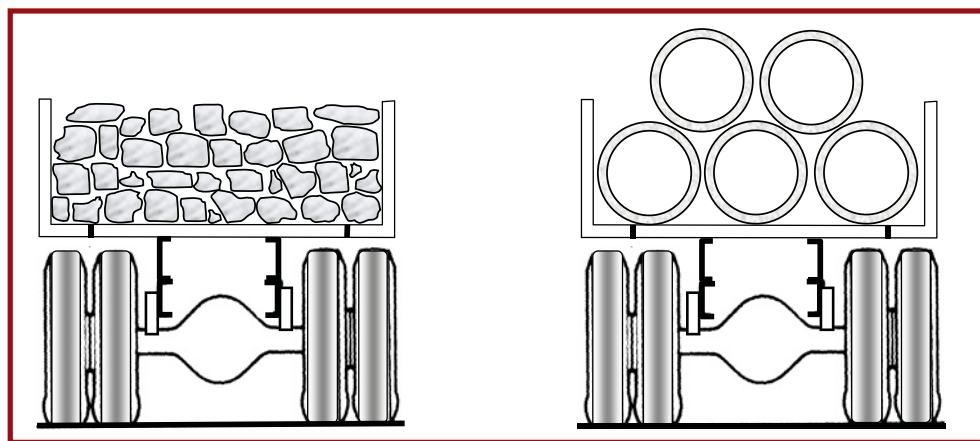
### 8.5.3

#### Pipe options

There are many different options available to the designer for constructing culvert pipes. The pipes can be either precast or constructed in situ, circular or square openings, reinforced or unreinforced and built from a variety of materials. In deciding which type of culvert to construct the designer has to assess the advantages and disadvantages of each construction option. Careful consideration must be given to the skills and resources available, the cost of each option, the prevailing site conditions for the region and the advantages of choosing a few standard designs for the majority of the culverts to be constructed.

#### 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 E.8.16) in bringing the pipes to site and the careful transportation and handling required to ensure the pipes are not damaged. 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.



**Figure E.8.16: Transportation issues**

### **In situ construction**

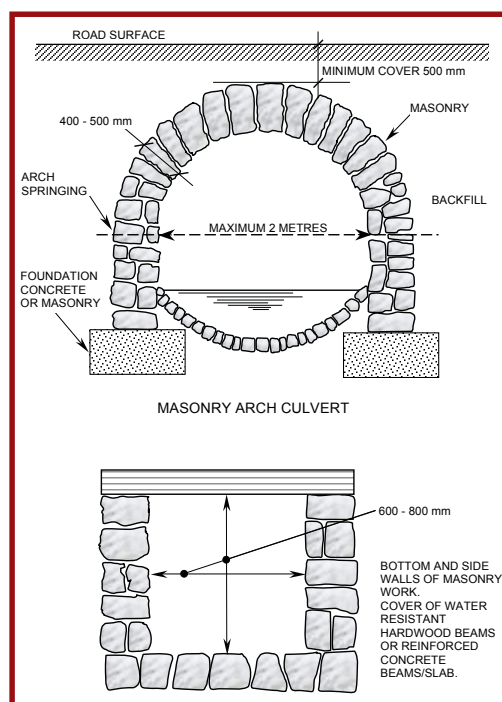
Pipes constructed in situ can be made from a variety of materials. Careful supervision will be required on site to ensure that the pipes are manufactured to sufficient quality, but the transportation costs may be reduced when compared with precast pipes if their transport distances are substantial (Figure E.8.16).

#### ■ **Masonry culverts (arch and box)**

Masonry culverts are generally constructed as box culverts for small sizes and arch culverts for larger sizes (Figure E.8.17). There are three stages to constructing a wall and slab box culvert:

- Excavation & 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 E.8.9.



**Figure E.8.17: Masonry Culverts**



**Table E.8.9: Masonry culverts**

Advantages	Disadvantages
<ul style="list-style-type: none"> <li>▪ The use of locally available material reduces the cost of construction</li> <li>▪ Simplicity of construction</li> <li>▪ Low level of maintenance required</li> <li>▪ Range of options available for the top slab on box culverts</li> </ul>	<ul style="list-style-type: none"> <li>▪ Arched culverts require dressed stone bricks, blocks or mortared jointing</li> </ul>

- **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 shown in Plate E.8.10 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 as 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 E.8.10.

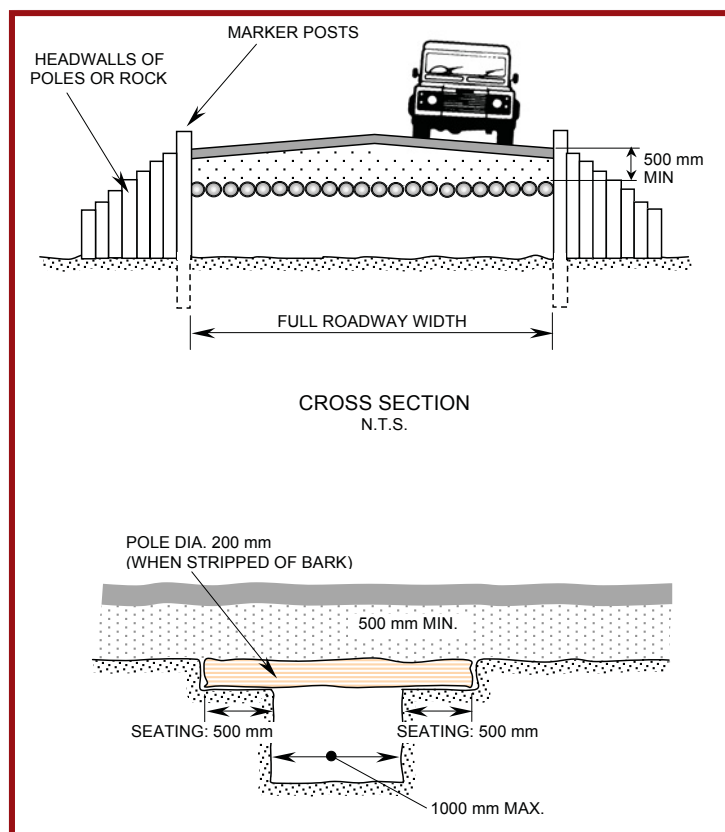
**Plate E.8.10: Timber barrel culvert****Table E.8.10: Timber barrel culverts**

Advantages	Disadvantages
<ul style="list-style-type: none"> <li>▪ Can provide cheap culvert if timber widely available</li> <li>▪ Culverts can be assembled at site allowing larger numbers to be transported on a lorry</li> <li>▪ Design life is over 25 years with treated wood</li> <li>▪ They are light and easy to handle</li> <li>▪ Culverts can withstand small ground movements and settlement without losing their structural integrity</li> <li>▪ Short working life if wood is badly treated</li> </ul>	<ul style="list-style-type: none"> <li>▪ Professional wood treatment facilities required</li> </ul>

### Option 2: Timber log culverts

A simple and quick method for constructing small relief culverts can be to use timber logs (see Figure E.8.18 and Plate E.8.11). These culverts will usually be unlined, bare earth and will only accommodate slow flows (up to 1 m/s). Figure E.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.

Advantages and disadvantages of timber log culverts are shown in Table E.8.11.



**Figure E.8.18: Timber log culvert details**



**Plate E.8.11: Timber pole culvert during reconstruction**

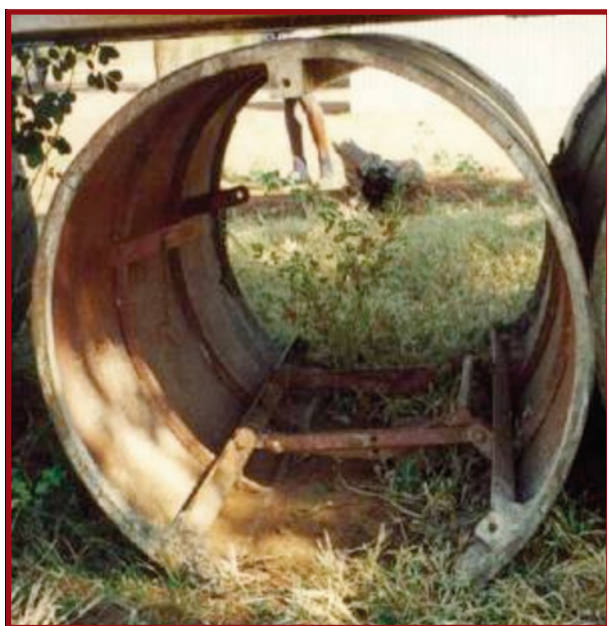


**Table E.8.11: Timber log culverts**

Advantages	Disadvantages
<ul style="list-style-type: none"> <li>Very quick and cheap to construct</li> <li>Minimal skills required for construction</li> </ul>	<ul style="list-style-type: none"> <li>Very short life, especially if timber is untreated</li> <li>Unlined ditch very susceptible to scour during heavy rains</li> </ul>

■ **Cast in-situ concrete culverts**

These culverts use a timber or steel mould (Plate E.8.12) 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. An example of a cast in-situ culvert is shown in Plate E.8.13 and the advantages and disadvantages of this type of culvert are given in Table E.8.12.



**Plate E.8.12: Reusable steel mould  
for cast in-situ culvert**



**Plate E.8.13: Cast in-situ culvert**

**Table E.8.12: Cast in-situ concrete culverts**

Advantages	Disadvantages
<ul style="list-style-type: none"> <li>Low cost as mould can be reused many times</li> <li>Quick construction methods</li> <li>Low cement requirements due to use of rubble concrete</li> </ul>	<ul style="list-style-type: none"> <li>Poor life expectancy if rubble concrete is not well placed or compacted</li> </ul>



- **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 good quality control conditions 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. Examples of the steel casting mould and the finished product are shown in Plates E.8.14 and E.8.15. The advantages and disadvantages are shown in Table E.8.13



Plate E.8.14: Steel mould



Plate E.8.15: Precast concrete culvert ring

Table E.8.13: Precast unreinforced concrete culverts

Advantages	Disadvantages
<ul style="list-style-type: none"><li>▪ The quality of the pipe can be ensured</li><li>▪ Do not require steel reinforcement</li><li>▪ Very good performance when bedding and backfilling has been carried out well</li><li>▪ Pipes up to 900mm dia. can be manhandled by labour alone</li><li>▪ Economic where a large number of identical pipes are required</li></ul>	<ul style="list-style-type: none"><li>▪ High cost for small batches</li><li>▪ Careful transportation required to ensure they are not damaged or broken</li><li>▪ Not suitable if site access route is in bad condition</li><li>▪ High transport costs due to their shape</li><li>▪ Diameters greater than 900mm dia. can not be made due to strength and handling problems</li><li>▪ Pipe lengths are restricted to 1m to ensure that they can be handled by labour alone</li></ul>

### ■ Steel culverts

Steel culverts will usually be constructed from pre-bent corrugated sheets (Plate E.8.16) 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 E.8.14.



**Plate E.8.16: Steel culvert**

**Table E.8.14: Steel culverts**

Advantages	Disadvantages
<ul style="list-style-type: none"> <li>■ The steel culverts can withstand small ground movements</li> <li>■ Light sections easy to handle and install</li> <li>■ The components for a number of culverts can be transported on one truck</li> </ul>	<ul style="list-style-type: none"> <li>■ Requires the transport and possible import of expensive steel sheets</li> <li>■ Secure storage of the sheets required to prevent theft</li> </ul>

## 8.5.4

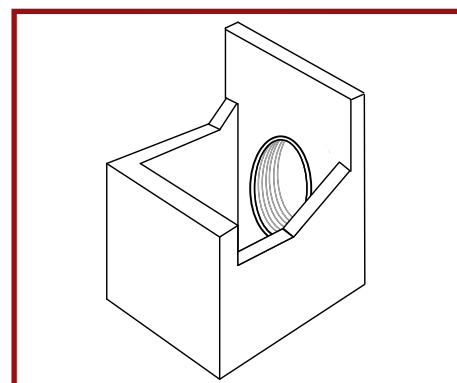
### Pipe inlets

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

The invert of a pipe should be placed on a 2-5% slope to ensure that the flow is not too great to cause extensive scour but fast enough to prevent debris and silt from being deposited in the culvert. If the culvert is located on steeply sloping ground 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 proposed. The drop inlet reduces the energy of the water leaving the culvert, preventing extensive scour. Drop inlets can also be used for relief culverts on long downhill lengths of side drain (see Figure E.8.19)



**Figure E.8.19:  
Drop inlet on relief culvert**



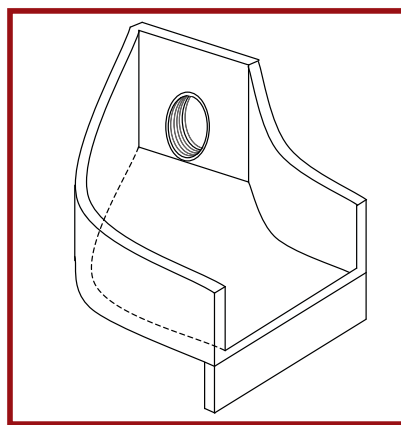
### Pipes transferring large water volumes

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 under 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. Plate E.8.17 and Figure E.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 box culvert option as this will cause less restriction and turbulence.



**Plate E.8.17: Drop inlet on stream culvert**



**Figure E.8.20: L-shaped inlet**



**Plate E.8.18: Skew culvert crossing with splay wingwall to prevent water continuing in side drain**

## 8.5.5

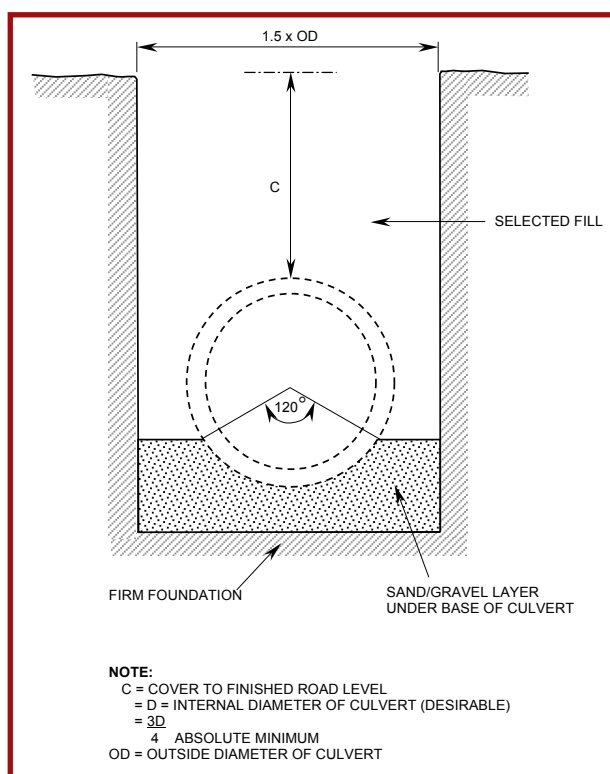
### Pipe bedding and cover arrangements

Culverts pipes should be constructed on a firm foundation to ensure that they will not settle and crack. 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.



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. If the preferred design option is a masonry culvert the foundation for the walls can be extended to form the base of the culvert (see Figure E.8.21).

Backfilling around the culvert is one of the most important stages in the construction. 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.



**Figure E.8.21: Pipe granular bedding and cover**



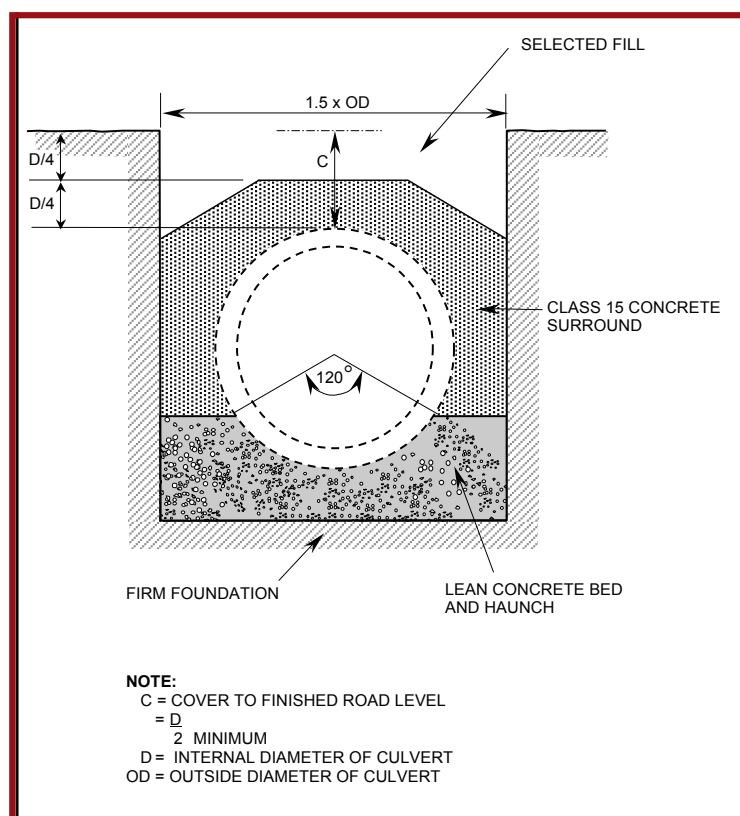
**Plate E.8.19: Poor quality jointing and bedding support for pipe culvert**

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 E.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 E.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 centre line 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 E.8.15 should be used to reduce the flow rates through the pipes derived previously in this chapter.

**Table E.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.

Box Culverts - The design of box culvert options is not covered by this Manual. Refer to the ERA Bridge Design Manual - 2011 and publications such as TRL Overseas Road Note 9.

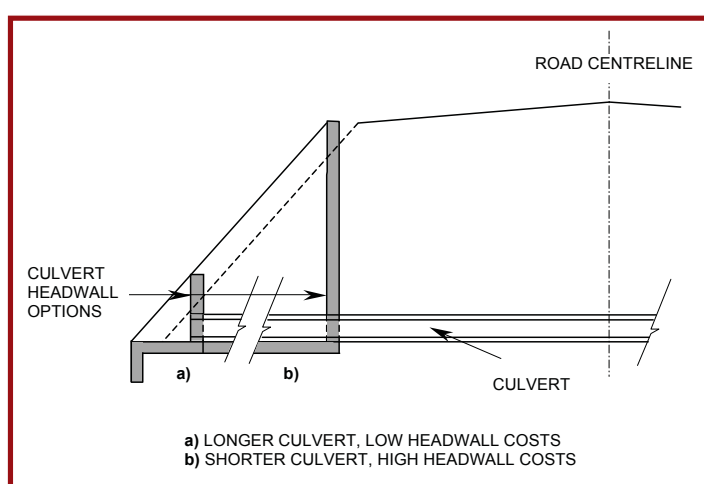
## 8.6 Headwalls and Wingwalls

### 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.

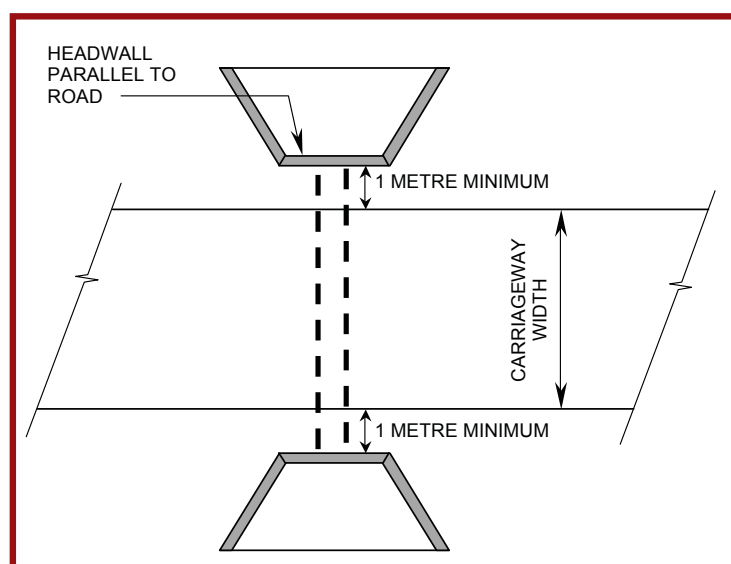
The headwall can be positioned at different places in the road verge or embankment as shown in Figure E.8.20.

**Figure E.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 structure cost 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 E.8.24).



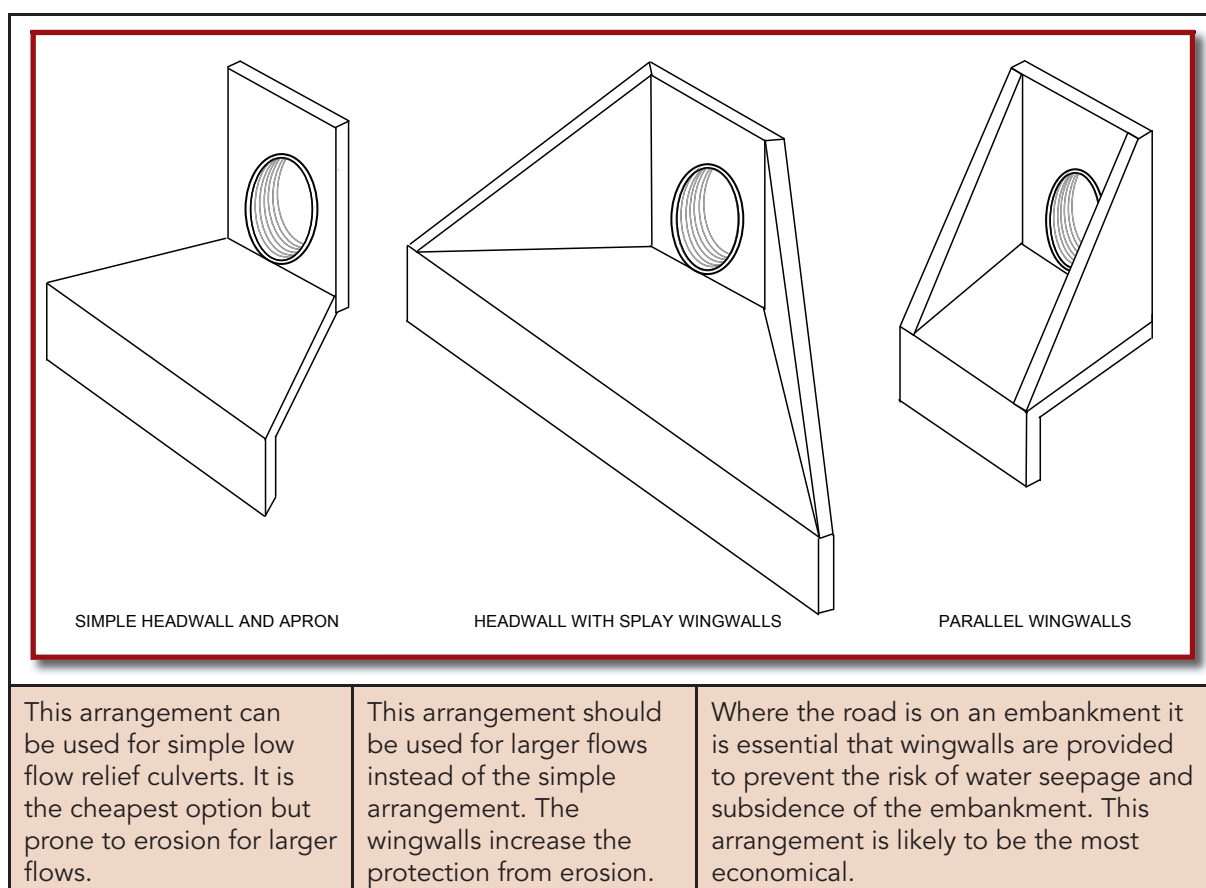
**Figure E.8.24: Position of culvert headwalls**

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 E.8.25.

**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 E.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).

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. Refer to chapter 10 on maintenance.



**Figure E.8.25: Headwall and wingwall arrangements**

## 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 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 E.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 (Plate E.8.20). The two main factors affecting the overall design of a wingwall are the construction material and the bearing capacity of the soil.

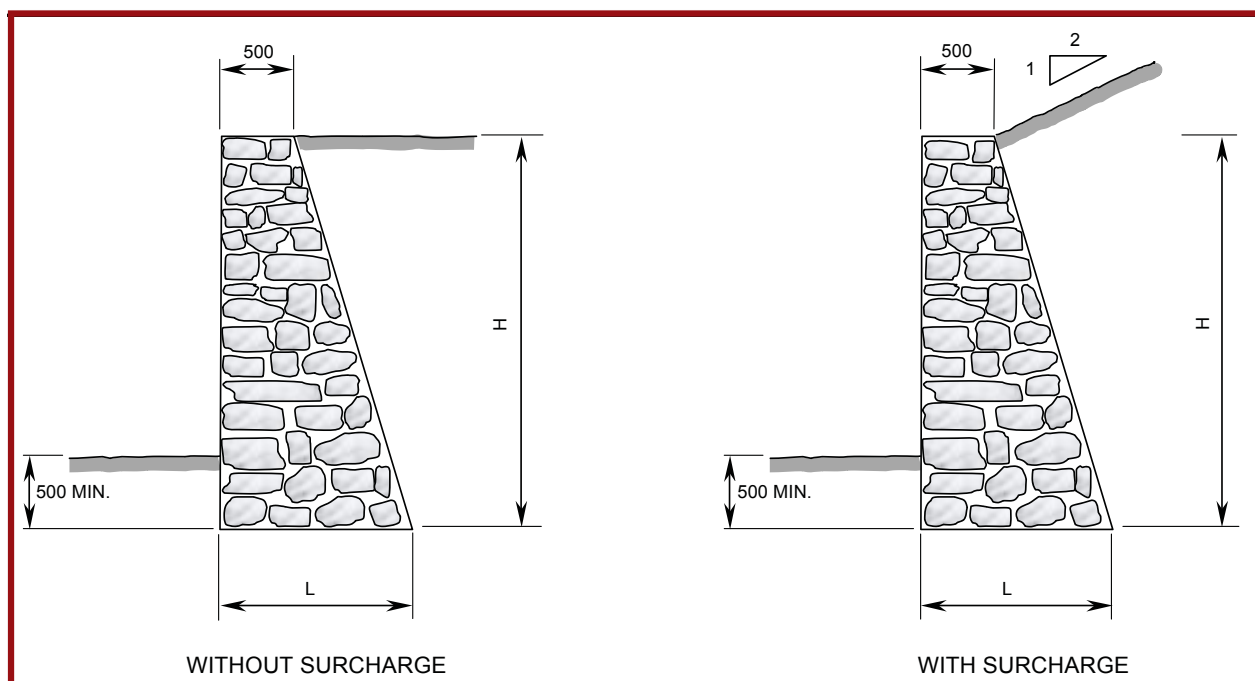


**Plate E.8.20: Wingwall cascade**

### **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 E.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 given in Chapter E.7.





**Figure E.8.26: Stone, brick or blockwork wall with and without sloping backfill (surcharge)**

Tables E.8.17 and E.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 E.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 E.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		improvement	2550

**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)

**8.6.4****Gabion baskets**

Gabion baskets may be used in areas where stones are available (Figure E.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.

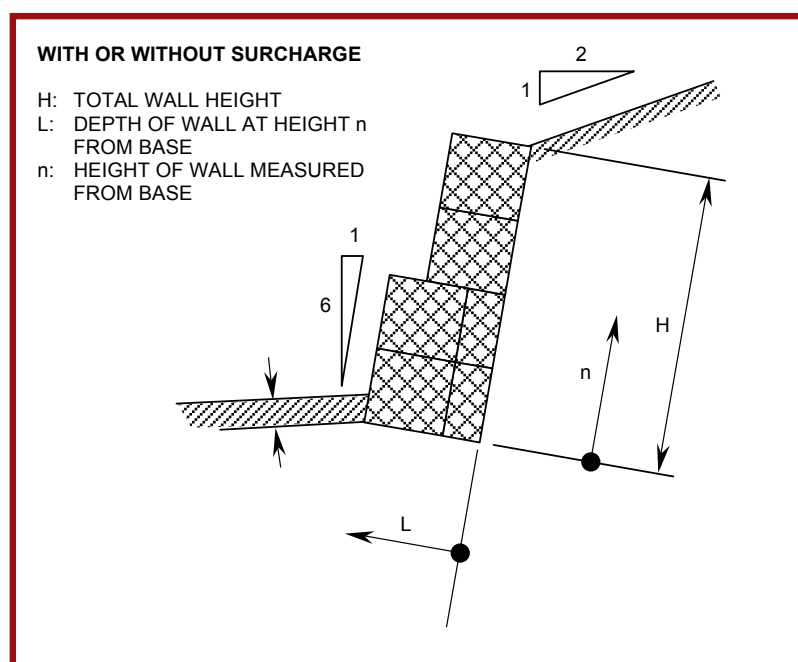
**Figure E.8.27: Gabion baskets for walls**

Table E.8.19 assumes that the gabion baskets have been filled according to the criteria outlined in Chapter E.7 and have a height and width of 1 metre.

**Table E.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								
		n (m)-								
		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 E.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 stream bed.

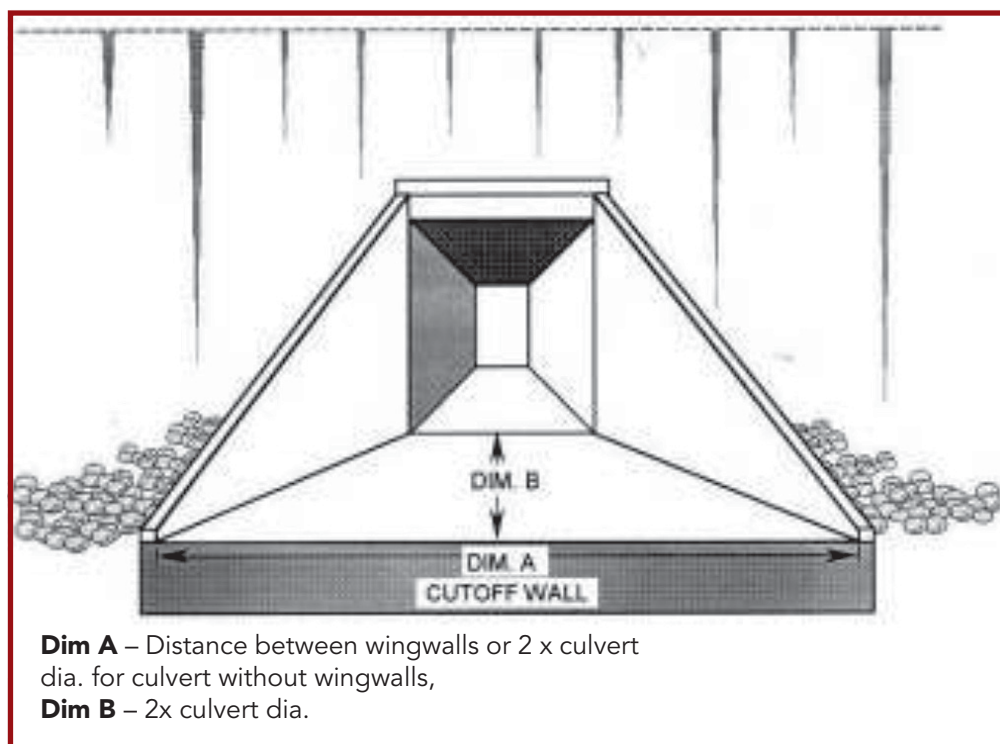
### 8.7.1 Drift aprons

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 down stream of the drift. For discharge velocities greater than 1.2m/s more substantial protection will be required which utilises 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 E.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.





**Figure E.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

The approaches to vented drifts, large bore culverts and bridges must allow vehicles to cross the structure without losing traction or getting stuck on the crossing. Ideally crossings should not have approaches steeper than 10%. 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 E.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).

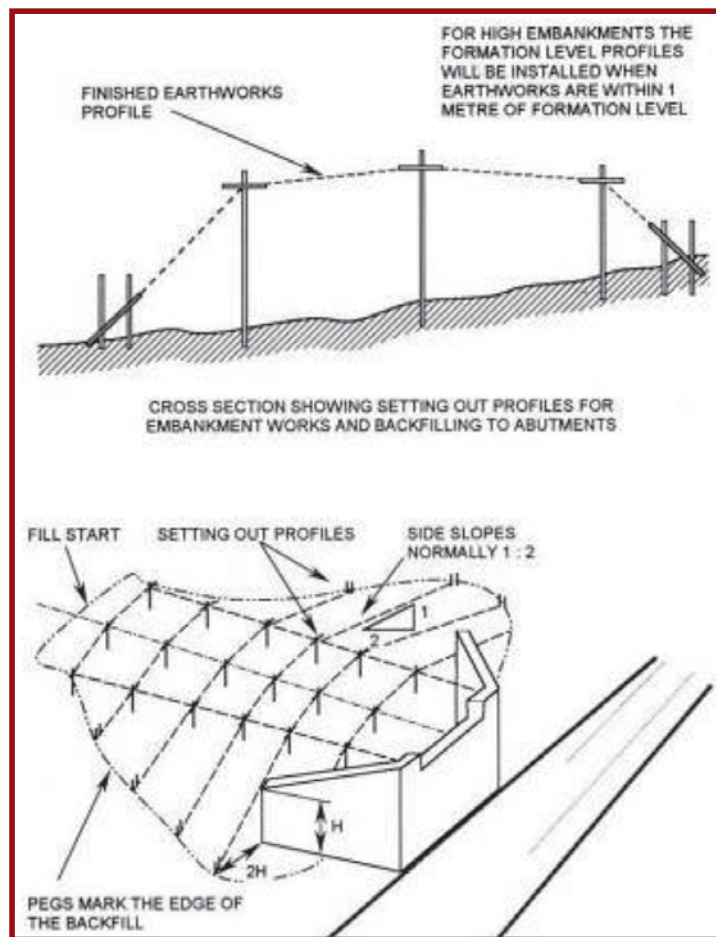
The design of these walls will be similar to the design of wingwalls described in Section E.8.6. The fill material in the approach way should be chosen from one of the three options shown in table E.8.20.

**Table E.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.

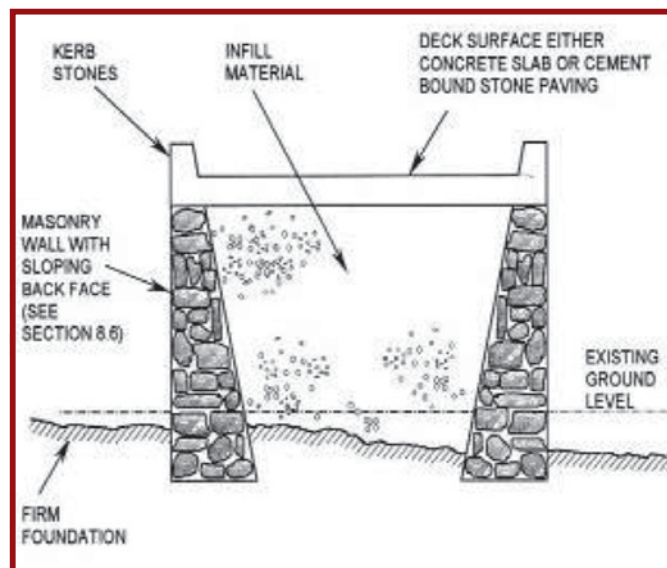
The running surface of the approach way should be designed as a structural slab of either concrete or cement bonded stone paving. The slab should also have a 2-3% crossfall in the direction of water flow to ensure that the deck drains quickly after rainfall.

Approach ways will be susceptible to scour from water flowing from the carriageway side drains into the water course 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 should be constructed see Figure E.8.29 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 E.8.29: Construction of approach ways**

Figure E.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. Plate E.8.21 shows a masonry side drains at the edge of an approach way to prevent erosion.



**Figure E.8.30: Approach way cross section**





**Plate E.8.21: Masonry side drains at the edge of an approach way**

## 8.9

### Downstream Protection

A previous section 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.

Plate E.8.22 shows a gully that has been formed due to water eroding soft material downstream of a culvert as the watercourse was unprotected. 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. Other examples of erosion through lack of protection are shown in Plates E.8.23 to E.8.26



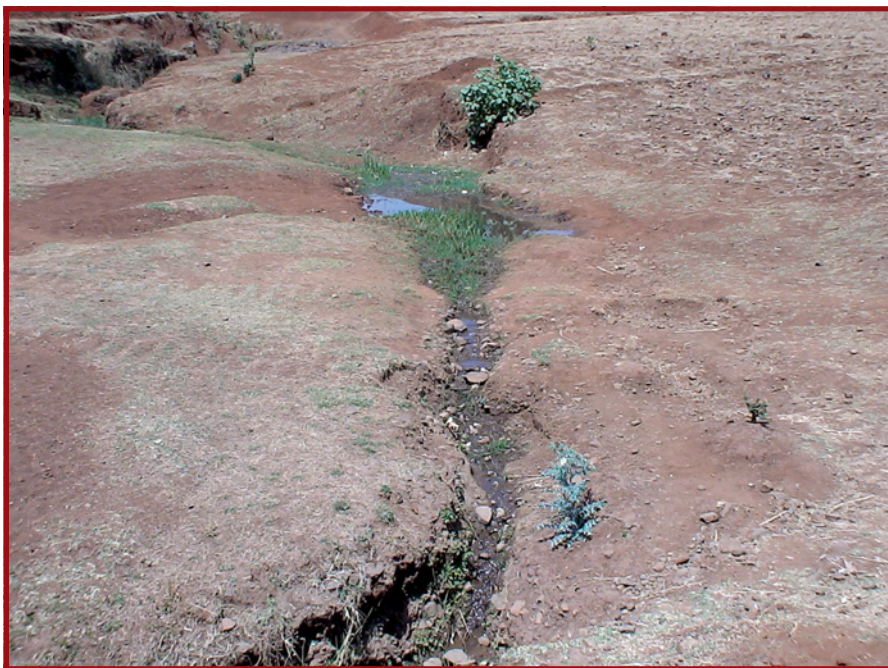
**Plate E.8.22: Example of damage due to lack of downstream protection**

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, which will be based on 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 E.8.21.





***Plate E.8.23: Minor erosion in watercourse upstream from culvert***



***Plate E.8.24: Serious erosion downstream from the same culvert due to concentration of flow and lack of appropriate protection measures***





***Plate E.8.25: Severe erosion downstream of a relief culvert due to inadequate protection measures***



***Plate E.8.26: Severe erosion downstream of a cross culvert due to inadequate protection measures***



**Table E.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

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.

### 8.9.1

#### Rip-rap

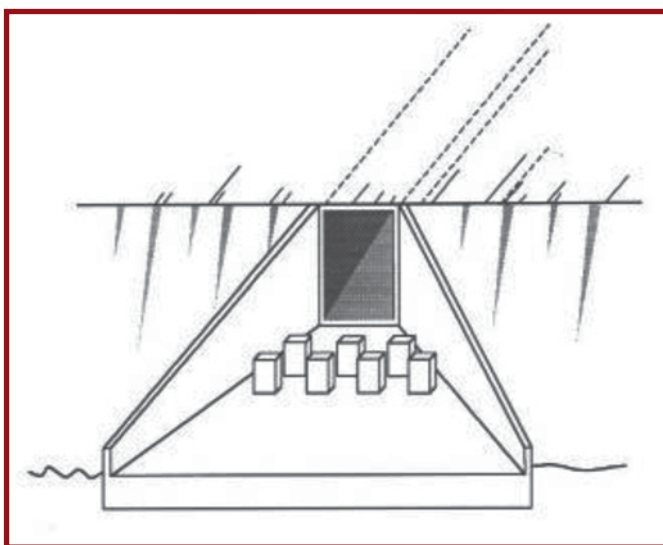
Rip-rap is the name given to stones placed in the river bed to resist erosion. In order to be effective the stones used should be large or heavy enough that they will not be washed away during floods. Although rip-rap may appear to consist of random rocks it should be well graded and placed as tightly 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 the watercourse which have a gradient steeper than 1:4. Flat slab stones should also be avoided as they can be easily dislodged by the water flow. Table E.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 E.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	100	0 %	0.5
	0.30	35	50 %	
	0.15	3	90 %	
2.5 - 3	0.55	250	0 %	0.75
	0.40	100	50 %	
	0.20	10	90 %	
3 - 4	0.90	500	0 %	1.0
	0.70	250	50 %	
	0.40	35	90 %	

**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 as 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 E.8.31). As the water velocity will be high it will be necessary to use mortar in the slab as hand pitched stones are likely to be washed out. It will not be necessary to make the slab smooth as a rough slab will help to reduce the energy in the water. Large stones may be fixed in the slab which project above the standard level 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.

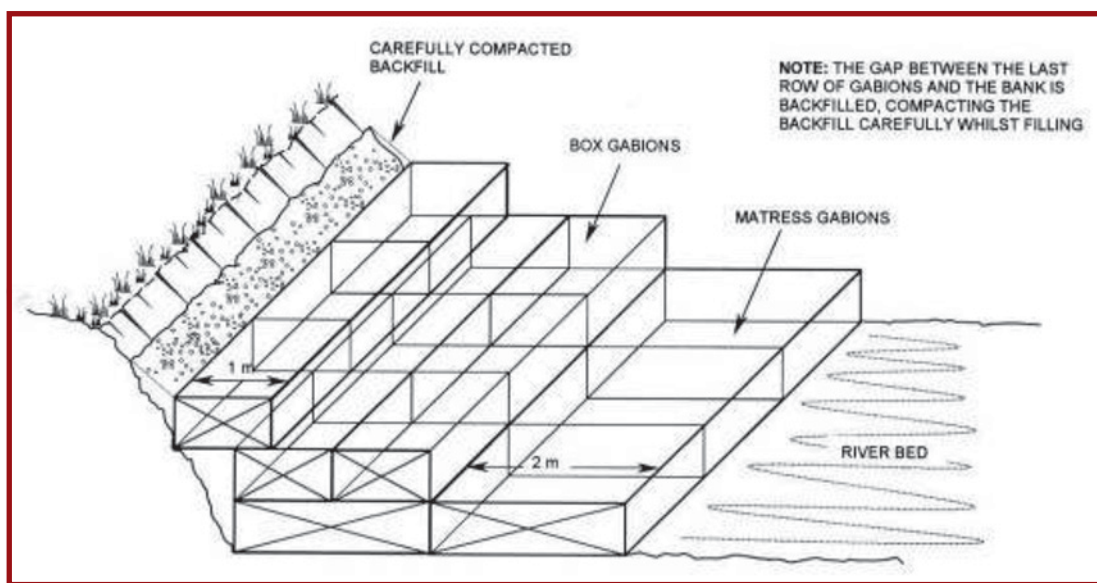
**Figure E.8.31: Energy dissipating apron**

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**

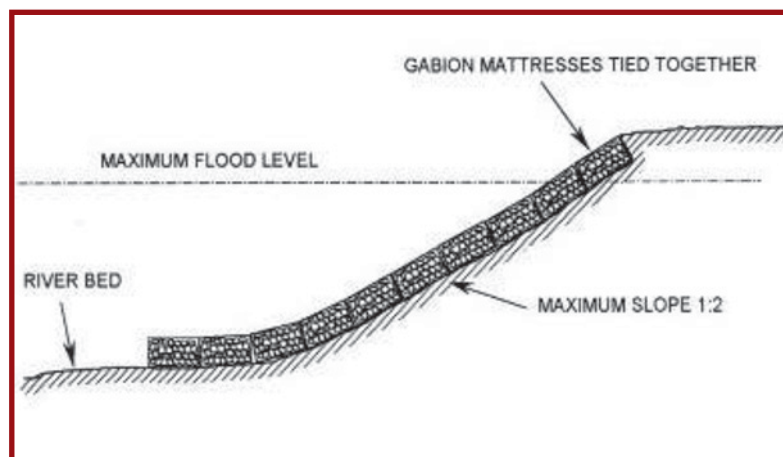
Gabions can be used to protect the bottom or banks of a watercourse (see Figure E.8.31). As the stones are confined by the wire cages much smaller stones than those used for rip-rap can be put in the cages. The disadvantage of gabions is that they have the additional cost of the wire for the cages when 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 river bed. 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 E.8.32 shows two methods for using gabions and mattresses for protecting the watercourse.



**Figure E.8.32: Gabion protection on steep banks**

Figure E.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 E.8.33: Gabion protection on shallow banks**

Any mattresses in the bottom of the water course should be 200-300mm thick for water velocities up to 3m/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. Plate E.8.27 shows an example of gabions being used for erosion control downstream of a culvert in a seasonal watercourse.



**Plate E.8.27: Gabion erosion control structure downstream of a culvert**

#### 8.9.4

#### Vegetation

Vegetation is likely to be the best option for small watercourses as 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, as 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 road side if it will not be damaged by vehicles or cattle. 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 river bed 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

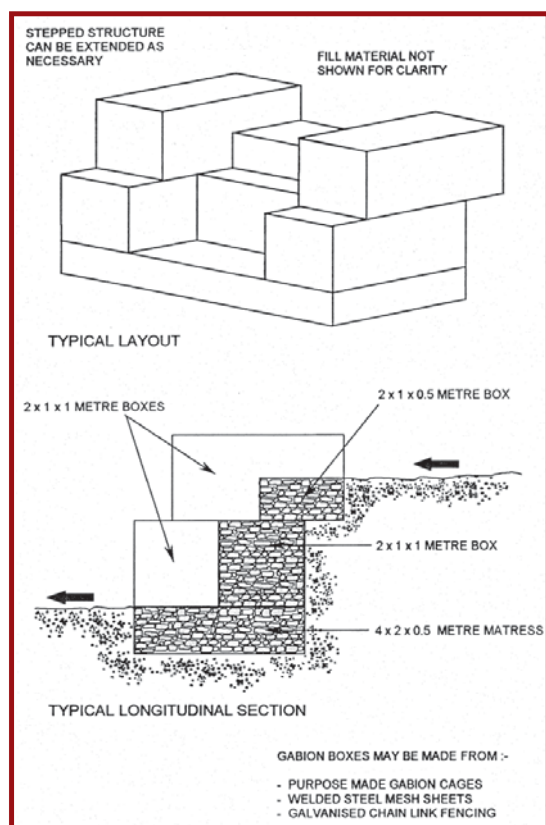
stone pitching. In channels with a permanent water flow the grass should only be planted towards the sides of the channel, as it will be unable to grow under water in the centre of the channel.

In Ethiopia, Wereda Agriculture Offices have adopted a wide scale use of bio-engineering to stabilise slopes and prevent erosion. In these countries nurseries have been set up in each region to cultivate and grow special grasses that are particularly good at resisting erosion. These nurseries are usually managed by Wereda Agriculture Offices and in some areas by NGO's and supply grasses and other plants to work sites in the area. Vetiver grass is the most commonly used as 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 E.8.34 and Plate E8.28).

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 E.8.34: Gabion basket step waterfall**



**Plate E.8.28: Gabion basket step waterfall**



## 8.9.6

**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 D.5 of the Manual.

## 8.10

**Arches**

It is often difficult to define the difference between large bore culverts and arch bridges (Plate E.8.29). 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.



**Plate E.8.29: Masonry Arch**

An example of a semi-circular arch bridge is shown in Plate E.8.30

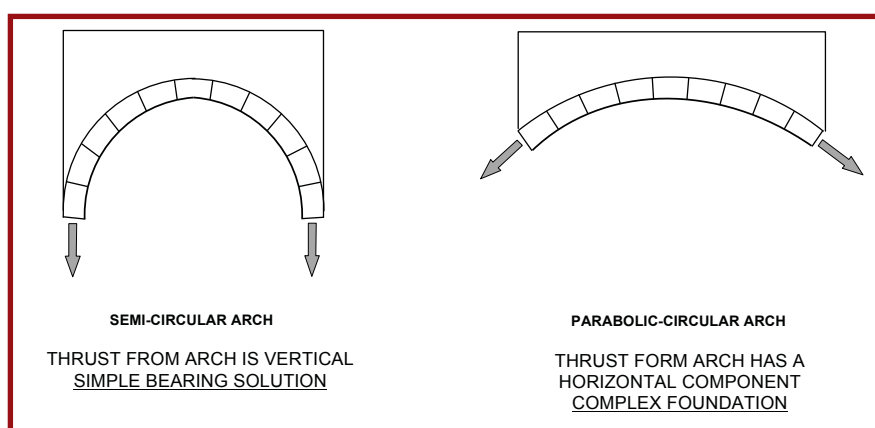


**Plate E.8.30: Semi-circular Arch bridge**



### 8.10.1 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 semicircular 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 semicircular 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 E.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 a good bearing capacity.



**Figure E.8.35: Arch forces**

### 8.10.2 Formwork reuse

Depending on the type of materials used to build the arch, formwork may be required during construction. Temporary formwork can be very expensive when compared with the cost of the construction materials. Where possible it should therefore be designed to be reused on future bridges in order to reduce the overall cost and unnecessary resource use.

### 8.10.3 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 E.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 E.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

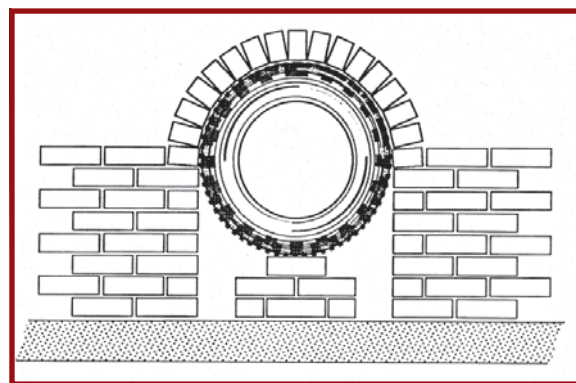
#### 8.10.4 Construction sequence

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 side wall construction should only commence once the ring is fully completed. The placing of fill material above the arch can proceed as the side walls are built. The placing of fill in layers about 1m below the constructed fill height would serve as a platform for the artisans who are laying the stonework for the side walls. Guide stones should be included on each side of the deck to mark the edge of the carriageway. These could be integral with the side walls 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.

#### 8.10.5 Arch materials

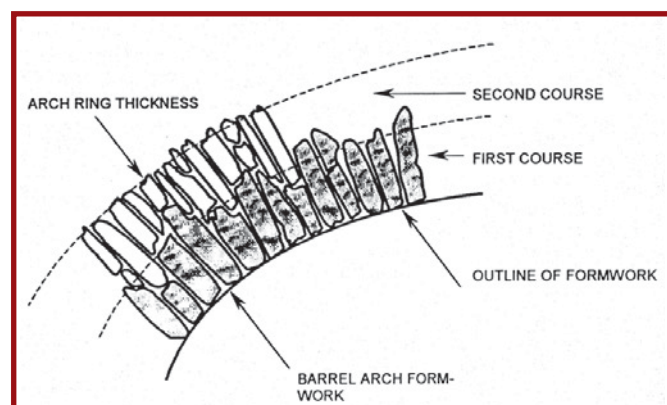
There are a number of different material options available for the construction of walls and temporary or permanent shutters for an arched bridge. Some of these options can be used in both the walls and arch, while others are only suitable for forming the arch (see Figure E.8.36).

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 E.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 a previous section.



**Figure E.8.36: Use of tyre in formwork**

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. Once constructed 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.



**Figure E.8.37: Two course arch**

All stonework used in an arch should be placed as shown in Figure E.8.37. The arch should consist of a minimum of 2 courses of masonry which should be interlocking where possible. In addition the minimum thickness of a semi circular arch ring is shown in Table E.8.24 below.

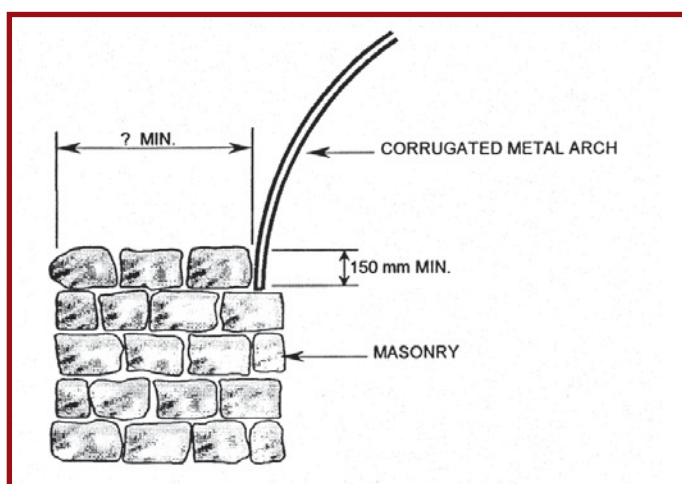
It is not possible to get the level of interleave shown in Figure E.8.34 if using bricks. The strength of brick arches can only be ensured if a good bond is achieved between the brick and mortar. As the arch will

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 E.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 E.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 temporary formwork and the possibility to use lower grade fill, lean concrete or stonework and skills in the construction of the arch over the corrugated sheets.



**Figure E.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.

#### 8.10.6 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 E.8.19:

- Well compacted gravel;
- Weak concrete mix with plums;
- Rubble masonry.

#### 8.11 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 (see Plate E.8.31). 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. The possible consequences of structural failure must be taken into account and given due emphasis in the design process.





**Plate E.8.31: Two span concrete deck bridge with masonry pier and abutments**

In this section, as in the rest of this Manual, emphasis is placed on relatively low-technology, labour based solutions, as these tend to be the most economic and socially beneficial in rural areas of Ethiopia. The previous text in this Manual is generally applicable to both single and two lane traffic small structures. 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 ERA Bridge Design Manual - 2011, Overseas Road Note 9 (TRL 2000) or other appropriate documents.

#### **8.11.1 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.

#### **8.11.2 Loading**

Careful consideration must be given to the type, volume and weight of vehicles which will use the road. It is often stated that "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 Ethiopia 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 ERA Bridge Design Manual - 2011 and documents such as Overseas Road Note 9 (TRL 2000).

### 8.11.3 Scour

The site of bridges must be carefully chosen to take local conditions into account to ensure durability and functionality, including alignment. Chapter E.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. The type of site investigation required to take the watercourse into account is outlined in Chapter E.6. 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.

### 8.11.4 Drainage

Every form of bridge requires some water management to ensure that water does not pond on the deck, which could cause a traffic safety hazard, rotting of timber, 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 road side drainage outfalls at the bridge site is essential to avoid erosion problems.

### 8.11.5 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, including preventative maintenance such as clearing of drains and removal of debris or garbage, on an annual basis. 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. In general and where possible deck soffits should be constructed a minimum of 300mm above the highest expected waterline. For timber decks this should be increased to 1000mm. For further guidance see Table E.8.24. Structure design and flood return period considerations are addressed in Section E.3.3.



In some cases, the construction of a low level bridge or vented ford might be appropriate where normal water depth exceeds fordable depth, and where dry access is not required all of the time. These are bridges which allow flooding approximately once a year for up to three days at a time. Most modern vehicles can drive through 150mm of water and this may be an acceptable economic solution for very low volume (traffic) roads. Scour protection should be provided to cope with the 50-year flood level where practical. This should be sufficient to prevent scour or even complete washout of both the deck and support system. Construction materials must be carefully chosen to prevent deterioration with time. In particular, the flood water must be prevented from flowing around the structure or flowing down the road. This can best be ensured by proper location of the bridge; retrospective work to keep flood water within the original channel can be very expensive, if not impossible.

#### 8.11.6 Choice of structure

The selection of structure type is discussed in Chapter E.4.

#### 8.11.7 Choice of materials and form of construction

The general properties of construction materials and how to identify and evaluate them are outlined in Chapter E.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 as the materials will be called upon to take greater loads, and local weaknesses or defects may lead to total collapse of the bridge. It is probable that in order to minimise the total cost of the structure, maximum use should be made of local materials and labour. Any choice of materials and form of construction may have maintenance implications and these should be included in the overall assessment of the options.

Reinforced concrete is generally considered to be the most economic material for construction of bridge spans up to 30m (see Plate E.32). This is because of the long life expectancy, 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 E.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 can cause loss of stability and early collapse. Typical faults include use of dirty water; sand and aggregate; inadequate mixing; placing and compacting of concrete; inaccurate fixing and positioning of reinforcement or formwork; and storing of cement in humid conditions. Mix design (ie 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.



**Plate E.8.32: Reinforced concrete deck on masonry abutments and pier**



Each region tends to have its own local construction artisans (eg 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.

Timber as a structural material has some major disadvantages which should be considered. All timber can rot and be eaten by insects. Some degree of protection such as creosote is required and this should be re-applied periodically through the life of the structure as required to ensure maximum life. Immersion in creosote or other preservative for several days prior to assembly provides long-lasting preservation. 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. When timber, either in the form of sawn sections or logs, is used for structural purposes it is very important to have a clear understanding of the strength and durability obtained from the particular material available. Seasoned timber free of defects and properly preserved should always be used. See Chapter E.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 E.7. Alternatively bricks can be used but for bridge structures it is important that they are consistent in strength and quality. Chapter E.7 gives some background on the expected properties of locally produced bricks.

### 8.11.8 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<sup>2</sup>. This is easily achieved in gravel, compact sand and strong clay. A simple check to indicate this minimum capacity is:

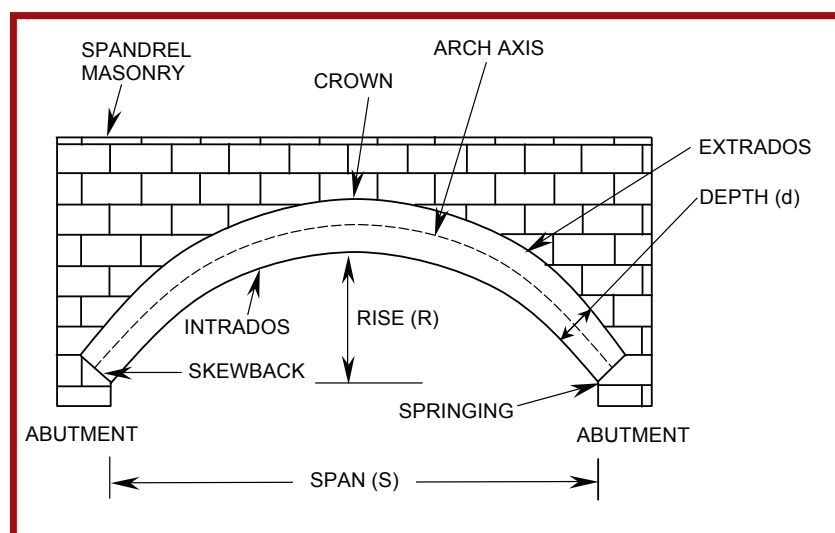
- A man's weight bearing on a 30mm diameter bar only penetrates 100mm;
- A 2m rod driven into the ground with a 3kg hammer experiences increasing resistance.

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.

### 8.11.9 Arch bridges

Arch bridges usually provide the best solution in consideration of the level of maintenance required. Spans greater than 10m require a properly engineered solution and reference should be made to the ERA Bridge Design Manual - 2011, Overseas Road Note 9 (TRL 2000) or other appropriate documents for design and construction. This Manual is appropriate only for spans less than 10m. Section E.8.10 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.

Arch bridges can be built in different forms and shapes. The key elements of an arch bridge are shown in Figure E.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 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. 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 E.8.39: Arch bridge details**

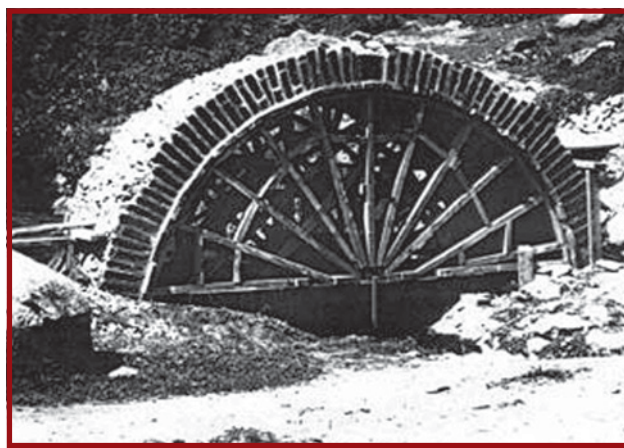
Arches can be constructed using any good quality stone or brick. Wedge shaped stone can be used without mortar but it is more common to use regular shaped rectangular stone or brick placed with a good quality mortar forming the slightly wedge shaped joints between each unit. The use of mortar can reduce 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 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.

For the arch barrel, extensive support is required during construction and it is likely that supporting falsework will be placed in the river bed. There are obvious related seasonal storm or flood risk considerations. Formwork will normally be made from timber of sufficient strength, fixed to give the correct shape to the arch (see Plate E.8.33). As the Section on arches suggests, other material can be used, eg. corrugated iron sheets. The formwork and supporting falsework must be firmly positioned and able to take the weight of the masonry and workmen. It must be devised in such a way that it can easily be removed once the arch has been constructed.





**Plate E.8.33: Masonry arch under construction with wooden formwork**

Distortion of the arch during construction must be avoided as this can have serious implications on the strength and stability of the completed bridge. The formwork should not distort or move noticeably due to workmen moving over it. It is economical to reuse the formwork and this should be kept in mind when devising the installation and method of removal after construction. To avoid having supports in the river bed, 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 river bed 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 E.8.23 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, ie 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. Plate E.8.33 shows an example of a masonry arch bridge under construction.



**Plate E.8.34: Completed masonry arch bridge with splayed wing walls on hard rock foundations**

For brick arches, it is also recommended that the formwork be removed after the mortar has fully hardened, 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.

#### 8.11.10

#### 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  $5\text{kN/m}^2$  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 E.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 ERA Bridge Design Manual - 2011 and Overseas Road Note 9 (TRL 2000) for further information.



### Material – Timber

The weight of timber is about 25% that of concrete and timber is therefore quite an effective construction material. All timber should be obtained from suitable hardwood which is generally available in tropical forest areas, and should be treated using creosote etc. to prolong life. There are three basic elements to a timber girder deck:

- **Road bearers:** These support the surface of the deck and are often called beams, girders or stringers, although trusses can also be used. The road bearers form the main structural elements of the deck and are described in more detail below.
- **Floor planking:** These are the boards which are nailed to the stringers to form the surface of the deck. These boards spread the wheel load to the girders. As the girders are generally spaced at less than 1m the individual pieces of floor planking do not need to be too long. A depth of 75-100mm 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 wheel base 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, floor planks and girders 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).

The design and suitability of the final product is very dependent on the type and grade of timber available. General advice is difficult because of the wide range of timber available. An example of a timber deck (in need of maintenance and repair) is shown in Plate E.8.35.

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 ERA Bridge Design Manual - 2011, Overseas Road Note 9 (TRL 2000) or similar documents to define the size and spacing of main structural elements.

The road bearers can consist of either a number of girders spanning between supports or a pair of trusses along the edges of the bridge with transverse stringers carrying the deck. Simple girder 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.



**Plate E.8.35: Timber deck with floor planking and edge beams in need of repair**

Timber girders 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. Chapter E.7 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 girder 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 E.8.25 provides the size and spacing of sawn timber girders 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 E.8.25: Sawn timber girder bridge deck for 6 ton vehicles**

Span	Timber size* (width x depth - mm)	Girder 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<sup>3</sup>



Logs are best used round but with the top shaven to carry the deck (Plate E.8.36). 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 (refer to Chapter E.9).



**Plate E.8.36: Log stringers from underside of bridge deck**

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 which 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 E.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 E.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.

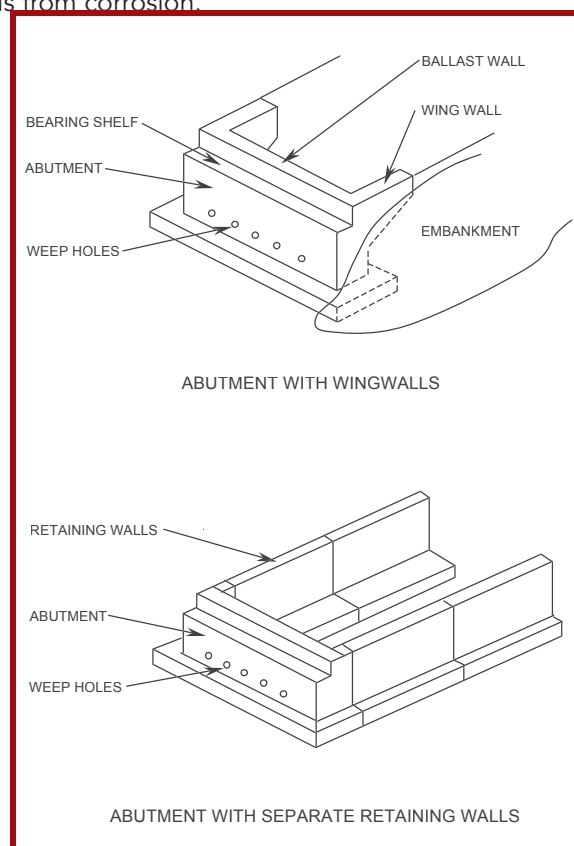
If available and of suitable length, old railway lines can be used to form a bridge deck. Because of difficulty of fixing to abutments and attaching deck planks, the rails can be encased in concrete so that the rails act as reinforcement. This also protects the rails from corrosion.

### 8.11.11 Abutments

Abutments provide the support system for the deck and retain the soil under the approach road (see Figure E.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 E.6; this will dictate the size of the abutment and the bearing area required.

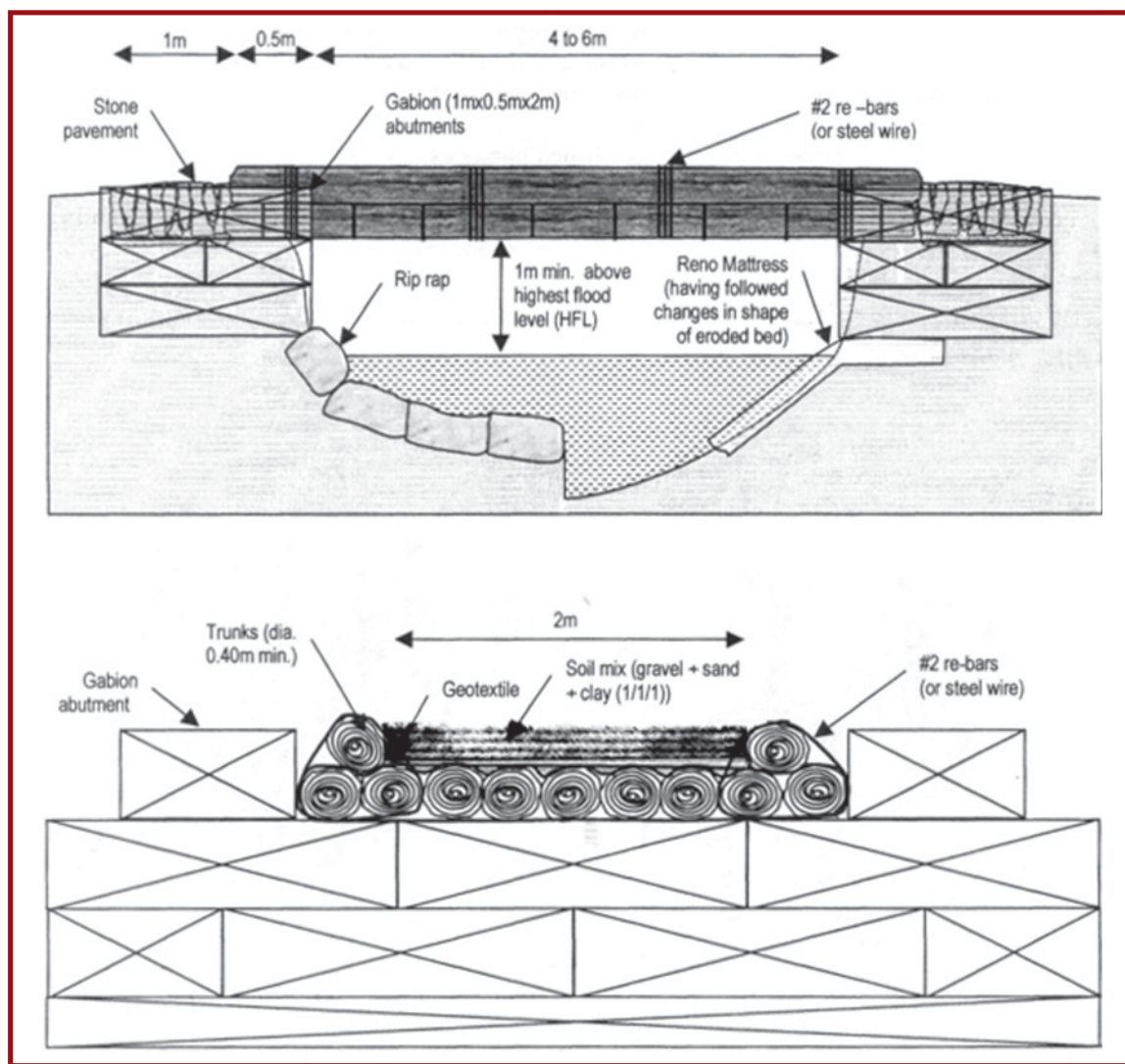
The material used for abutment construction depends primarily on the availability of local material. It is recommended that concrete or masonry be used to make abutments where possible. Mass concrete can be used provided the concrete is of sufficient quality and the abutment is of sufficient size.

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 E.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 of paved road surfaces due to the settlement risks.



**Figure E.8.40: Abutment details**





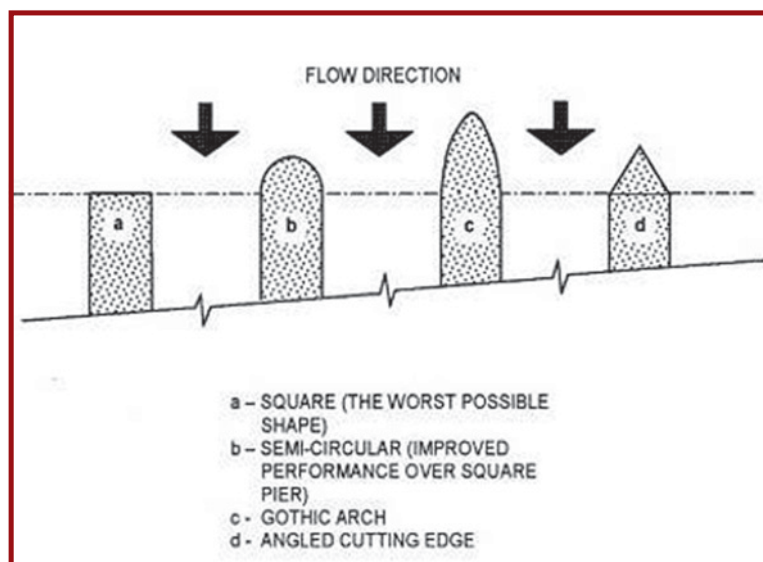
**Figure E.8.41: Gabion Abutment Log Deck Bridge**

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 the section 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.

#### 8.11.12: 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 E.8.42.



**Figure E.8.42: Pier shapes (Plan view)**

The section 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 E.5, Section 5.1.5.

Stonework or brick masonry (Plate E.8.37) 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 the section on fill material in approach ways). Reinforced concrete piers will tend to be more expensive than masonry due to the increased temporary works required and the probable need to transport to the location the steel, and the shuttering and 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 due to scour and settlement risks.



**Plate E.8.37: Brick pier**

### 8.11.13 Bearings and joints

On major bridge spans (>20m) bearings and joints are required to allow movement of the structure due to temperature or imposed loading without causing 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, pedestrians, temperature, wind and earthquakes. Wind and earthquake loading are major considerations for long span bridges and 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 and 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.

#### 8.11.14: 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 (see Plate E.8.38) 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 (see Plate E.8.39) 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.



**Plate E.8.38: Raised kerbs on a vented causeway allow water to pass over the structure with minimum disturbance, but provide protection from vehicles driving off the structure**



**Plate E.8.39: Timber bridge with handrails**

## 8.12 Other design issues

### 8.12.1 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, as it not designed to withstand the water flow. Table E.8.27 below provides minimum clearances that should be provided between the maximum water level and the bottom of the bridge deck.

**Table E.8.27: Minimum deck clearances**

Discharge (m <sup>3</sup> /s)	Minimum clearance (mm)
< 0.3	150
0.3 - 3.0	450
3.0 - 30	600
> 30	1000

### 8.12.2 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 (see Plate E.8.39). 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.

### 8.12.3 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.

### 8.12.4 Climate change

It is unlikely that there will be significant Climate Change implications for the design of small structures in the typical design lives being applied under the guidance provided in this Manual.



**Plate E.8.39:**  
**Road narrows sign**



## 9.

## CONSTRUCTION

The purpose of this chapter is to provide guidance on the actual construction of structures, from the preparatory work, through the various site activities to the completion of site works. It includes aspects of programming, construction, supervision and monitoring of works, whether the structure is built by a contractor, a road authority work force or a work group set up specifically for the task.

Not all issues dealt with in this chapter will arise during the construction of a structure, especially a small one. Checklists are provided and where appropriate the text refers to other documents for further reference and information.

## 9.1

**Preparatory work****Culverts**

The limited resources and costs involved, and usually standardised nature of culverts, will often mean that the amount of preparatory work may be limited. However some aspects of the preparatory work in the following sections for larger structures may be relevant.

**Bridges, drifts and large culverts**

The size, resources and funding required for larger structures will usually necessitate considerable preparatory work before the actual site works can begin.

It is assumed that structural survey and design will be carried out in accordance with the guidelines elsewhere in this Manual and with any locally established standards. It is also assumed that cost estimates, detailed drawings and bills of quantities will be prepared for the works.

If the work is contracted, appropriate contract documentation should be prepared in accordance with local standards and procedures. When a contractor will be appointed, local contractor classification, tendering, selection and award procedures should also be complied with. Arrangements should be in place for resolution of any disputes that may arise through the contract.

**(Note:** Inappropriate contract documentation has often been used in the past for relatively simple structures. Fortunately, simplified model documentation and guidelines are now available from organisations such as FIDIC and ICE, which are more appropriate for small structures contracts. Contract documentation should be appropriate, equitable and acceptable in the local legal environment. The ERA Low Volume Roads contract documentation and specifications are most appropriate for LVR structures in Ethiopia.)

Arrangements for management, supervision, testing, approval and audit of the works should be established. All of these issues should be clearly documented and known to the parties involved in the construction process. If there is any doubt about the responsibilities, adequacy or arrangements for any of these issues, then professional advice should be sought to rectify the situation.

The construction of any structure for a public road involves risks and responsibilities which must be appreciated and should be assigned to the most appropriate parties.

Inadequate attention to some aspects of the work can result in a structure not fit for its purpose, waste of resources, or even serious damage or eventual loss of the structure.

**Structure costing**

It will usually be necessary to prepare a detailed costing of the structure, either for internal budgeting and funding purposes, or for contracting out the work. This will normally be achieved through preparation of a Bill of Quantities which can be priced by the client/promoter and by a contractor.

Sample bills of quantities are provided in Volume 2. The following checklist indicates the components which should be included in any complete costing of a structure.

Table E.9.1 below (checklist for preparing a construction programme) may be used as the basis for developing a Bill of Quantities. Bills of Quantities in a national standardised format, with activity related items, will assist clients and contractors in pricing works and assessing value for money.

**Table E.9.1: Checklist of cost components for detailed costing of a structure**

Direct costs	Overheads
<ul style="list-style-type: none"> <li>▪ Materials</li> <li>▪ Unskilled labour</li> <li>▪ Skilled labour</li> <li>▪ Equipment purchase</li> <li>▪ Equipment operating costs</li> <li>▪ Equipment hire</li> <li>▪ Tools</li> <li>▪ Temporary works</li> <li>▪ Services hired in</li> </ul>	<ul style="list-style-type: none"> <li>▪ Supervisory and technical staff</li> <li>▪ Survey and setting out</li> <li>▪ Main office, workshop costs</li> <li>▪ Supervision vehicles</li> <li>▪ Transport to and from site</li> <li>▪ Site camp and stores</li> <li>▪ Security measures and facilities</li> <li>▪ Communications (telephone, mail)</li> <li>▪ Insurances, bonds</li> <li>▪ Banking and other charges</li> <li>▪ Training</li> <li>▪ Protective clothing and safety</li> <li>▪ Traffic control/signs</li> <li>▪ Testing</li> <li>▪ Welfare, pensions, social costs</li> </ul>
Contingency/risks	
(eg unforeseen additional work, late payment, delays)	
Profit	
The contractor should normally be expecting to make in the order of 10% profit on his work, after covering ALL other costs. However this percentage will be affected by local market conditions, competition and perceived risks	

### 9.1.1

#### Planning of site works

Good planning of the site works is essential, particularly as many structures sites are remote from organisational bases, sources of some materials and skilled manpower, and communications can be difficult. Poor planning can lead to serious delays and increased costs. Table E.9.2 provides a checklist for planning of site works and Table E.9.3 provides a checklist for preparing a construction programme.



**Table E.9.2: Checklist for planning site works**

1. List all construction and support activities and prepare a construction programme (using a bar chart) based on the Bill of Quantities, expected productivities and logical sequence of activities.
2. Prepare resource plan and cash flow requirements.
3. Plan in recognition of the seasonal watercourse conditions and expected flood conditions. Plan adequate arrangements for damming, diverting or control of water.
4. Ensure compliance with all laws and regulations regarding recruitment, labour, (permanent/casual) employment, gender and disadvantaged groups opportunities, payment, security for payment to labourers, conditions of work.
5. Plan compliance with environmental requirements, particularly with regard to materials exploitation, replacement of felled timber, watercourse pollution and waste disposal.
6. Inspect site. Check site survey. Review designs and documentation for compatibility and with the actual site conditions. Clarify any inconsistencies
7. Plan and arrange land (acquisition/lease/use) and setting up site, camp and stores. Cement to be stored in a secure, dry and well ventilated place.
8. Ensure adequate site access arrangements, particularly if the structure is being built in advance of the road works.
9. Plan water supply, other services requirements and sanitation arrangements
10. Plan site security (particularly against theft of handtools & materials; cement is particularly susceptible)
11. Ensure availability and accessibility of funds and contingency finance.
12. Ensure payment arrangements for (sub)contractors, and suppliers are in place.
13. Plan staffing, identify skills locally available or required to be imported to the site area, accommodation, logistics, transport to site, recruitment and training of workforce.
14. Arrange for supplies of materials to site.
15. Plan safe and adequate temporary arrangements for traffic and pedestrians where replacing an existing structure or facility.
16. Plan actual/contingency arrangements for de-watering and shoring of foundations.

**Table E.9.3: Checklist for preparing a construction programme**

The construction programme will involve some or all of the following activities:

1. Clear trees, bush and scrub dispose of safely.
2. Primary setting out and establishment of reference points.
3. Remove topsoil, stockpile for re-use or disposal.
4. Dig catchwater drains to protect site and any side drains.
5. Remove/bury nearby/break surface boulders (see below).
6. Detailed setting out and establishment of levels and profile boards.
7. Excavate foundations and any cut-off trenches.
8. Temporary shoring, watercourse diversions, piling, cofferdams, de-watering/drainage.
9. Drill and blast any solid rock.
10. Replace "soft spots" in ground, clean and prepare foundation area.
11. Construct foundations.
12. Construct temporary works for superstructure.
13. Erect abutments, piers, deck, wingwalls.
14. Fix deck timbers and running boards where applicable.
15. Erect kerbs, parapets barriers and safety structures.
16. Install drainage layers and features against structure.
17. Backfill against and adjacent to the structure, compacting each layer according to the specifications. Particular attention to be paid to all compaction within 5 metres of the structure.
18. Construct road pavement/surfacing and markings, road shoulders.
19. Construct road drainage features.
20. Construct gabions and erosion control measures.
21. Lay topsoil/turfes and planting.
22. Install traffic warning signs if necessary.
23. Clear site, remove surplus materials and leave tidy.

The productivity standards shown in Table E.9.4 may be useful in estimating the resources and time required for each activity.

**Table E.9.4: Recommended productivity standards**

Site clearance (bush clearing, tree felling, etc)	100 – 350m <sup>2</sup> / worker day
Removal of tree stumps	1 / worker day
Soil excavation (and stockpiling alongside)	2 - 5m <sup>3</sup> / worker day
Rock (fractured) excavation (solid rock will require drilling and blasting/ splitting)	0.8m <sup>3</sup> / worker day
Loading	8.5m <sup>3</sup> / worker day
Haulage by wheelbarrow	
0 - 20m	8.5m <sup>3</sup> / worker day
20 - 40m	7.0m <sup>3</sup> / worker day
40 - 60m	6.5m <sup>3</sup> / worker day
60 - 80m	5.5m <sup>3</sup> / worker day
80 - 100m	5.0m <sup>3</sup> / worker day
100 - 150m	4.5m <sup>3</sup> / worker day
Install only 600 or 900mm diameter culvert lines (including excavation and backfill)	0.8 - 1.2 lin.m / worker day
Mix and place concrete	1.0m <sup>3</sup> / worker day
Erect masonry work	1.0m <sup>3</sup> / worker day

Productivity depends on a number of factors, including worker nutrition, fitness, experience and motivation, site organisation, tool quality and condition, and climate. Individual small structures sites do not allow much scope for improvement of performance with experience due to the short time spans involved for individual activities. New workers under training will also be less productive. Poor quality and condition of handtools can affect productivity by up to 25%.

The following list shows the range of skills which may be required on a structures site.

- Surveying and setting out;
- Drilling and blasting;
- Piling/cofferdam;
- Carpentry;
- Masonry;
- Temporary works;
- Steel bending and fixing;
- Concreting;
- Equipment maintenance.

The more specialist skills may need to be imported into the project area. Some skills may be taught through on-the-job training. This will involve costs and loss of productivity. Workers not from the area of the structure site may require temporary accommodation and incur costs relating to travel and allowances. Table E.9.5 provides a checklist of hand tools and site equipment that could be required to execute the works.



**Table E.9.5: Checklist of handtools and site equipment**

Handtools		Equipment
Ranging rods	Hand drills	Culvert moulds
Spirit level / Abney level / water tube level	Plugs and feathers	
Stringlines, pegs		Plate compacter
Profile boards & travellers	Masons trowels	Pedestrian vibrating roller
Plumb bob	Masons hammers	Water bowser
Tape measures	Spirit levels	Water pump
	Straight edges	Concrete mixer
Felling axes	Lifting tackle	Batching boxes
Tree felling saws	Buckets	Vibrating poker
Bush knives	Mortar pans	Piling equipment
Brush hooks	Mixing boards	Hydraulic excavator
Ropes	Water containers/drums	Compressor and air tools
	Screeding boards	Craneage
Pick axes	Pointing tool	Aggregate crushing eqp.
Mattocks		Aggregate screens
Hoes	Hand rammers	Supply and site transport
Crowbars	Rakes/spreaders	Formwork/moulds
Shovels		
Sledge hammers	Slump test equipment	Traffic signs and barriers
Wheelbarrows	Concrete cube moulds and curing tank	
Head pans/baskets	Soil density testing equipment	Safety helmets and equipment
Earth 'stretchers'		
	Sandbags for water control	
Carpenters tool kits		

## 9.2

### Site works

The works will be organised according to the activities in the construction programme. Guidance on the individual activities is provided in the previous chapters of this Manual. However some specific aspects warrant further explanation.

Temporary works should be designed to withstand the watercourse (eg flood or debris) conditions expected and temporary loading situations.

Works must be carried out according to the specifications and drawings. Quality control arrangements should ensure compliance in accordance with specifications. The control of cement requires particular

attention; this is a valuable commodity and it is difficult to detect reduced inputs until after construction. Batching should be carefully controlled and the making and curing of cubes should be closely supervised. It will normally be necessary to arrange for cubes to be crushed at a reliable laboratory remote from the site. The laboratory must be consulted to ensure that the testing can be carried out according to the standards specified. It is advisable to visit the laboratory to assess the standard of service provided.

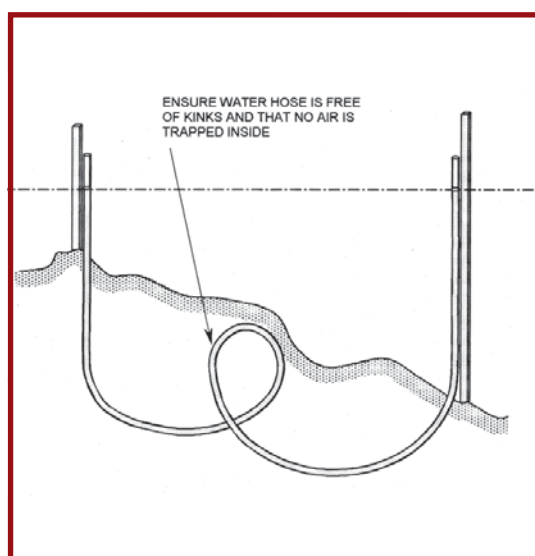
The slump test (see Chapter E.7) should be used to control concrete workability and check the water: cement ratio. Treatment of permanent timbers should be closely supervised or guaranteed.

### 9.2.1

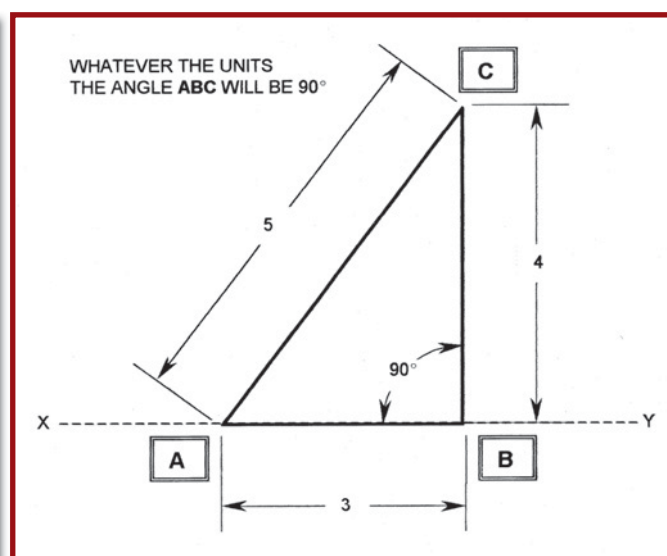
#### Simple setting out techniques

The following simple setting out techniques are illustrated in the respective figures:

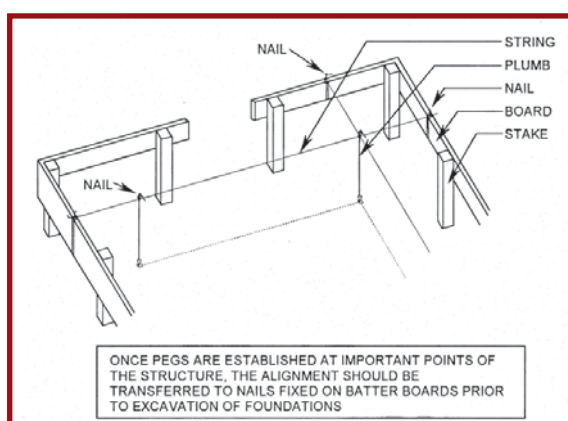
- Levelling with a water hose (Figure E.9.1);
- Setting out a right angle (Figure E.9.2);
- Use of batter boards (Figure E.9.4).



**Figure E.9.1: Levelling with a water hose**



**Figure E.9.2: Setting out a right angle**



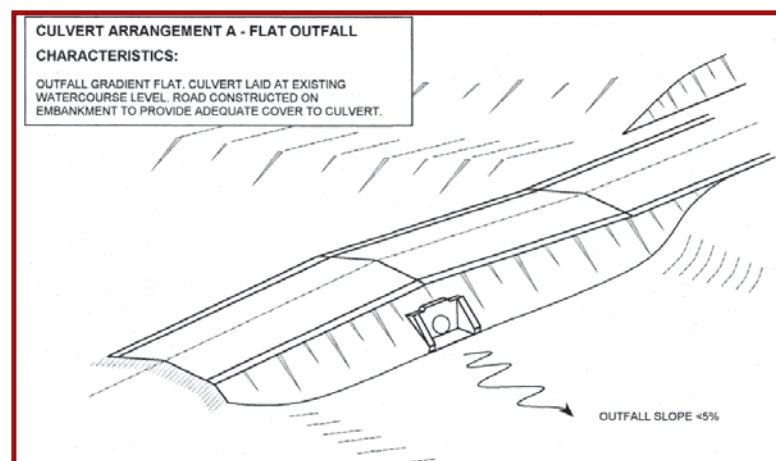
**Figure E.9.3: Use of batter boards**

### 9.2.2

#### Setting out culverts and drifts

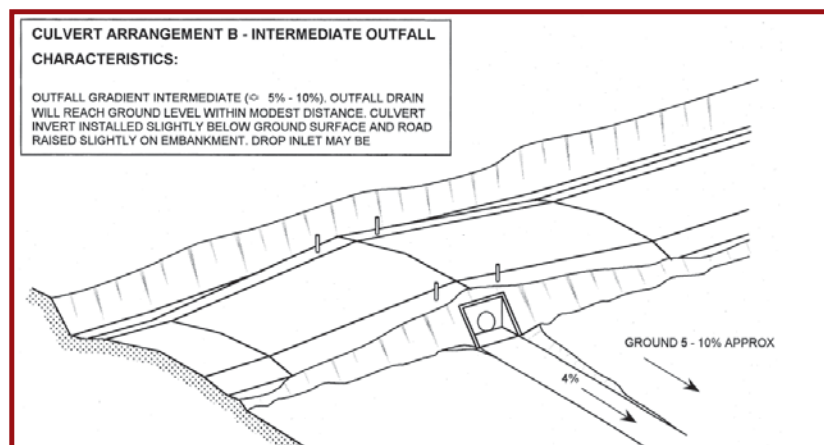
The setting out should be according to the design. The principal setting out requirements are the establishment of the centreline of the barrels (for culverts), the extent of the structure (ends and corners) and the inlet/upstream and outlet/downstream invert/slab levels (see Figure E.9.4).



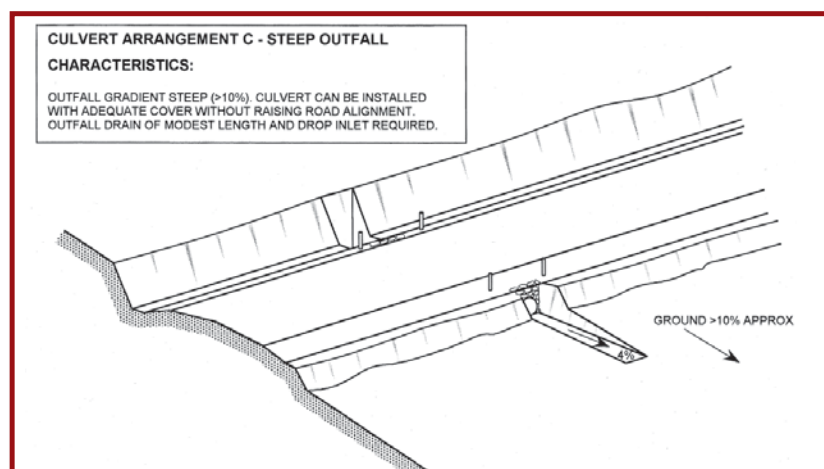


**Figure E.9.4: Culvert arrangement A (flat outfall)**

Wooden pegs should be used to establish key positions and levels. For minor culverts and drifts where no levels are provided, the invert of the culvert or drift slab should follow the level of the existing watercourse as closely as possible. The guidance in Figures E.9.5 and E.9.6 and the procedure for setting out a culvert shown in Figures E.9.7 and E.9.8(a) and (b) will minimise the possibility of silting or erosion of a culvert due to installation at an incorrect level.



**Figure E.9.5: Culvert arrangement B (intermediate outfall)**

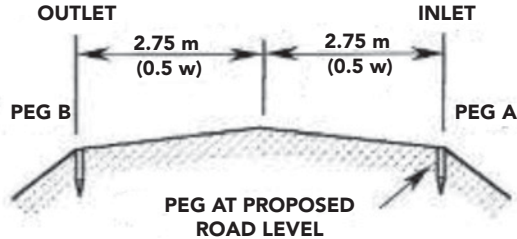
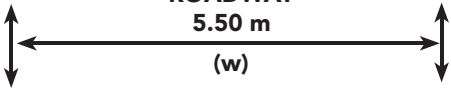


**Figure E.9.6: Culvert arrangement C (steep outfall)**

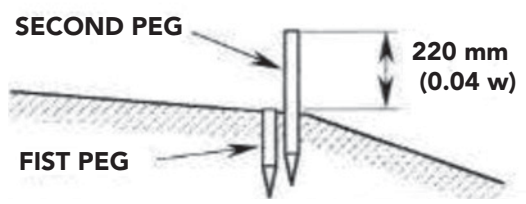
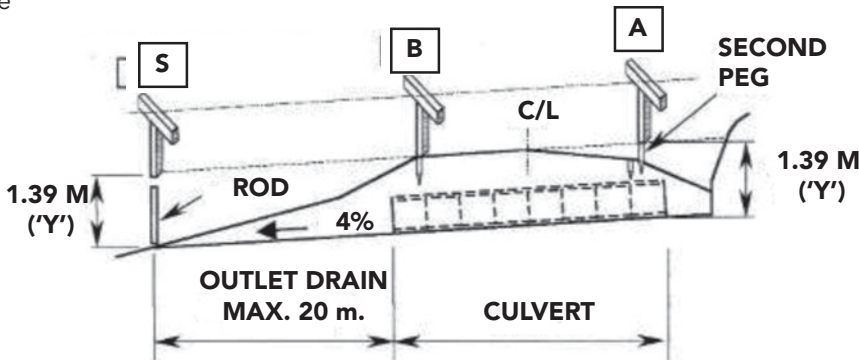
If the culvert site is flat, check the watercourse gradient for 20 metres downstream from the location of the culvert outlet. Use boning rods and Abney Level, or line and level, for this purpose. If the gradient is less than 5% (1 metre fall in 20 metres), then construct the culvert in **Arrangement A** with the culvert inverts as close to existing ground/water course level as possible. Also construct **Arrangement A**, if the height of embankment fill (measured from ground level to edge of road running surface) at culvert site is at least 1.1 metres. Otherwise proceed with the following steps to install **Arrangement B and C**.

#### SETTING OUT OF 600 mm Ø CULVERT - ARRANGEMENT B OR C

**MAIN DIMENSIONS ARE FOR ROADWAY WIDTH OF 5.5 m. (DIMENSIONS IN BRACKETS ARE FOR CROSS SECTION WITH ROADWAY WITH OF 'w' METRES)**

PROCEDURE STEP BY STEP	EXAMPLE/EXPLANATION												
<b>STEP 1</b>  Fix the centreline of the culvert. Establish two pegs (peg A and peg B) at the location of both roadway edges and at proposed finished roadway level. Make sure that pegs are on the same level (use line and level or Abney level).													
<b>STEP 2</b>  Measure distance between peg A and B (5.50 m, or 'w' for other cross sections).													
<b>STEP 3</b>  Calculate the minimum depth (d) to be excavated from proposed road level to underside of culvert pipe at the inlet to ensure adequate cover (at peg a).	<table><tr><td>OUTSIDE DIAMETER OF CULVERT or 600 mm</td><td>0.72 m</td></tr><tr><td>OVERFILL (MINIMUM COVER)</td><td>+ 0.45 m</td></tr><tr><td><b>TOTAL DEPTH (d)</b></td><td><b>1.17 m</b></td></tr></table>	OUTSIDE DIAMETER OF CULVERT or 600 mm	0.72 m	OVERFILL (MINIMUM COVER)	+ 0.45 m	<b>TOTAL DEPTH (d)</b>	<b>1.17 m</b>						
OUTSIDE DIAMETER OF CULVERT or 600 mm	0.72 m												
OVERFILL (MINIMUM COVER)	+ 0.45 m												
<b>TOTAL DEPTH (d)</b>	<b>1.17 m</b>												
<b>STEP 4</b>  Calculate the difference in culvert level between peg a and b with the chosen culvert gradient (4% is normally selected as the ideal gradient).	<table><tr><td>GRADIENT:</td><td></td></tr><tr><td>DIFFERENCE IN LEVEL:</td><td></td></tr><tr><td><math>\frac{4\% \times 5.50 \text{ m}}{100\%}</math></td><td>4% = 0.22 m</td></tr><tr><td></td><td>(FOR ROAD WIDTH w, = 0.04 w)</td></tr></table>	GRADIENT:		DIFFERENCE IN LEVEL:		$\frac{4\% \times 5.50 \text{ m}}{100\%}$	4% = 0.22 m		(FOR ROAD WIDTH w, = 0.04 w)				
GRADIENT:													
DIFFERENCE IN LEVEL:													
$\frac{4\% \times 5.50 \text{ m}}{100\%}$	4% = 0.22 m												
	(FOR ROAD WIDTH w, = 0.04 w)												
<b>STEP 5</b>  Calculate the depth to be excavated from proposed road level to the underside of culvert at the outlet (at peg b).	<table><tr><td>ROAD WIDTH (m)</td><td>5.50</td><td>(w)</td></tr><tr><td>INLET DEPTH</td><td>1.17 m</td><td>1.17 m</td></tr><tr><td>DIFFERENCE IN LEVEL +</td><td>0.22 m</td><td>0.04 w</td></tr><tr><td>DEPTH AT OUTLET</td><td>1.39 m</td><td>y = (1.17 + 0.04 w)</td></tr></table>	ROAD WIDTH (m)	5.50	(w)	INLET DEPTH	1.17 m	1.17 m	DIFFERENCE IN LEVEL +	0.22 m	0.04 w	DEPTH AT OUTLET	1.39 m	y = (1.17 + 0.04 w)
ROAD WIDTH (m)	5.50	(w)											
INLET DEPTH	1.17 m	1.17 m											
DIFFERENCE IN LEVEL +	0.22 m	0.04 w											
DEPTH AT OUTLET	1.39 m	y = (1.17 + 0.04 w)											

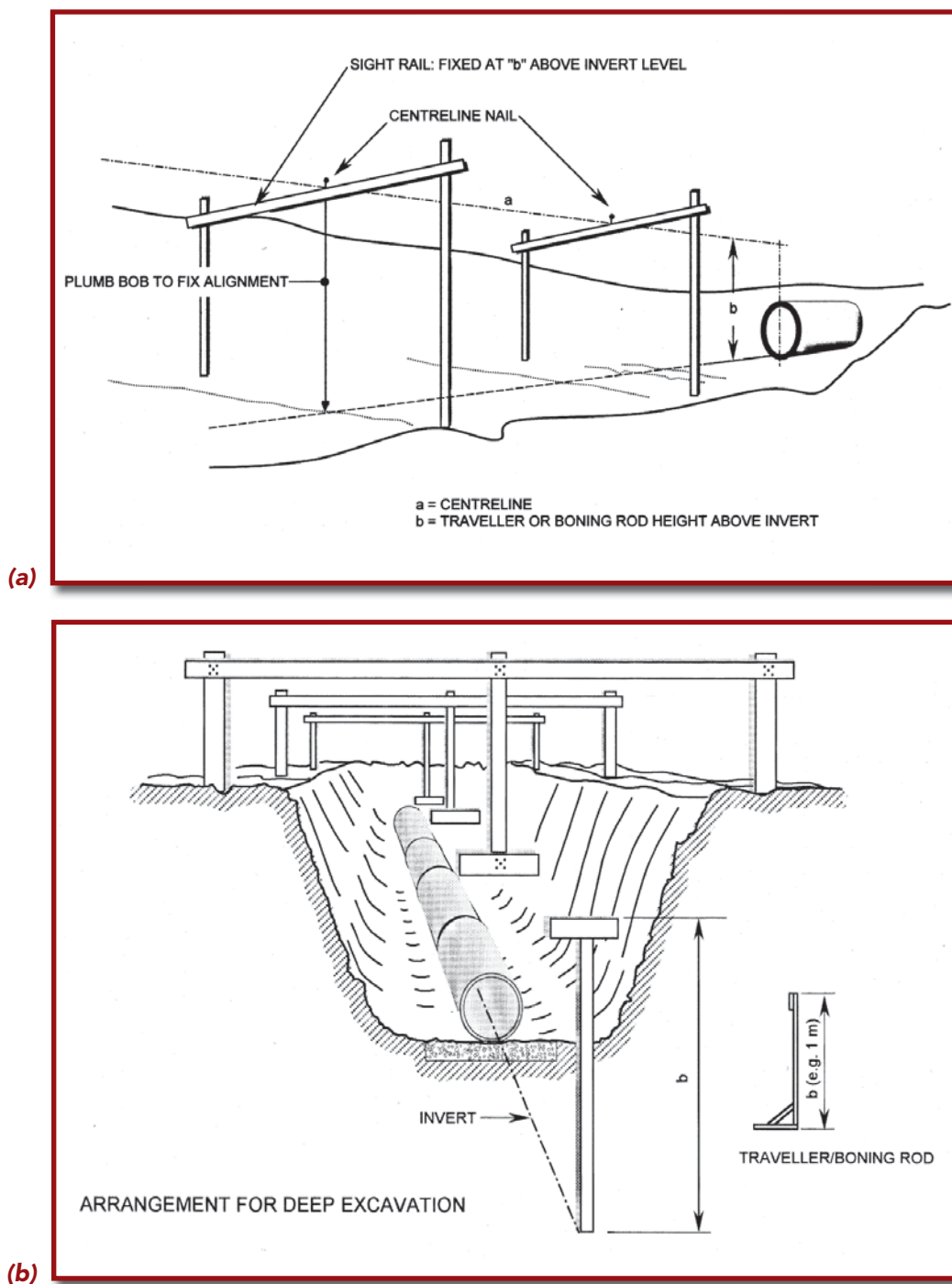
**Figure E.9.7: Procedure for setting out a culvert**

PROCEDURE STEP BY STEP	EXAMPLE/EXPLANATION
<p><b>STEP 6</b></p> <p>Raise level peg A by the same measurement that you have calculated under step 4 establishing a second peg (difference in level).</p>	
<p><b>STEP 7</b></p> <p>Find the end of the outlet-drain by using boning rods and a stick or rod of length 1.39 m ('y' for other cross section road widths) (see sketch below): Walk S and rod away from B until the tops of A, B and S are in line</p> 	
<p>If the length of the outlet drain SB is <u>less than 20 metres</u> then establish the drain outlet peg at ground level at point S. Construct the culvert in <b>Arrangement C.</b> (ie the road alignment will not need to be raised). Establish the excavation level for the underside of the culvert pipe by measuring vertically down 1.39 m ('y') from peg B and the top of the second peg at point A. The excavation pegs should be 5.50 m apart ('w' for other cross section road width).</p>	
<p><b>STEP 8</b></p> <p>If the drain outlet cannot be found within 20 metres of the culvert outlet then place a peg at ground level at point S, 20 metres away from the culvert outlet point B. Adjust the boning rod at points S until the tops of the 3 boning rods A, B and S are in line. Measure the distance from the bottom of the boning rod S to the ground level: z metres. The road level at A and B will have to be raised by 1.39 - z metres (y - z for other cross sections). To fix the culvert inlet excavation level, measure (1.39 - z) metres (y - z for other cross sections) down from the top of the second peg at point A. To fix the culvert outlet excavation level, measure (1.39 - z) metres (y - z for other cross sections) down from the peg at point B (these pegs should be 5.50 m apart, or w for other cross sections). This is <b>Arrangement B.</b> The road will need to be raised as indicated above and the vertical alignment raised or a suitable ramp constructed either side of the culvert.</p>	

- NOTE:**
- 1. Where pipes will be bedded on imported material, excavation levels will have to be lowered by the thickness of bedding material.
  - 2. For 900 mm Ø culverts the dimension in step 3 is increased to 1.05 + 0.70 = 1.75 m. In step 5 the depth at outlet will be 1.97 m (1.75 + 0.04 w).

Figure E.9.7 (continued)





**Figure E.9.8(a) and (b): Setting out culvert profiles**

Plate E.9.1 shows an example of the setting out of a culvert apron and Plate E.9.2 shows a completed culvert and inlet apron.





**Plate E.9.1: Construction of culvert inlet apron with guide pegs and strings**



**Plate E.9.2: Completed culvert inlet apron**



## 9.2.3

## Setting out bridges and large structures

Benchmarks and reference points must be established. They should be well marked and protected. The structure centreline should be set out. Front faces of abutments and centrelines of piers should be set out. All setting out pegs should be located well back from the main working areas and be protected by (preferably brightly painted) timber markers. Two pegs established in a line both sides of a structure will mean that lines can be re-established if one of the pegs is accidentally disturbed. Right angles can be set out using the '3:4:5 triangle' rule (see Figure E.9.9 for simple setting out techniques).

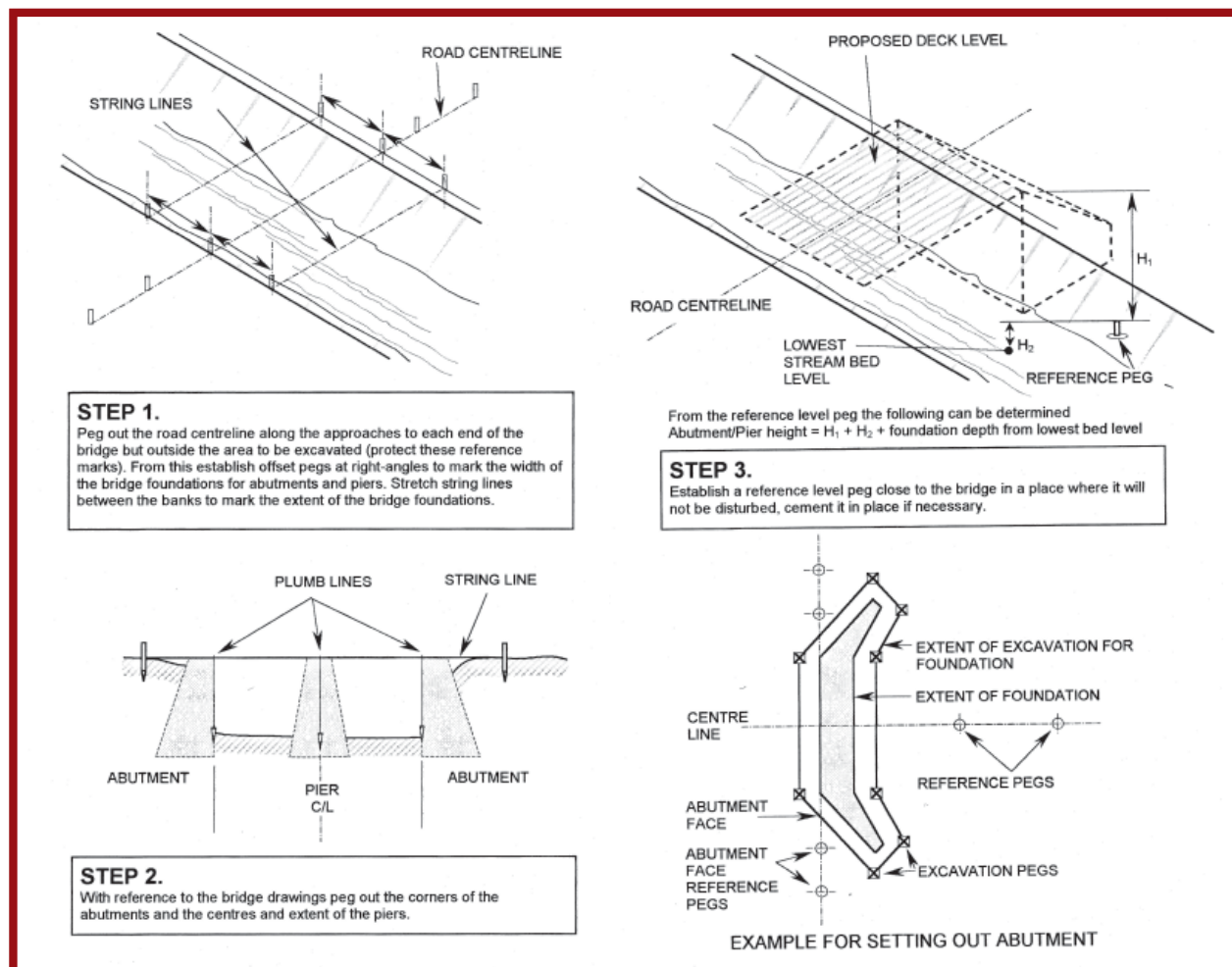


Figure E.9.9: Basic setting out techniques for structures

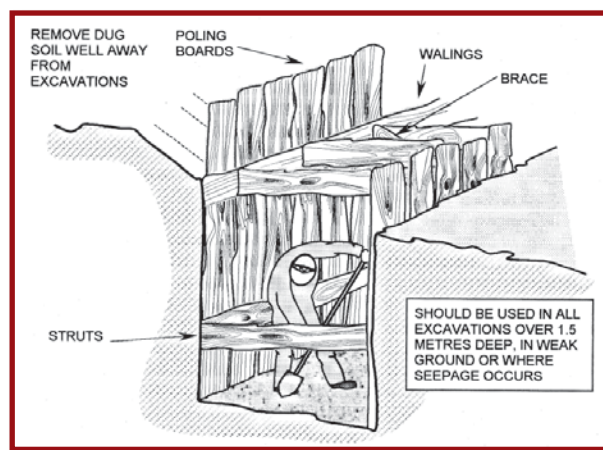
## 9.2.4

## Excavations

Foundations (if not on bedrock) are usually the most risky stage of the construction process. Whatever site surveys were carried out beforehand, the actual foundation conditions cannot be determined until full excavation takes place. Unforeseen problems may occur. If problems are not adequately tackled at the foundation stage, they can be particularly difficult or expensive to rectify later.

Particular care must be taken to ensure the safety of workers and suitable precautions as illustrated in Figure E.9.10. Excavations can collapse particularly in weak ground or where groundwater seeps into the excavation. Temporary shoring should be used if there is any risk of this.



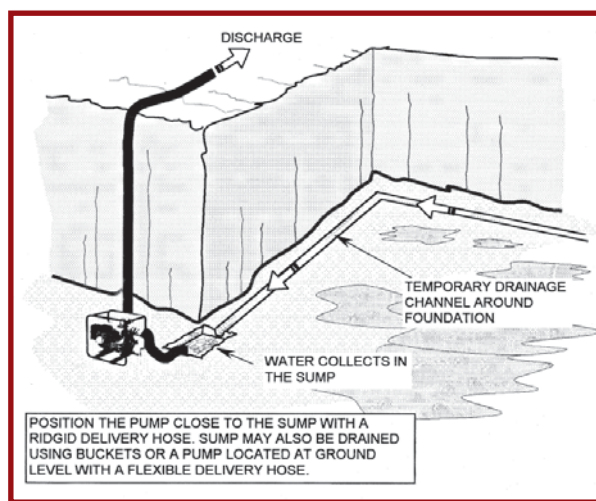


**Figure E.9.10: Safety issues**

Foundations should be kept as dry as feasible and covered as soon as possible. If weak or soft spots are uncovered then they should be replaced with imported suitable material such as clean gravel or crushed stone. The bearing capacity of the actual foundation soil can be checked using simple apparatus such as the DCP.

A sump and drainage channels may be necessary to keep the foundation dry. Buckets or a water pump may be used to remove the water from the sump see Figure E.9.11.

If the ground conditions are worse than expected then the design engineer should be consulted (his availability at this critical stage should be ensured during the construction planning process).



**Figure E.9.11: Pumping arrangements**

If steel reinforcement is incorporated in the foundations it is advisable to use a blinding of lean mix concrete directly on to the trimmed soil to form a clean working platform for arranging and fixing the reinforcement. For other works compacted gravel or crushed stone can be used for a clean working surface.

If the foundation is on bedrock a good key must be ensured. This can be achieved by chipping the complete rock surface and exposing a rough clean rock face. The drilling of holes and insertion of dowels may be necessary to ensure a good key. Sloping bedrock should be excavated in steps (benched) to provide a stable foundation.

Culverts on busy existing roads may be built in two halves with adequate traffic control and safety measures. Otherwise a diversion must be arranged with adequate warning signs and traffic control measures. Table E.9.6 provides a supervisory check box of precautions that should be taken during excavation works.

**Table E.9.6: Supervision check box - Excavation**

- Inspection and approval by engineer/senior technician
- Keep as dry as possible
- Trim to correct levels (and falls for a culvert or drift)
- Ensure firm foundation - remove soft spots and replace with good material
- Culvert excavations should be no wider than necessary to install culvert

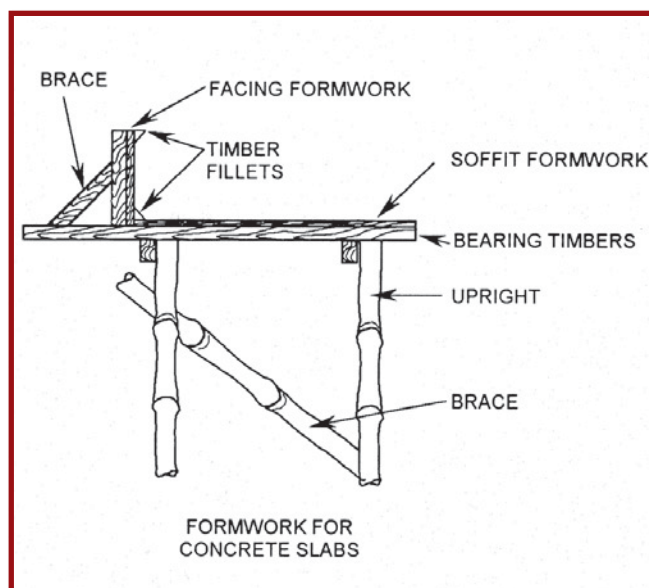
### 9.2.5 Temporary works

Scaffolding, shuttering and temporary works should be constructed by skilled artisans to designs prepared taking account of the local materials and loadings expected.

### 9.2.6 Shuttering/formwork and steel reinforcement for concrete work

Formwork and steel reinforcement (where specified) for concrete should be constructed in accordance with current standards and guidelines. Each stage of the work should be thoroughly checked before concreting is permitted. Checks should include cleanliness, soundness and quality of formwork and to ensure that it will not move or leak under the loading of fresh wet concrete and workers. Details of the formwork for concrete slabs are shown in Figure E.9.12.

Timber chamfer fillets (eg 20mm x 20mm timber sawn at 45°) should be fixed on all external 90° angles to ensure smooth finished edges to the concrete.

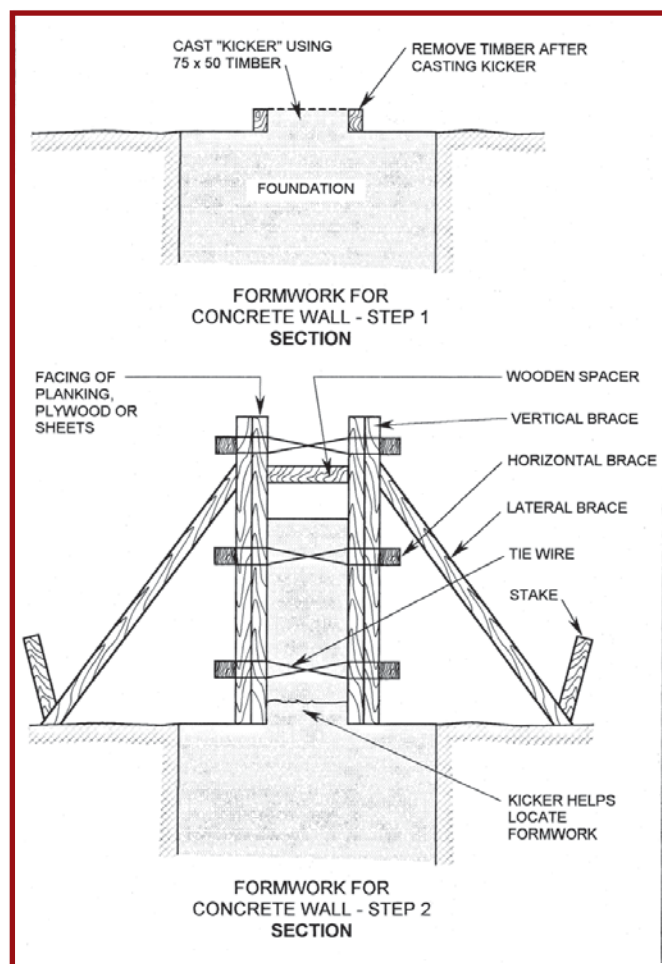


**Figure E.9.12: Formwork detail**

The steps for formwork for concrete walls are shown in Figure E.9.13.

### 9.2.7 Steel reinforcement

Table E.9.8 provides a check list of precautionary measures for steel reinforcement with details of spacers for the reinforcement given in Figure E.9.13.



**Figure E.9.13: Wall Formwork detail**

Formwork should be coated with mould oil to allow easy striking of formwork after the concrete has set. Linseed oil, old engine oil or other cheaply available oils may be suitable for this. Table E.9.7 provides a checklist of precautions that should be taken in the erection of formwork for concreting.

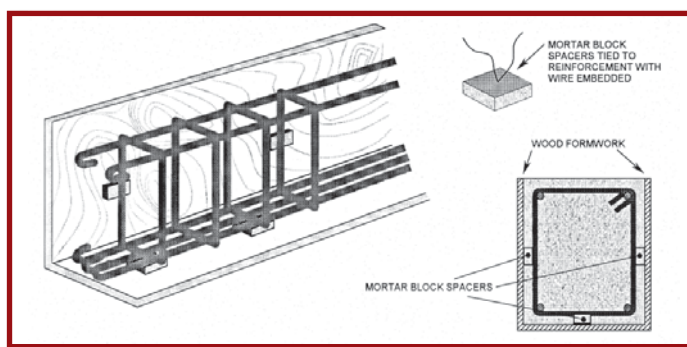
**Table E.9.7: Supervision Check Box - Shuttering/formwork**

- Faces of sawn timber/plywood/sheet steel securely fixed and supported on a timber/bamboo/steel framework
- Erected to the correct levels, alignment and tolerances, strong enough to support the weight of wet concrete and operations without distorting/settling
- No gaps or holes in faces for wet concrete to escape
- Oiled to assist with striking/removal
- Weep holes/scuppers/fixings/joints etc. in correct locations
- Clean with all debris removed prior to concreting



**Table E.9.8: Supervision check box - Reinforcement steel fixing**

- Ensure steel bar grades, sizes, numbers, spacing and shapes according to design drawings
- Ensure minimum cover to steel from soffits, walls and top surfaces (50 - 100mm)
- Ensure minimum overlaps between bars
- Ensure steel and shuttering is clean with no loose rust or contamination (slight corrosion assists bonding of concrete to reinforcement)
- Reinforcement should be cut to the specified lengths, bent cold and provided with the minimum laps specified. Overlapping and lapped bars should be bound tightly with binding wire at ALL points.

**Figure E.9.14: Reinforcement spacers**

The spacers supporting reinforcement should be securely fixed so that they will not move during concreting. Spacers can be made from mortar cubes with binding wire cast in. The amount of cover to the reinforcement (usually 50 mm in moderate conditions to 100 mm in extreme exposure conditions) is important for reinforced concrete durability.

## 9.2.8

### Concrete work

The requirements of the specifications and guidelines elsewhere in this Manual should be followed. Water for concrete should be clean and free from contaminants such as salt and silt. Water with solids in suspension should be allowed to stand in barrels so that the sediments settle out. Water that is drinkable is usually fit for concrete works. Concreting is usually not permitted at ambient (shade) air temperatures below 30°C. Hot weather concreting must also be avoided as the uncured concrete will dry out too quickly. Usually concreting is not permitted in ambient (shade) temperatures above 40°C. In ambient temperatures well below this figure structures and aggregates in direct sunlight can rise to unacceptable temperatures. Shading and timing of concreting during cooler hours can be important countermeasures.

CONCRETE CAN BE BATCHED BY VOLUME.  
GAUGE BOXES MADE FROM STEEL, WOOD OR PLYWOOD ARE USED FOR THIS.

**Figure 9.11  
Batch Box**

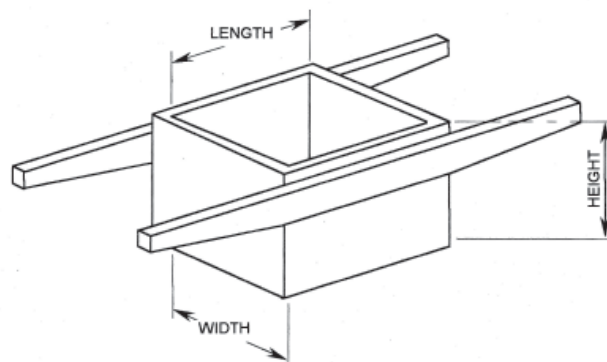
#### BOX DIMENSIONS - INSIDE MEASUREMENTS

LENGTH = 400 mm, WIDTH = 300 mm, HEIGHT = 300 mm

#### VOLUME

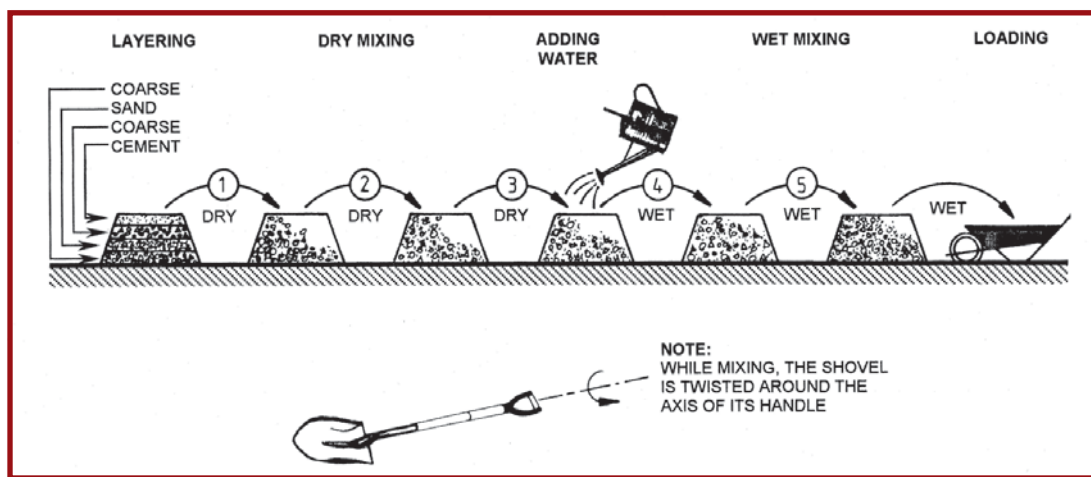
0.036 m<sup>3</sup> OR 36 LITRES

36 LITRES ARE EQUAL TO 1 (50 kg) BAG OF CEMENT

**Figure E.9.15: Batch box**

Concrete strength and durability depends particularly on the correct mix proportions as specified elsewhere in this Manual. Batching boxes (Figure E.9.15) or weighing methods should be used to ensure correct quantities. Volume batching should be carried out using batching or gauge boxes of volume equivalent to one 50kg bag of cement. A box of internal dimensions 400 x 300 x 300mm will have the correct unit volume of 0.036m<sup>3</sup>.

Hand (see Figure E.9.16 and Plate E.9.3) or machine mixing of concrete is acceptable. Either method must ensure complete mixing of the components. For Mechanical mixing the order of adding the materials to the drum should be: coarse aggregate, cement, fine aggregate, water. Water should be added at the specified water:cement ratio. Less water will not allow the materials to be properly mixed and placed. Too much water will lead to segregation and a weak concrete. If the aggregates are already wet, then adjustment of the quantity of added water will be necessary. The slump test should be used (see Figure E.7.16 in Section E.7.4.4) to check the water:cement ratio and workability of the wet concrete.



**Figure E.9.16: Concrete hand mixing**



**Plate E.9.3: Hand mixing mortar on a clean surface**



Wet concrete must not be transported long distances as segregation will occur. It must not be dropped more than 1.5 metres as this will also encourage segregation. Concrete should be vibrated with a mechanised immersion poker placed throughout the fresh wet concrete to agitate the particles into a compact matrix and expel the excess air. Over vibration must be avoided as this will result in segregation. The vibrator should be kept away from the formwork. For minor works and standard concrete grades it is acceptable to use lengths of reinforcing rods to agitate the concrete if a vibrating poker is not available. Good supervision is required to ensure a methodical process.

Finished concrete surfaces should be tamped and screeded with excess concrete removed and disposed of. Exposed surfaces should be finished smooth with a steel or wooden trowel. The finished surface of the concrete must be protected from rain within the first two hours after placing. Curing with water should commence three hours after casting. Concrete must be adequately cured for quality and durability and adequate arrangements must be made for this for at least the first 7 days after casting. Sacking or sand or other suitable material should be used to cover the concrete and retain the curing moisture/water. The surface of the concrete should be kept damp with repeated wetting during the curing period.

Formwork must not be removed until the concrete is strong enough to support its loading. Removal must be carried out carefully as point loads can damage "green" concrete.

A checklist for supervision or concreting works is shown in Table E.9.9.

**Table E.9.9: Supervision check box - Concreting**

- Permissible air temperatures for placing
- Clean water for concrete mix
- Correct mixing proportions (check especially that correct cement quantities used and that batches are weighed or gauge/batching boxes are used)
- Correct water:cement ratio (check workability with slump test)
- Concrete placed and compacted within 30 minutes of mixing
- Cure continuously (keep all surfaces damp) for at least 7 days

### 9.2.9

#### Precast concrete

Where possible and where transport arrangements allow, precast units can be built at a central location (eg culvert pipes or reinforced concrete beams). This should allow the benefits of efficient production arrangements and greater quality control.

Precast culvert rings should be carefully lowered into position using ropes or straps to control the operation. Particular care must be taken to prepare the bed to ensure uniform support of the pipe. Final adjustment of position should be carried out with the aid of crowbars. Joints should be mortared and protected (for example with banana leaves) prior to backfilling. After backfilling the joints should be inspected internally and repaired if necessary. Precast box culvert deck slab units or even bridge deck beams may be cast on site and then placed in final position. Crane or heavy lifting and moving equipment will be required for precast deck beams.

### 9.2.10

#### Timber stave culverts (Plate E.9.4)

These pre-treated timber culverts may be transported in component form to the site. The efficiency of the system means that a number of culverts can be transported in one truck load. The timber culvert is assembled with its binding hoops at ground level alongside the culvert site. It is then gently lowered into its permanent location. Particular care must be taken to ensure that the culvert does not move during backfilling and compaction.



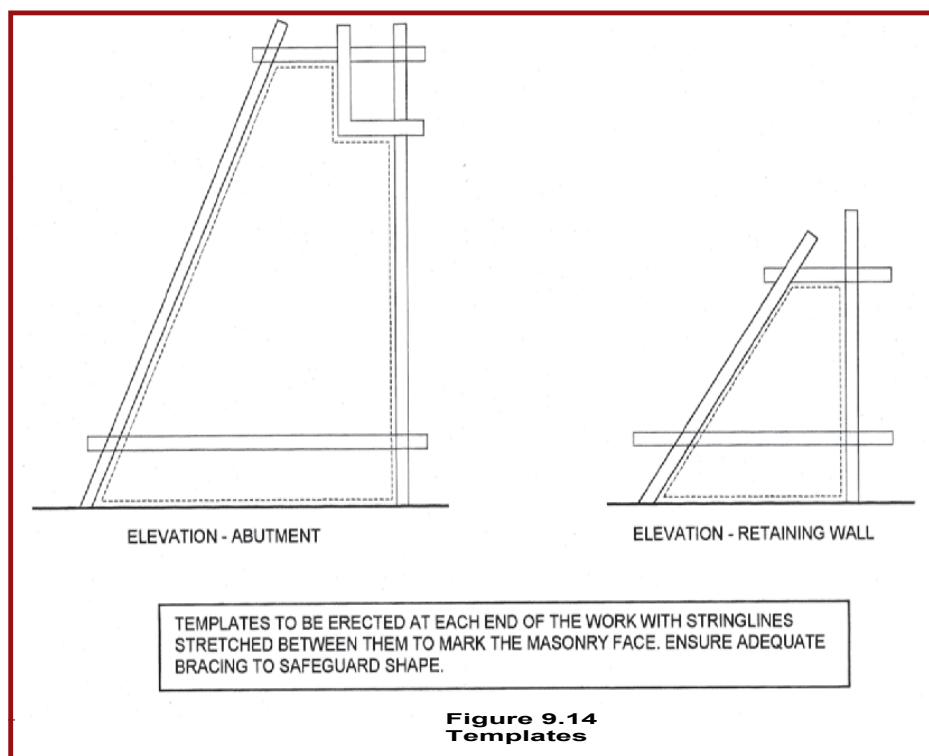
**Plate E.9.4: Timber stave culvert**



As with all precast unit systems, particular care is required to ensure a completely uniform bedding, surround and backfill operation to avoid later settlement or failure problems.

### 9.2.11 Masonry work

In masonry work, the corners and ends should be constructed first, with particular attention to verticality and alignment. String lines can then be stretched between the initial work to guide and ensure smooth faces and coursing of the subsequent work. Adequate bonding should be ensured with vertical joints staggered. A timber template may be fabricated to assist with constructing irregular shapes (see Figure E.9.17 and Plate E.9.5). Mortar must be used within 30 minutes of mixing. Masonry work should be cured as concrete.



**Figure E.9.17: Masonry Templates**



**Plate E.9.5: Example of Masonry works**

A checklist for masonry work is shown in Table E.9.10.

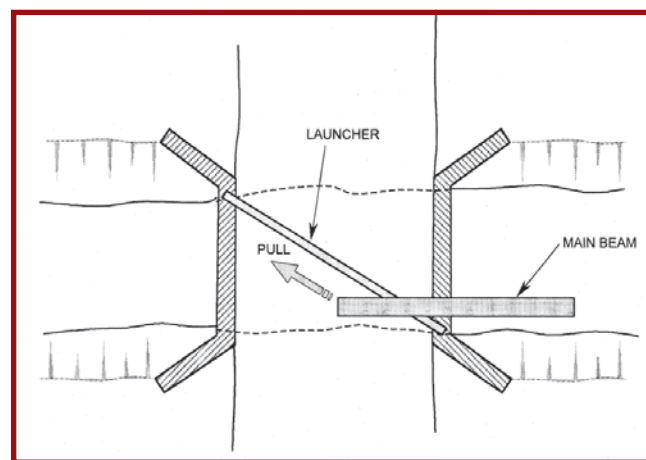
**Table E.9.10: Supervision check box - Masonry**

- Stone must be clean, sound and firm
- Vertical joints staggered
- Edges and corners true, and appropriate stones selected for these locations
- Faces true without irregularities, dishing or bulges
- All joints to be pointed to ensure effective load transfer and minimise water penetration

## 9.2.12 Timber superstructure

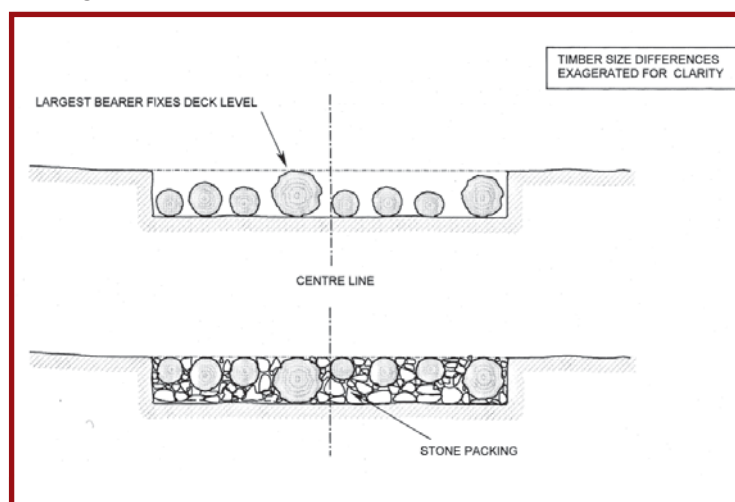
Although timber may be used for bridge abutments and piers, its eventual replacement can involve considerable work when resources may not be readily available. Timber beams, decks and running boards are comparatively low cost and easy to replace, and are discussed in the following text.

Sawn timber or logs can be used for bridge deck beams or bearers. Timber plank decking or running boards can be fixed to the timber bearers or to steel beams. All timbers should be carefully treated prior to installation to achieve acceptable service life. A small diameter pole or timber can be used to launch the first main beams across the bridge span as shown in the diagram, using log rollers and ropes if necessary. Once two main beams are in place then these can be used as a platform to manhandle the remainder of the main beams into place (see Figure E.9.18)



**Figure E.9.18: Timber beam launching**

Log bearers should be selected which are as straight as possible and do not taper substantially over their length. Log bearers will not all be of exactly equal diameter. After all bearers are in place they should be levelled with string lines and spirit level so that all top faces are reasonably level. They should then be packed with stones/bricks and mortared into position at the abutments and piers (Figure E.9.19). The ends of the logs should be concreted or mortared to discourage insect access. If logs vary in diameter along their length, then adjacent logs should be laid with their thick sections at opposite ends of the deck to provide uniform deck stiffness and strength.

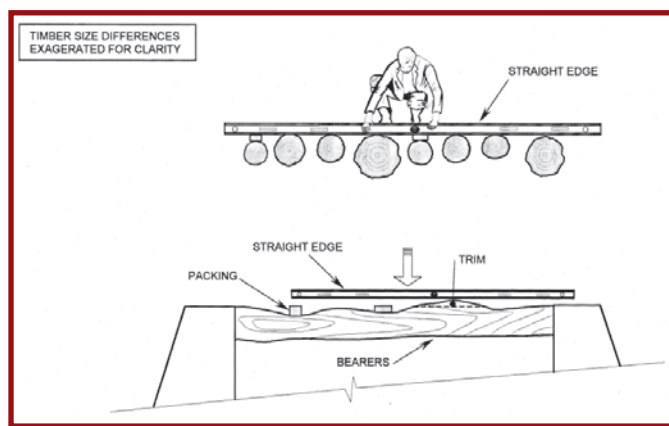


**Figure E.9.19: Log packing**



There will usually be high and low points on the log beams. These are either trimmed off with an axe or built up with packing to achieve a level area to which the deck planking can be fixed. Packing timbers should be at least 300mm long, treated and securely nailed to the bearers before the deck planking is laid.

Decking timbers are fixed by nailing or bolting at right angles to the main beams (even on a skew bridge). These timbers will spread the vehicle loads to the main beams. Each deck timber should be fixed to every beam as close to its centre as possible (Figure E.9.20).

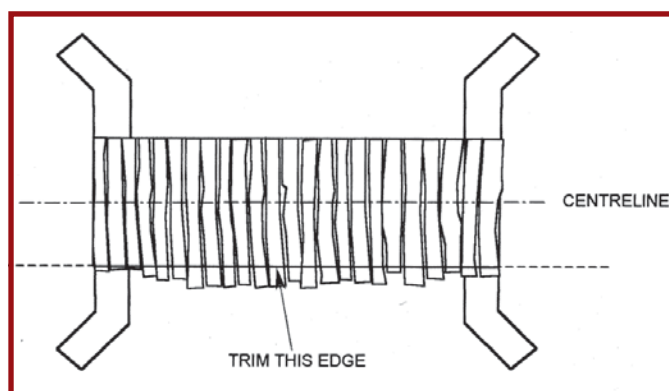


**Figure E.9.20: Fixing deck timbers**

If the timber is particularly hard the nail holes may need to be pre-drilled to a diameter slightly smaller than the nails to avoid the timber splitting yet achieve a secure fixing.

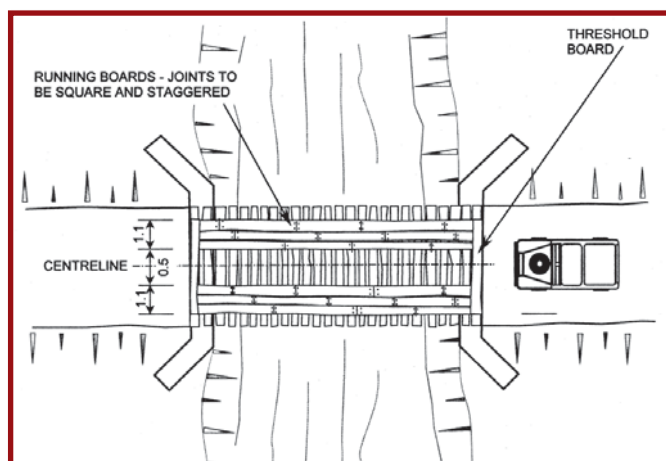
Excess timber should be trimmed from the ends of the deck planking.

Running boards are fixed to the decking by nailing or bolting. Heads should be recessed to avoid damage to vehicle tyres. Running boards should be laid to form a running surface for each wheel of at least 1.1m wide for safety. Joints in running boards should be staggered and cut square. All board ends must bear on a decking timber and be securely fixed to it and trimmed (see Figure E.9.21). A threshold board should be fixed across the end of the running boards at each end of the bridge. This will absorb the initial impact of a vehicle and protect the running boards.



**Figure E.9.21: Trimming running boards**

Kerb timbers should be fixed to the edges of the deck and parapets provided for pedestrian safety (see Figure E.9.22).

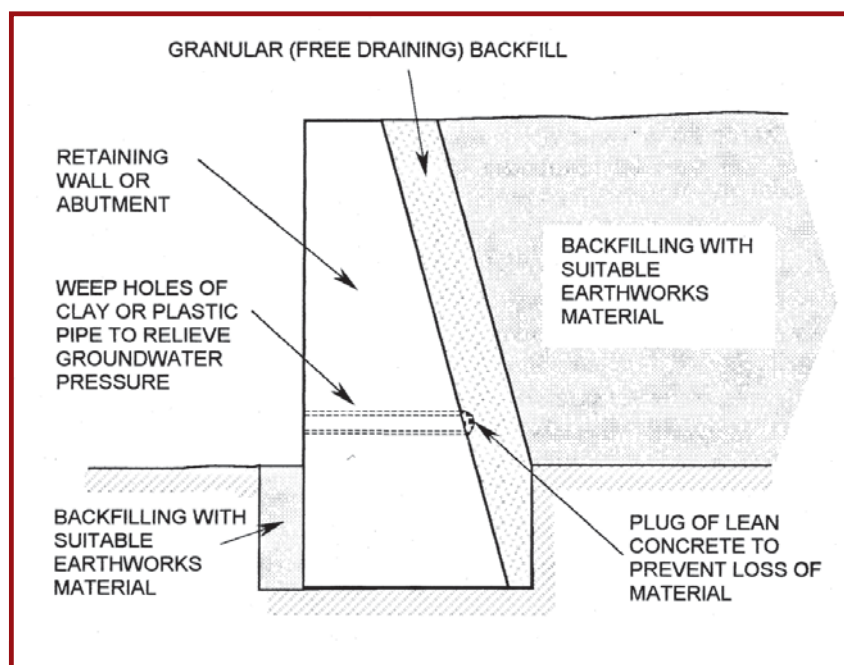


**Figure E.9.22: Kerb timber fixing**

### 9.2.13 Earthworks/Backfilling

Prior to backfilling, weep holes in masonry and concrete walls should be backed with a lean concrete plug. This will be porous to allow ground water drainage, but will prevent the backfill material from washing out.

Backfilling (Figure E.9.23) and compaction should be carefully and methodically carried out. Adjacent to structures it is usually not possible to use heavy compaction equipment; in confined spaces small plant or hand tools must be used. The backfilled area adjacent to the structure is particularly susceptible to settlement in contrast to the relatively rigid structure. Good procedures and supervision are required to minimise the risk of later settlement so that particular care must be taken within 5 metres of the structure. The control of layer thicknesses is important.



**Figure E.9.23: Backfilling**



Control of compaction should either be by “end-product” specification, or “method” specification. Nuclear density testing is quick and convenient and avoids the need for laboratory testing and time delay using the sand replacement density method. Method specifications rely entirely on the presence and integrity of an inspector throughout the filling and compaction process.

**Table E.9.11: Supervision check box - Backfilling**

- Backfill with selected suitable material in even layers of no more than 150mm thickness and thoroughly compacted. Material to be moistened if necessary to aid compaction.
- No large stones or rocks to be placed directly against structure.

## 9.2.14 Safety measures

Markers, chevrons and/or reflectors should be installed at the ends of the bridges to clearly show the extent of the structure and the vehicle path. Kerbs and ends of the structure should be painted white. Warning signs should be installed on the bridge approaches in accordance with the local traffic sign recommendations.

## 9.3 Site administration

The activities shown in Table E.9.12 will be required to be carried out in support of the site works. It is important to keep accurate records of the actual works carried out to compare to the planned progress, resource use and expenditure. This will help to ensure value for money. Any problems encountered should be recorded along with explanations of how they were overcome. This will assist in explaining any delays or cost over runs and help to improve future planning of structures.

**Table E.9.12: Checklist of site administration tasks**

- Set and review individual/gang task rates
- Daily muster roll and work achievement record for site labour force
- Daily diary of works achieved; problems encountered and methods of solving them should be recorded
- Update work programme
- Daily checks on site stores, tools, materials, re-order as necessary
- Daily checks and service of site equipment
- Testing of materials, inspection and quality control
- Prepare payrolls
- Arrangements for payment of labour force
- Keep a careful record of all costs
- Reporting of progress to client/senior management
- Safety and first aid arrangements

Weekly and daily programmes should be prepared based on the Bills of Quantities, the overall works programme and expected local productivities. Adjustments will be required to be made continuously based on actual experience. Weekly reports should be prepared for management monitoring purposes. Key indicators should be used to monitor the progress of the work, such as cement or worker days used against the quantities planned.

For structures, ‘as-built’ drawings should be prepared; these should particularly record differences from the original design, and important details such as actual foundation levels and concrete strengths. If there are no changes, this is also valuable information.

A cost analysis of the completed structure should be carried out to enable cost estimating of future structures to be more accurate.

A final inspection of the completed structure should be carried out prior to handing over to the authority that will be responsible for its maintenance. The following chapter discusses maintenance arrangements.

It is advisable for an independent performance audit to be carried out on a completed structure to review the works. This should verify the structure's 'fitness-for-purpose' and value for money.



## 10.

## MAINTENANCE

Cross drainage structures 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 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 culvert, bridge 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' (eg 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 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 (eg corrosion, attack by insects), or suddenly (eg 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.

### 10.1 Managing the structure

The maintenance works required to be carried out on a structure will range from basic seasonal clearing of silt and debris 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 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 (ie 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 provides comprehensive guidelines on the inspection and documentation of inventory and condition information on structures. A paper based system is quite adequate. 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 ongoing 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. 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 (eg 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.



10.2 Maintaining the structure

Structure maintenance activities can be grouped into regular routine maintenance (Table E.10.1) and periodic major operations.

Table E.10.1: Structure - Routine

<ul style="list-style-type: none"><li>1.Cleaning/clearing<ul style="list-style-type: none"><li>sweeping</li><li>de-silting</li><li>unblocking</li><li>removal of vegetation and flood/wind borne debris).</li><li>(This includes inlets and outlet channels as well as culvert openings themselves)</li></ul></li><li>Repair of loose/missing connectors and fixings</li><li>Replacement of damaged/missing planks or kerbs</li><li>Painting</li><li>Wood preservation</li><li>Pointing/repair of masonry</li><li>Repair of parapets, marker posts, safety barriers and features/signs</li></ul>
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Table E.10.2: Structure - Periodic

<ul style="list-style-type: none"><li>Random stone filling</li><li>Retaining wall repairs</li><li>Riverbed scour repairs</li><li>Gabion repairs</li><li>Structural repairs to the following defects:-<ul style="list-style-type: none"><li>structural timber decay, splitting or insect attack</li><li>bulging masonry</li><li>cracked concrete or masonry</li><li>honeycombed concrete</li><li>spalling concrete</li><li>serious rust or chemical stains</li><li>exposed or corroding reinforcement or pre-stressing steel</li><li>damp patches on the concrete</li><li>seriously corroded structural steelwork</li><li>damaged/distorted structural steelwork</li><li>loose structural rivets, bolts or other fixings</li><li>cracks in structural steelwork</li><li>settlement of deck, piers, abutments or wingwalls</li><li>expansion joint or bearing defects</li><li>erosion requiring piling works</li></ul></li></ul>
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Major repairs will generally require technical expertise for the design and supervision of remedial work.

Maintenance works should be planned, organised and supervised using the guidelines set out in the previous construction chapter. Maintenance records should be kept for each structure, which include:

- Estimates of work proposed;
- Details of work carried out;
- Date of completion of the repair;
- Supervisor's quality control reports;
- Actual costs of repair.

Storage of information should be on a structure by structure basis so that the complete history can be easily viewed.

Further guidance on maintaining structures is provided in the PIARC International Road Maintenance Handbook, Volume 4. The handbook includes advice on the defects, resources and maintenance methods involved.

### 10.3 Common maintenance requirements

Damage due to scour and erosion is the most likely cause of major or unrepairable damage to a structure. Once scour or erosion around a structure starts the damage can increase very rapidly. It is therefore essential that maintenance is carried out quickly to prevent further structural damage.

#### 10.3.1 Drifts

The drift must maintain a firm roadway across the width of the river which is not covered by debris or eroded by the flood water. The face of the river embankments should also be protected against scour and erosion. It may be possible to encourage the growth of vegetation along the banks to improve the bank stability and prevent erosion. The common maintenance issues to address are:

- Cracking of the slab;
- Undercutting on the downstream side;
- Erosion at ends of slab where it is not extended above high flood levels;
- Lack of downstream protection;
- Guidestones knocked off.

#### 10.3.2 Culverts

The most common maintenance problem associated with culverts is blockage due to silt and other debris. Hence regular cleaning of the culverts is essential as illustrated in Plates E.10.1 and E.10.2. A blocked culvert can result in damage to the road in 3 ways:

1. Water can seep into the subgrade of the road and reduce its strength. The road will tend to subside and the road surface will break up.
2. The water can undermine the head and wingwall of the culvert causing it to collapse. The road embankment will then be unsupported and rapidly subside.
3. In an extreme case the water level may continue to increase until the water floods over the road. The road may then become impassable and major damage occur as the water erodes the road and culvert. Ultimately the road will be washed away and a large gully will be scoured across the road.

Water discharging from culverts with excessive velocity will erode the stream bed and possibly undermine the whole structure. It is therefore essential to provide some form of protection to the beds below the outlet of a culvert. The protection is usually in the form of a masonry apron. It may also be necessary to prevent erosion of the watercourse itself further downstream of the culvert. Bio-engineering planting may be an appropriate and low-cost solution.



**Plate E.10.1 and Plate E.10.2: Culvert cleaning tool**



The main cause of blockage of culverts is by water carried debris and vegetation (Plate E.10.3). Larger debris tends to collect at the entrance to the culvert causing blockage at the headwall, while silt is deposited in the culvert barrel. Long grass at the outlet of a culvert can cause silting at the outlet and eventual blockage of the culvert. It is therefore necessary, particularly before the rainy season, to clean culvert barrels, inlets and outlets to allow water to flow freely through the culvert.



**Plate E.10.3: Box culvert partially blocked by vegetation**

Any material removed from a culvert should be disposed of downstream of the culvert to prevent it washing back into the structure. Other common defects that require maintenance to be carried out on culverts include:

- Downstream erosion;
- Headwall knocked down or damaged;
- Outfall channel eroded or silted;
- Undercutting of the culvert outfall apron;
- Ponding of water at the inlet and/or outlet causing subsidence of the road embankment.

### 10.3.3 Vented drifts and large bore culverts

The common maintenance requirements with vented fords and large bore culverts are similar to culverts and drifts (Plate E.10.4). In addition to the issues discussed above the following defects may need to be corrected during maintenance:

- floating debris, such as tree branches, can block the culvert barrels;
- cracking and breaking of roadway slab;
- cracking and breaking of structure faces.



**Plate E.10.4: Cleaning the drop inlet and barrel of a large bore culvert**

## 10.3.4

**Bridge Maintenance**

The substantially larger investment in bridges, compared to smaller structures, justifies greater attention to inspection and maintenance of these vital road components. The consequences of failure due to lack of maintenance can be routes being severed for considerable period with serious adverse social and economic outcomes. It is therefore important to establish a regime of regular bridge inspections and active maintenance response works.

Inspections should be formulated on a regular basis to identify and initiate maintenance repairs for the following possible defects:

- Minor Defects (non-structural)
  - Accumulation of dirt or soil on bridge deck;
  - Blocked scuppers;
  - Stones, soil or dirt in joints or around bearings;
  - Vegetation or soil in weep holes or in backfill drainage outlets;
  - Flood debris at or under bridge;
  - Wind-blown debris on or under bridge.
- Minor Defects (structural)
  - Loose or missing nailed/bolted connectors or fixings;
  - Damaged running boards or deck planks;
  - Rusty steel, faded paint;
  - Untreated wood;
  - Defective masonry joints.
- Minor Defects (Safety)
  - Damaged safety barrier or parapet;
  - Damaged warning signs.

The following defects may require major repair works and specialist expertise to ensure appropriate remedial works. The inspection system should initiate mobilisation of the necessary expertise when these defects are identified:

- Major Defects
  - Scour adjacent to structure;
  - 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;
  - Damp patches on the concrete;
  - Seriously corroded structural steelwork;
  - Damage/distorted structural steelwork;
  - Loose structural rivets, bolts or other fixings;
  - Cracks in structural steelwork;
  - Settlement of deck, piers or abutments;
  - Erosion requiring piling works;
  - Vehicle Impact damage (especially to steel panel bridges).

Further guidance on bridge and structures maintenance is available from the PIARC International Road Maintenance Handbook Volume IV.





***Plate E.10.5: Serious vehicle impact damage to steel panel bridge***

## 11.

## REFERENCES



The references below may be used to supplement the information contained in this Manual. In order to assist readers in the selection of relevant additional information the following information has been provided with each reference;

- list of the topics covered
- a brief review of the issues discussed in each reference
- contact details of selected publishers

Many of the documents and further information on specific topics may be accessed on the global Transport Knowledge Partnership website: [www.gtkp.com](http://www.gtkp.com)

Berger L, Greenstein J, Arrieta J, 1987, *Guidelines for the Design of Low Cost Water Crossings*, TRR 1106, Transportation Research Board, Washington

(Finance, Bridges, Design, Materials) pp10

- This paper reviews the different designs and materials used for the construction of bridges on low volume roads in Central America. The article indicates that the standards used on these roads need only be suitable for vehicles up to 10 tonnes, resulting in major cost savings when compared with full specifications. The use of gravelled fords, split deck concrete bridges and timber bridges are discussed. The paper outlines a design for timber bridge decks.

Brandon T, 1989, *River Engineering – Part 2, Structures and Coastal Defence Works*, Institute of Water and Environmental Management, London

(Design, Hydraulics, Maintenance) pp332

- This book is the second of two volumes and covers the design, construction and maintenance of water structures. It is primarily concerned with the design of river control structures such as locks, weirs and sluices, but also includes limited discussion on river protection, culverts and bridges. There are two useful chapters on maintenance issues and construction planning and management.

Clark J, Hellin J, 1996, *Bio-Engineering for Effective Road Maintenance in the Caribbean*, Natural Resources Institute, Chatham, UK

(Environmental, Materials, Erosion Protection, Slope Stability) pp122

- This book discusses the use of vegetation for the control of erosion and stabilising slopes, indicating the functions different types of vegetation can perform. Six simple techniques are described, along with the vegetation species that may be used, which are useful in the road sector for drainage control. The book also contains a large section which gives background details of eleven species which are suitable for bio-engineering. These species are normally found in the Caribbean, however the description of the species and specification of different planting material should allow practitioners in other areas to make use of the information.

Dzung Bach The, Petts Robert, 2009, *Report on Rice Husk Fired Clay Brick Road Paving, Vietnam*, global Transport Knowledge Partnership

- This report documents the experiences in Vietnam of the established practice of burning high quality clay bricks for building and road works use. The flexibility of the process suggests that other agricultural wastes could be used to produce high quality clay bricks for structures and other road works uses.

Ethiopian Roads Authority *Bridge Design Manual - 2011*

- This manual is the principal design reference for highway and road structures in Ethiopia.

Farraday R, Charlton F, 1983, *Hydraulic Factors in Bridge Design*, Hydraulics Research, Wallingford

(Bridges, Design, Hydraulics, Erosion Protection) pp102

- This book explains in fairly simple terms the different hydraulic issues which need to be addressed when designing bridges over rivers. It describes the data which needs to be collected and a step by step design process which must be undertaken to ensure that bridges will be able to withstand the



loads exerted by the water and changing flow patterns due to scour of the river bed. Each chapter is extensively referenced.

Flavell D. (ed), 1994, *Waterway Design*, Austroads, Sydney  
(Bridges, Culverts, Design, Hydraulics) pp138

- This book provides guidance on the selection of design floods required for the various aspects of the design of waterway structures and the hydraulic design of bridges, culverts and floodways. It also provides information for the design of works required to protect these structures from the effects of scour.

Gupta D P, 1997, *Manual on Route Location, Design, Construction and Maintenance of Rural Roads*, Special Publication 20, Indian Roads Congress, New Delhi  
(Design) pp108

- This book primarily covers the design and construction of roads, however it has two chapters covering drainage and cross drainage structures. Other sections of the book highlight design issues which are affected by highway structures. This book would be a useful reference if structures were to be designed on a new road.

Heyman J, 1980, *The Estimation of the Strength of Masonry Arches*, Proc. Institution of Civil Engineers Part 2 Dec 1980  
(Design) pp921-937

- This paper discusses the development of the simplified method for estimating the strength of masonry arches by the military load classification. It discusses the mathematical proof of the assumptions made and explains that the strength of an arch is closely related to its span and crown thickness. The paper suggests that nomographs could be used to predict strength with correction factors used to account for span/rise ratio, mortar condition and quality of material used.

Hindson J, 1983, *Earth Roads: Their Construction and Maintenance*, IT Publications, London  
(Culverts, Design, Drifts, Erosion Protection, Site Construction) pp124

- This book covers the design and construction of earth roads for traffic up to about 50 vehicles per day. It concentrates on the control of water through drainage control measures. The first half of the book deals with the theory of road design which includes splashes, drifts and culverts. The second half of the book deals with the techniques of construction offering different solutions for different topological conditions. The second half of the book also includes a section on maintenance.

ILO, 1991, *Stone Masonry*, (Training Element and Technical Guide for SPWP Workers Booklet 2), UNDP/ILO, Geneva  
(Materials, Site Construction) pp84

- This booklet covers the design, construction and maintenance of small masonry structures which include culverts and small headwalls. It may be used as a technical manual for site personnel or as the basis for a training course for site supervisors in the use of masonry for construction.

ILO, 1986, *Gabions*, (Training Element and Technical Guide for SPWP Workers Booklet 3), UNDP/ILO, Geneva  
(Materials, Site Construction) pp84

- This booklet is similar to its predecessor covering stone masonry. It does not specifically deal with highway structures but highlights the uses of gabions and how they should be constructed.

Jayanetti, L. 1990, *Timber Pole Construction*, IT Publications, UK  
(Materials) pp64

- Although not focused on road structures this book provides information to designers of timber pole bridges.

Jones T, Parry J, 1993, *Design of Irish Bridges, Fords and Causeways in Developing Countries*, Highways and Transportation (Jan 1993), Institution of Highways and Transportation, London  
(Drifts) pp28-33

- This article explains the differences between the different types of low level water crossing. It discusses site selection and the materials which may be used for different crossings. The article also describes with a series of photographs and diagrams the key design points of the different structures.

Kadam S.P, 1993, *Vented Paved Dips for Rural Roads*, Indian Highways (Design, Hydraulics, Drifts) pp14

- This paper discusses the use of vented fords on rural roads to allow for monsoon rains. It concentrates on the issues of scour downstream of the structure but also discusses the hydraulics of a vented ford when it is being overtopped. The optimum dimensions for a structure are provided which include a standard construction drawing.

Khanna, P.N. , 1996, *Indian Civil Engineer's Practical Handbook*, 15th Edition, Engineer's Publications, New Delhi.

(Design, Site Construction)

- This book provides a wide range of practical information for engineers involved in the design, planning and construction of civil engineering projects. The handbook contains a chapter specifically covering the engineering aspects of roads and road structures, in addition to chapters covering surveying, setting out, material properties and basic design principles.

Lal G, 1995, *Guidelines for the Design of Small Bridges and Culverts*, Special Publication 13, Indian Roads Congress, New Delhi

(Bridges, Culverts, Design, Hydraulics, Drifts, Erosion Protection) pp176

- This book covers the complete design of small bridges and culverts from the collection of the initial design data to the preparation of construction drawings. It concentrates on the mathematics of the estimation of maximum water flows and scour around structural supports. However, other empirical results and solutions are also described throughout the book to simplify the design process where applicable.

Morris, J, 1995, *Earth Roads*, Avebury

(Bridges, Culverts, Drifts, Materials, Maintenance, Erosion Protection, Site Construction) pp304

- This book is a practical guide for managers and engineers of agricultural estates to provide guidelines and advice on how roads can meet the needs of their commercial operation. It concentrates on earth and other unsealed roads in developing countries, but has extensive sections covering bridges and culverts. The majority of the solutions discussed make use of timber which is likely to be available as a by-product from the agricultural operations.

PIARC, 1994, *International Road Maintenance Handbook*, Transport Research Laboratory (for the World Road Association (PIARC)), UK

Vol. 1 Maintenance of Roadside Areas and Drainage,

Vol. 2 Maintenance of Unpaved Roads,

Vol. 3 Maintenance of Paved Roads,

Vol. 4 Maintenance of Structures and Traffic Control Devices (Maintenance)

- These four handbooks are aimed at the supervisors of road maintenance contracts. They explain the causes and the measures required to prevent road deterioration. Each maintenance task is addressed in turn with simple text and illustrations to show the labour and tools required to carry out the task.

Shadmon, A, 1989, *Stone; An Introduction*, IT Publications, London

(Materials), pp184

- This book provides a good introduction to the extraction and use of both field and cut stone. It describes the different types of stone and outlines tests that can be carried out to determine the tensile and compressive strength of stone samples.

Spence, R, and Cook D, 1983, *Building Materials in Developing Countries*, John Wiley and Sons.

(Materials) 356pp



- This book provides practical information about various building materials commonly available in developing countries. The majority of the information is focused on housing construction. However, a significant proportion of the information available will be useful to designers of road structures.

Stern, P. et al, 1983, *Field Engineering*, IT Publications, London  
(Bridges, Culverts, Design, Maintenance, Site Construction) pp272

- This book is aimed at individuals working on engineering projects in rural areas. It has a detailed section dealing with site survey and setting out techniques. In addition to sections on roads, simple river crossings and bridges, it also covers water supply, sanitation and small dams.

Stulz, R and Mukerji, K, 1993, *Appropriate Building Materials*, SKAT, St Gallen, Switzerland.  
(Materials) 456pp

- This book provides technical data and practical information about various building materials for low cost construction. The majority of the information is focused on non road structures. However, a significant proportion of the information available will be useful to designers of road structures.

Thagesen B (ed), 1996, *Highway and Traffic Engineering in Developing Countries*, E & FN Spon, London  
(Culverts, Design, Maintenance, Site Construction) pp485

- This textbook covers the planning, design, construction, maintenance and management of roads in tropical developing countries. It contains a section on drainage design which covers hydrology and hydraulic design and another section which discusses maintenance strategies and management.

TRL, 1988, *Bridge Inspectors Handbook Vol. 1 & 2, (ORN7)*, Transport Research Laboratory, Crowthorne, UK  
(Bridges, Culverts, Maintenance) pp40 & pp250

- The object of these two volumes is to allow a district engineer to establish and operate an effective bridge and culvert record system. The guide explains the principles of record keeping and contains a series of proforma record sheets. The pocket size handbook (Vol. 2) deals with the actual inspection, highlighting, through the use of photographs and drawings, the items which should be checked and recorded.

TRL, 1992, *A Design Manual for Small Bridges, (ORN9)*, Transport Research Laboratory, Crowthorne, UK  
(Bridges, Culverts, Design, Hydraulics, Drifts, Materials, Maintenance, Erosion Protection, Site Construction) pp223

- This manual prepared by TRL offers a comprehensive set of guidelines to highways engineers for the design of small bridges and culverts. It covers the whole process from the planning stage to the final preparation of detailed specifications and drawings. It is intended for practising engineers who may not be highway specialists. The designs which are discussed in the manual are appropriate for relatively large roads or traffic flows and predominantly utilise reinforced concrete.

TRL, 1997, *Principles of Low Cost Road Engineering in Mountainous Areas (ORN16)*, Transport Research Laboratory, Crowthorne, UK  
(Culverts, Environmental, Erosion Protection, Slope Stability) pp150

- This manual describes and explains techniques for designing, constructing and maintaining roads in mountainous areas. It contains sections on drainage and retaining walls as well as methods to control erosion and maintain slope stability.

Tufnell R, 1995, *Dry Stone Causeways*, Appropriate Technology Vol. 22 No. 1, IT Publications, London  
(Drifts, Materials) pp3

- This article explains in simple practical terms, with sketches, how to build a masonry causeway or vented ford.

Watkins L and Fiddes D, Highway and Urban Hydrology in the Tropics, Pentech Press, London

#### **Selected publishers' addresses:**

- Austroads:  
Suite 2, Level 9, 287 Elisabeth St, Sydney, NSW 2000, Australia  
Fax: +02 264 1657, [www.austroads.com.au/](http://www.austroads.com.au/)
- Global Transport Knowledge Partnership (gTKP), Chemin de Blandonnet 2, 1214 Vernier, Genève, Switzerland, [www.gtkp.com](http://www.gtkp.com)
- Hydraulics Research:  
Hydraulics Research Station Ltd, Wallingford, Oxfordshire, UK,  
[www.hrwallingford.co.uk](http://www.hrwallingford.co.uk)
- International Labour Organisation (ILO):  
4 route des Morillons, Geneva, CH 1211, Switzerland,  
[www.ilo.org/public/english/](http://www.ilo.org/public/english/)
- Indian Roads Congress (IRC):  
Sector 6, (Near RBI Quarters), R K Puram, New Delhi- 110022, India,  
[www.irc.org.in](http://www.irc.org.in)  
Institute of Agricultural Engineers:  
The Bullock Building, University Way, Cranfield, Bedford, MK43 0GH,  
UK, [www.iagre.org](http://www.iagre.org)
- Institution of Civil Engineers (ICE):  
1 Great George St, Westminster, London, SW1A 3AA, UK, [www.ice.org.uk](http://www.ice.org.uk)
- Intermediate Technology Publications / Practical Action Publishing:  
The Schumacher Centre for Technology & Development, Bourton on Dunsmore, Rugby,  
Warwickshire CV23 9QZ, United Kingdom, [www.practicalactionpublishing.org/publishing](http://www.practicalactionpublishing.org/publishing)
- Natural Resources Institute (NRI):  
University of Greenwich at Medway, Central Avenue, Chatham Maritime, Kent, ME4 4TB  
United Kingdom, [www.nri.org](http://www.nri.org)
- Transportation Research Board (TRB):  
The National Academies, 500 Fifth Street, NW, Washington, DC 2000, USA,  
[www.trb.org](http://www.trb.org)
- Transport Research Laboratory (TRL):  
Crowthorne House, Nine Mile Ride, Wokingham, Berkshire, RG40 3GA,  
United Kingdom, [www.trl.co.uk](http://www.trl.co.uk)