MINISTRY OF RURAL DEVELOPMENT

ROYAL GOVERNMENT OF CAMBODIA

SOUTH EAST ASIA COMMUNITY ACCESS PROGRAMME

DEVELOPMENT OF LOCAL RESOURCE BASED STANDARDS

SEACAP 19

Rural Road Standards and Specifications:

Classification, Geometric Standards and Pavement Options

Final Project Report

May 2009

UNPUBLISHED PROJECT REPORT

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Final Project Report

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ABBREVIATIONS AND TERMINOLOGY

AASHTO	American Association of State Highway and Transportation Officials
AADT	Average Annual Daily Traffic (sum in both directions in PCUs –passenger car units)
ADB	Asian Development Bank
ADT	Average Daily Traffic (same as ADT)
CBR	California Bearing Ratio
CC	Commune Council
CNCTP	Cambodia National Community of Transport Practitioners
CRC	Community Road Committees
CREAM	Cambodia Rural Roads Economic Appraisal Model
CSIR	Council for Scientific and Industrial Research (South Africa)
DBM	Dry Bound Macadam
DBST	Double Bituminous Surface Treatment
DCP	Dynamic Cone Penetrometer
DfID	Department for International Development
E	Elastic modulus
ENS	Engineered Natural Surface
esa	equivalent standard axles
RGC	Royal Government of Cambodia
gTKP	global Transport Knowledge Partnership
GVW	Gross Vehicle Weight
HDM4	Highway Development and Management Model
IFRTD	International Forum for Rural Transport Development
ILO	International Labour Organisation
IRI	International Roughness Index
KN	Kilo Newtons
km	kilometre
LCS	Low Cost Surfacing
LVRR	Low Volume Rural Road
m	metre(s)
mesa	million equivalent standard axles
MDG	Millenium Development Goal
MN	Mega Newtons
mm	millimetres
MPa	Mega Pascals
MPWT	Ministry of Public Works and Transport

MRD	Ministry of Rural Development
ORN	Overseas Road Note
PCU	Passenger Car Unit
Pen Mac	Penetration Macadam
PIARC	World Road Association
PDRD	Provincial Department of Rural Development
psi	pounds per square inch
QA	Quality Assurance
RRGAP	Rural Road Gravel Assessment Programme (Vietnam)
RRSR	Rural Road Surfacing Research (Vietnam)
RRST	Rural Road Surfacing Trials (Vietnam)
SBST	Single Bituminous Surface Treatment
SE	Super-elevation
SEA	South East Asia
SEACAP	South East Asia Community Access Programme
SIDA	Swedish International Development Cooperation Agency
T	Tonne
TRL	Transport Research Laboratory
UK	United Kingdom
UNDP	United Nations Development Programme
US	United States
VN	Vietnam
VOCs	Vehicle Operating Costs
VPD/vpd	Vehicles per day
WB	World Bank
WBM	Water Bound Macadam
WLC	Whole Life Costs

CONTENTS

1 Introduction

1.1 Background and Context

Reducing transport costs through rural road improvement generates significant reductions in poverty. It does this through improving the income earning opportunities of rural people and through reducing the costs of the goods they consume. During the past 20 years or so, DfID and other Donors have supported research on various aspects of low volume roads specifically with the aim of reducing costs and increasing the effectiveness of the provision of such roads for rural and peri-urban communities. Much of this research has been highly successful, resulting in innovative and unconventional approaches that can provide highly beneficial and cost effective solutions for low volume roads in these counties, for example, the use of alternative sustainable road surfacings.

Key to the success of these innovative solutions is recognition that conventional assumptions regarding road design criteria need to be challenged and that the concept of an appropriate, or Environmentally Optimised Design, approach provides a way forward. Low volume road standards and designs need to support the *task* that the road is providing, namely the traffic and its composition, as well as recognising the important influences of the deterioration mechanisms. For example, the use of locally available, but frequently non-standard, pavement construction materials plays a significant role within this concept.

International and regional research in recent years has shown that, compared with roads designed for high levels of traffic, low volume rural roads (LVRRs) respond to the range of factors collectively known as the “road environment” in a quantitatively different way. One of the implications from this is that appropriate road design options need to be specially researched and adopted for LVRR regimes.

1.2 Requirement

Undertaking research and developing likely solutions is not nearly enough. There has to be a framework within which they can be mainstreamed. Suitable rural road Standards are therefore seen as essential to provide the context within which local resource-based pavement options may be assessed and selected for appropriate use. These standards should ideally identify classes of rural road in terms of usage and geometry that can be linked to sustainable pavement options defined by appropriate technical specifications.

Many low volume rural road alignments may have developed over the years from tracks rather than being newly constructed and hence little attention may have been given to imposing overall rural road Standards. The result may be that there are basic design deficiencies on existing rural roads, with variable widths and geometry and poor drainage provisions. This situation may be further compounded by the number of Donors, Agencies and NGOs involved in developing the Cambodian rural infrastructure utilising their own standards.

Appropriate overall rural road Standards involving Classification and Geometric Design are therefore seen as a priority by the RGC and MRD. The design standards should take into account the road environment, road conditions, traffic characteristics, driver behaviour and the technology available for construction. In so doing, the design aims to provide a road with an alignment and cross-section that are not only the best compromise between operational efficiency, safety and economy but also minimises any adverse environmental and social/cultural impacts.

1.3 Document Objectives

This principal objective of this document is to describe proposed rural road Classification and Geometric Standards that are recommended for formal adoption by the Ministry of Rural Development. It is also includes technical explanations of all the steps in deriving the classification and geometric standards as well as containing a matrix of structural designs for suitable for use with the proposed classification and standards.

A summary of the Rural Road Classification and Geometric Standards is included as an appendix to the document. This is essentially a summary of the classification and geometric standards without any technical details of their derivation. It is aimed at the engineer or planner who simply needs to look-up the values of all the key parameters.

This document focuses on pavement issues and does not deal with structures (bridges and culverts), earthworks, drainage or maintenance issues.

1.4 Principles

A road classification based on road task allows for a consistent treatment of all similar roads within the infrastructure system in terms of their design, construction, maintenance requirements, users expectations, and safety.

The main objective of the rural road Classification and Geometric Standards is that they must be appropriate for Cambodia in terms of current road usage and rural infrastructure developments. They should be:

- Task based – they suit the road function and its traffic (the people as well as the vehicles) which will pass along them.
- Local resource-based and compatible with the road sector in Cambodia: the engineers and technicians who will design the roads, the contractors and labourers who will construct them, the villagers who maintain them and the construction materials that are available.
- Finally they must facilitate the construction of roads with whole life asset costs that will not exhaust the provincial and district budgets or place excessive maintenance burdens on local communities.

The rural road Standards are intended for application in the construction or upgrade of all-weather roads so as to provide all-year basic access to villages and communities with minimal disruption. Good road engineering principles have been adhered to and careful consideration has been given to the safety of pedestrian, non-vehicular traffic, and light 2 or 3-wheeled motorized traffic.

1.5 The Low Volume Rural Road Environment

The Rural Road Standards have been drafted with a view to their application in an Environmentally Optimised Design (EOD) strategy that takes full account of the various road environment impact factors within two principle categories; task and environment. EOD can be considered as the over-arching principle for a range of practical actions for improving or creating low volume rural access – from dealing with individual critical areas on a road link (Spot Improvements) to providing a total whole rural link design, which, in the latter case, could comprise different design options along its length.

Some of the road environment factors have impact upon the surface of the road, some on the pavement and others on geometric aspects such as width, gradient and curvature..

2 Rural Road Classification

2.1 Introduction

Rural public roads in Cambodia are currently categorised as follows (MRD's Policy for Rural Roads).

- National (the responsibility of the Ministry of Public Works and Transport)
- Provincial (the responsibility of the Ministry of Public Works & Transport)
- Other Rural (the responsibility of Ministry of Rural Development).

The 'Other Rural' category is subdivided into four categories based on an administrative classification as follows,

- Tertiary roads – connecting district centres
- Sub-tertiary 1 – connecting district centres to communes
- Sub-tertiary 2 – connecting commune to commune
- Sub-tertiary 3 – connecting villages to other villages or to commune centres.

Thus the classification is not currently based on the characteristics of the traffic that the road has to carry (types of vehicles, their volume and numbers of non-motorised users). This distinction is important because, from an engineering point of view, roads should be designed for the task that they are expected to perform, namely to carry the traffic.

2.2 Traffic

The arguments in favour of classifying the roads for design purposes based on administrative classes appears to be based on the need to cater for the problem of lack of information about both current and future traffic. Roads are designed to provide good service for many years and therefore the traffic level to be used in the design process must take into account traffic growth. Designing for the current traffic will invariably lead to inadequate standards in the future unless the traffic growth rate is extremely low.

To deal with these uncertainties it is generally expected that there is (or will be) a strong correlation between traffic level, traffic growth rates and the administrative function of a road and therefore an administrative classification is seen as a suitable alternative to represent traffic. However, although traffic levels often increase in line with the administrative classification, this is not always true and, furthermore, the traffic levels are likely to differ considerably between different areas and different regions of the country. For example, the traffic on a commune-to-commune road in one area of the country might be considerably more than on a district-to-commune road in another area. The design of the road should reflect this.

Secondly, traffic growth rates are also expected to be considerably higher on roads connecting district centres than on roads connecting villages. A simple example will illustrate that this argument is unlikely to be true. Consider the introduction of a single development activity in or near one of the villages. This is likely to attract traffic to and from neighbouring villages and this is likely to represent a considerable percentage increase i.e. a high growth rate, because existing traffic is low. The new development is also likely to increase the traffic to the district centre but the traffic on the district road is already likely to be quite high (in comparison with the village roads) hence the *growth* rate will be correspondingly low. Ignoring traffic passing through, only if *all* the village roads exhibit a high growth rate will the same growth rate occur on the district roads.

An administrative classification is necessary to enable ownership, responsibilities, resources and management to be assigned but such a classification should not be the basis for engineering design.

For geometric design it is the daily traffic that is important (for structural design, cumulative traffic is used). There are essentially three ways in which the design traffic is estimated. Two of them require a value for the ‘design life’ of the road. Recommendations for this vary widely ranging from 10 years to 30 years. It is normally considered prudent to opt for a shorter design life in areas where future growth is uncertain, either potentially high, but also potentially very low. A design life of 15 years is recommended for Cambodia. The three methods are;

1. Designing for the traffic expected to use the road in the middle of its design life. This requires an estimate of the growth rate. This is the method recommended for Cambodia.
2. Designing for the traffic expected to be using the road at the end of its design life. This also requires an estimate of the growth rate but, in view of uncertainties in long term predictions, the true traffic after 15 years might be considerably in error. However, this method is necessary where traffic is high and where in the later years it is likely to exceed the capacity of the road; in other words, if serious congestion is possible. For the Rural roads being considered here, this is very unlikely hence this method is not recommended.
3. The third method (TRL, ORN 6) relies only on knowledge of the current traffic. It is based on defining carefully the traffic ranges for each class of road in terms of traffic increments. The method then requires the user to estimate the current traffic and then to carry out the design based on the next higher class of road. Whilst this is simple, it can lead to significant errors when traffic is near to the class boundaries because it can result in the same design for both low and high growth rates which cannot *both* be suitable in the middle years of the design life.

Where there is no existing road of any sort, estimating the initial traffic is not easy and estimating future traffic especially so. Nevertheless the arguments in favour of designing for the traffic level rather than an administrative class are strong and will ensure more roads are designed to an appropriate standard and that the available funds are used logically.

It should be noted that the issue of classification to determine the standards to be applied is not as difficult as it sounds. A number of different standards may be defined for rural roads each applicable over a specific traffic range. These ranges can be quite wide such that little difficulty should normally be experienced in assigning a suitable standard to a new road project. Where the expected traffic is near to a traffic boundary, prudence would suggest that the higher classification should be used.

2.3 How Standards are used

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

It is important to note that there is no reason why a higher standard than the defined standard should not be adopted in specific circumstances. For example, a road may need to be built for a specific but temporary purpose. A common example is the need to build a road for a special event where the traffic is high or heavy for a short period of time only, reverting to low and light traffic for most of the life of the road.

Thus higher standards can be used if required but lower standards should not be used.

3 Factors Affecting Geometric Design

The geometric design standards are intended to provide minimum levels of safety and comfort for drivers by provision of adequate sight distances, coefficients of friction and road space for manoeuvres, provide the framework for economic design, and ensure a consistency of alignment. Geometric design covers road width, cross-fall, horizontal and vertical alignments and sight lines.

The principal factors that affect the optimum geometric design of a rural road are listed here and discussed below;

1) Cost
2) Terrain
3) Pavement type
4) Traffic (volume and composition)
5) Roadside population (open country or populated areas)
6) Safety

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

3.1 Cost

The cost of roads is usually the most critical factor. It is also the most difficult to include in the *setting* of the design standards. This is because the standards are essentially minimum standards based on judgements about levels of service, safety, convenience and so on. Such judgements will always vary between the technical experts involved in the provision of a country’s roads and it is for this reason that a consensus needs to be established when standards are defined and adopted.

Donor-lead research over the last 40 years aimed at calculating the whole life costs of constructing, maintaining and using roads has quantified the trade off between road standards and road user costs. As road standards increase, agency costs (road construction and maintenance costs) increase but road user costs decrease. As a result, the total costs calculated as a function of ‘road standard’ first decrease, pass through a minimum, and then increase again. From an economic point of view the standards adopted should be those applicable to the minimum total costs. The position of this minimum is strongly dependant on traffic level, as would be expected, hence, from an economic point of view, standards should increase as traffic increases. This is, of course, what happens.

Whilst such calculations are now common in economic appraisal for roads carrying high volumes of traffic, they are less common for LVRRs. This is because such roads are not justified merely on the economic grounds that are based primarily on motorised and predominantly freight traffic. Such roads carry many bicycles, motor cycles, motor cycle taxis, trailers drawn by agricultural engines, animal drawn carts and more. They serve social functions that are vital but which are difficult to fit into traditional economic theory. Methods have evolved to show the importance of LVRRs for comparative ranking but the connection between traffic and justifiable standard is much more difficult to establish. The standards are largely based on consensus, strongly overlain with logical factors based on safety.

Funds are never sufficient and therefore roads are rarely designed to a standard higher than that specified for the traffic. This is why the standards have such high importance. On the rare occasion when funding is not a problem, for a prestigious road for example, then a higher standard can be adopted.

3.2 Terrain

Terrain has a major effect on road costs to such an extent that the same standards cannot be applied in all terrains. Fortunately drivers of vehicles are familiar with this and lower standards are expected in hilly and mountainous terrain. Provided that the standards are consistent within the terrain type so that vehicles can pass along the complete length of a road, lower standards are acceptable.

There is a consensus about the definitions of the terrain classes based on the number of five-metre contours crossed per kilometre in a straight line linking the two ends of a road section.

Flat	0-10 five-metre contours per km. The natural ground slopes perpendicular to the ground contours are generally below 3%.
Rolling	11-25 five-metre contours per km. The natural ground slopes perpendicular to the ground contours are generally between 3 and 25%.
Mountainous	More than 26 five-metre contours per km. The natural ground slopes perpendicular to the ground contours are generally above 25%. This category includes very severe terrain. It may not always be possible to meet the basic minimum standards

3.3 Pavement type

For a similar ‘quality’ of travel there is a difference between the geometric design standards required for an unsealed road (gravel or earth) and for a sealed road. This is because of the very different traction and friction properties of the two types of surfaces and the highly variable nature of natural materials. Thus higher geometric standards are generally required for unsealed roads. A road that is to be sealed at later date should be designed to the higher unsealed geometric road standards.

3.4 Traffic volume and composition

In order to simplify design, traffic must be quantified in a rational way. For both structural design and geometric design, the numbers of each type of vehicle is important. For structural design it is also the weight of trucks and their wheel loads that determine the strength and thicknesses of materials that will be suitable for the road pavement. For geometric design it is the physical dimensions of a vehicle that are also important. A truck requires more space than a motorcycle, for example, and this does not depend on whether the truck is empty or fully loaded.

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

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

In some countries historical precedent has meant that the truck population in rural areas is predominantly one or two types and sizes of vehicle. This makes it relatively easy to select a typical vehicle for setting geometric standards. Conversely some countries have a wide variety of truck sizes and selecting a suitable truck size for geometric design is more difficult. It is strongly recommended that a survey is carried out in Cambodia to identify details of the vehicle population..

3.4.1 Use of Passenger Car Units (PCUs) or numbers of 4-wheeled vehicles

A traffic scale needs to be agreed that identifies the traffic levels at which design standards change. In some countries this is based solely on 4-wheeled vehicles, either all 4-wheeled vehicles or those above a certain size. Alternatively it has been suggested that this be based on PCUs or some variant of the PCU concept.

In order to quantify traffic for normal *capacity* design the concept of equivalent passenger car units (PCUs) is often used. Thus a typical 3-axle truck requires about three times as much road space as a typical car hence it is equivalent to 2.5 PCUs. A motor cycle requires less than half the space of a car and is therefore equivalent to 0.4 PCUs. The PCU concept is very useful but does not help to resolve all of the geometric design problems, especially those associated with rural roads. Vehicles that are slow-moving cause congestion problems because of their speed rather than because of their size. In effect, they can be considered to occupy more road space than would be expected from their size alone. Thus the real PCU rating of a vehicle is affected by the function of a road (i.e. the nature of the other traffic) and varies as the traffic mix varies and as the traffic volume and traffic speeds vary. Universal agreement on the PCU rating of different vehicles is therefore difficult to achieve because the nature of traffic and roads differ so much between regions and between countries.

The values that have been proposed previously for Cambodia are shown in Table 3.1. Some of the local vehicles are illustrated in Figures 3.1 to Figure 3.5.

Figure 3.1 Kantray type Koyun

Figure 3.2 Koyun

Figure 3.3 Koyun assembly shop

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Figure 3.4 Sarmlor

Figure 3.5 Sarmlor

A higher standard might be chosen for a road carrying many motorcycles, motor cycle trailers, bicycles and pedestrians, but few cars. Within the range of traffic levels on rural roads such a standard is unlikely to be strictly necessary based on conventional methods. The much smaller size and manoeuvrability of these vehicles ensures that they can pass each other relatively easily and congestion is unlikely. On the other hand, if standards are based on the ability of trucks of a certain size being able to pass each other, a high standard will be dictated by a relatively small number of users. This may not be considered very equitable. The choice between the two methods and the boundaries between different standards need to be agreed with those responsible – there is no ‘correct’ decision, only a consensus. It is proposed that the number of 4-wheeled vehicles is used in Cambodia. This has become the most common method internationally and allows direct comparisons with the standards of other countries. This will include Koyun and Sarmlor types of local vehicle because these are of comparable size to more conventional 4-wheeled vehicles such as cars, small buses, trucks and pick-ups.

Table 3.1 PCU values

Vehicle	PCU value
Bicycle	0.3
Animal cart; bicycle with trailer	0.4
Motor cycle	0.4
Motor cycle with trailer [1]	1
Passenger car	1
Light vehicle/van	1
Mini bus 4 tyres; pickup truck; Sarmlor [2]	1.1
Bus > 4 tyres	2.3
Light truck and Koyun[3] with 4 tyres	1.5
Medium truck 6 tyres	2
Heavy truck > 6 tyres	2.5

Notes

1 Local people call this a Remorque Moto. This vehicle is very cost effective mode of transport commonly found in Cambodia. It can carry passengers up to 15 persons.

2 Samlor is locally assembled vehicle with three wheels. This vehicle has laden capacity up to 2T or more.

3 Koyun is locally assembled truck using imported truck spare-parts.

3.4.2 Other road users

Geometric design for rural roads recognises that many of the road users will not be 4-wheeled motorized users, therefore, wide shoulders of at least one metre will be required.

Another important aspect of geometric design concerns the ability of vehicles to ascend steep hills. Roads that needed to be designed for very heavy vehicles or for animal drawn carts, for example, often required specific standards to address this. Fortunately the technology of trucks has improved greatly over the years and, provided they are not grossly overloaded, do not usually require special treatment. On the other hand, animal drawn vehicles remain a problem and catering for them is rarely economically justified.

3.4.3 Traffic and structural design

For structural design purposes traffic is described in terms of equivalent standard axles. These are based on the axle loads of the vehicles but only the heavier vehicles are important. This concept is essential to determine the pavement layer thicknesses for roads that carry significant numbers of trucks and buses. However, such traffic is absent for some categories of rural roads and in such cases the structural design is determined primarily by the strength of the subgrade on which the road is to be built and the heaviest vehicle likely to use the road.

3.5 Roadside population (open country or populated areas)

More populated areas in village centres are not normally defined as ‘urban’ but in any area having a population of 1000 people or more where markets and other business activities take place the geometric design of roads needs to be modified to ensure good access and to enhance safety. This may be by using wider shoulders, including specifically designed lay-byes for passenger vehicles to pick up or deposit passengers, roadside parking areas and so on, dependant on the need.

3.6 Safety

Experience has shown that simply adopting ‘international’ design standards from developed countries will not necessarily result in acceptable levels of safety on rural roads. The main reasons include the completely different mix of traffic, including relatively old, slow-moving and usually overloaded vehicles, a large number of motorcycles and bicycles, poor driver training and poor enforcement of regulations. In such an environment, traffic safety assumes paramount importance.

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

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

These factors are all inter-related. In addition, safety is also affected by,

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

Conflicts between motorised vehicles and pedestrians or bicycles are a major safety problem with the type of mixed traffic that occurs on the rural roads of Cambodia where separation is generally not economically possible. The World Bank Basic Access document (2001) considers that there are sound arguments based on safety for keeping traffic speeds low in mixed traffic environments rather than aiming for higher design speeds, as is the case for major roads. The use of wider shoulders is also suggested. These recommendations have been taken into account in drafting these proposals. However, traffic level and composition should both be considered and the choice of PCUs or 4-wheeled motorized vehicles for selecting the boundary between standards is important here. Few conflict situations arise when motorised traffic volume is low but when expressed in terms of PCUs the number of conflicts can vary considerably because the number of 4-wheeled vehicles can vary a great deal within the same category. This is because the proportion of 4-wheeled to non 4-wheeled vehicles can vary greatly. It is therefore recommended that the overall traffic classes are based on the number of 4-wheeled vehicles and that additional safety features for other road users should be based on the number of PCUs of non 4-wheeled vehicles and pedestrians.

3.7 Administrative function

In many countries including Cambodia an administrative classification of roads is essential and it may be that a certain standard may be expected for each class of road irrespective of the current levels of traffic. Generally, of course, the hierarchy of administrative classification broadly reflects the traffic levels observed but anomalies are common..

In these proposals the standards are firmly based on the task or traffic level of the road in question but a minimum standard for each administrative class can be selected if required.

3.8 Matrix of standards

In order of their effect on costs and therefore their importance, the main determinants of standards for roads are,

- Traffic volume,
- Terrain,
- Pavement type
- Safety.
- Population density (i.e. rural or not rural)

Each of these, except safety, determines two or more different road standards (road classes) that need to be defined. Safety does not affect the number of road standards because an acceptable level of safety must be applied to each road class. This will differ *between* classes (greater safety features for higher traffic) but not within classes. A basic matrix of geometric standards has been defined based on five levels of traffic and three types of terrain (flat, hilly, mountainous). This basic matrix has been duplicated for rural and non-rural areas and for unpaved roads.

3.9 Principal components of the standards

The following aspects of geometric design require particular consideration from a policy perspective because they have a major influence on the whole life-cycle costs of rural roads. The basis for developing the standards is discussed in the following Sections.

1. Road width (Chapter 4)
2. Design speed (Section 5.1)
3. Horizontal curvature (Section 5.3, 5.4 and 5.5)
4. Vertical alignment (Section 5.6 and 5.7)
5. Shoulders and safety measures (Section 5.8)

The proposed rural road geometric standards are presented in Table 6.3 to Table 6.7.

In contrast to the judgements required about quantifying traffic for classification, the geometric standards themselves are largely dictated by the selected design speed and form a continuous range as design speed increases. There is relatively good international agreement about sensible increments between standards and therefore the possible standards for rural roads can be defined relatively easily. Usually, in each terrain type, just five standards are defined. The final step is simply to agree about the traffic levels for which each standard should be applied.

4 Road Width

Road width (running surface and shoulders) is one of the most important geometric properties since its value is very directly related to cost. It is usually considered separately. For this study a review was carried out of the standards adopted by a range of countries or organisations (Table 4.1) where many of the conditions and problems are similar, although not identical, to those in Cambodia, for example, mixed traffic and non-motorised traffic. The standards recommended for roads designed for smaller trucks in Lao were also reviewed.

Table 4.1 Standards included in the survey

Number	Country/Authority
1	ORN 6 TRL (Overseas Road Note 6)
2	ARRB (Australia)
3	South African Roads Board
4	Thailand
5	Lao
6	Southern Africa Transport and Communications Commission
7	Swedish International Development Agency Secondary and Feeder Road Development Programme
8	Zimbabwe, Kenya, Tanzania
9	World Bank

4.1 Standards for 'normal' trucks

In many of the standards consulted, the size of the design vehicle is not specifically described but a truck or bus of 2.5 or 2.6m width and a length of between 9 and 12m has been used by many. Figure 4.1 illustrates the range of road widths recommended.

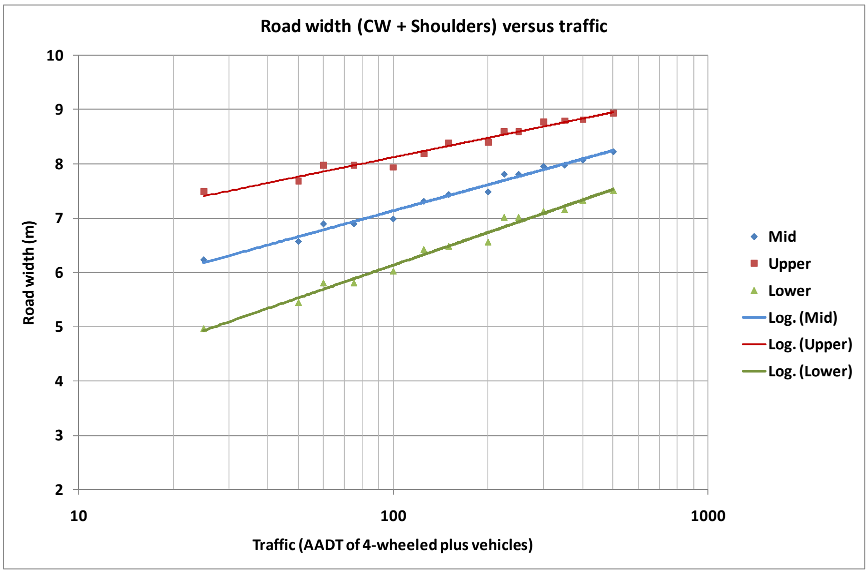

Figure 4.1 Road width versus traffic

The central line is the average. The outer lines are plus and minus one standard deviation. Designs specifically for small trucks are not included in the averages. In reality the lines are not straight but comprise a number of steps as shown in Figure 4.2. Above 200 ADT the roads are not strictly defined as 'low-volume'.

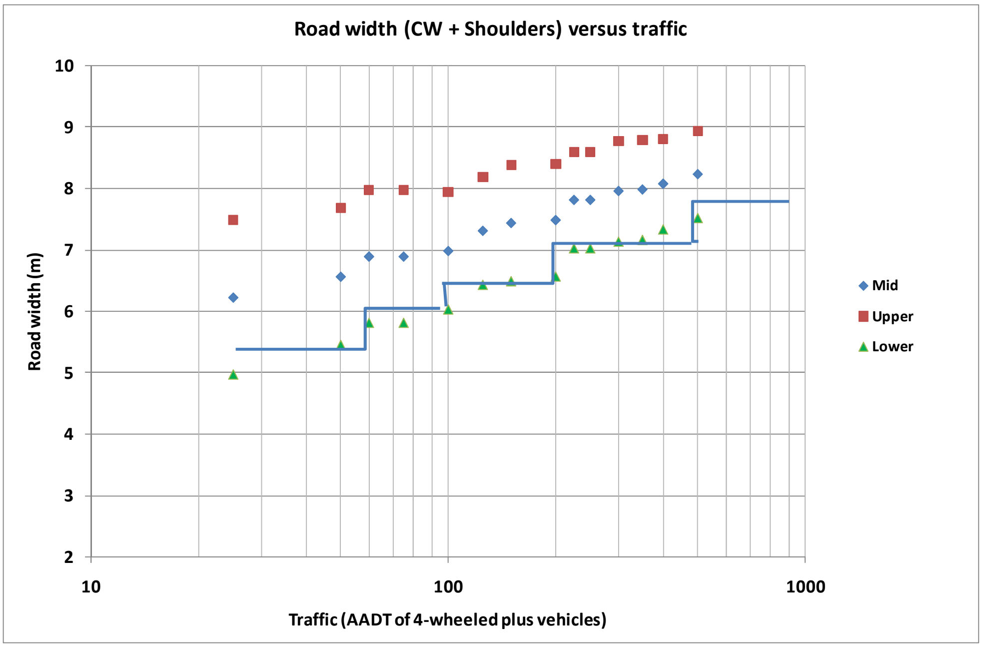

Figure 4.2 Road width versus traffic showing steps

Figure 4.3 shows how road width can be assigned to traffic ranges. The solid arrows show suggested widths when the volume of non 4-wheeled vehicles is high. In this example a road width of 7.0m or 8.0m is assigned to the traffic range 100-200 ADT depending on the number of non 4-wheeled vehicles. These widths span the middle of international practice.

For traffic in the range 30-100 ADT, a wider road of 6.5m is shown for high numbers of non 4-wheeled vehicles. This spans the average of international practice. The narrower road of 5.5m for this ADT range is for use when the volume of non 4-wheeled traffic is low and is similar to the lower values found internationally.

It can be seen that there are a number of alternatives that could be defined for width and traffic ranges whilst keeping within the ranges used internationally.

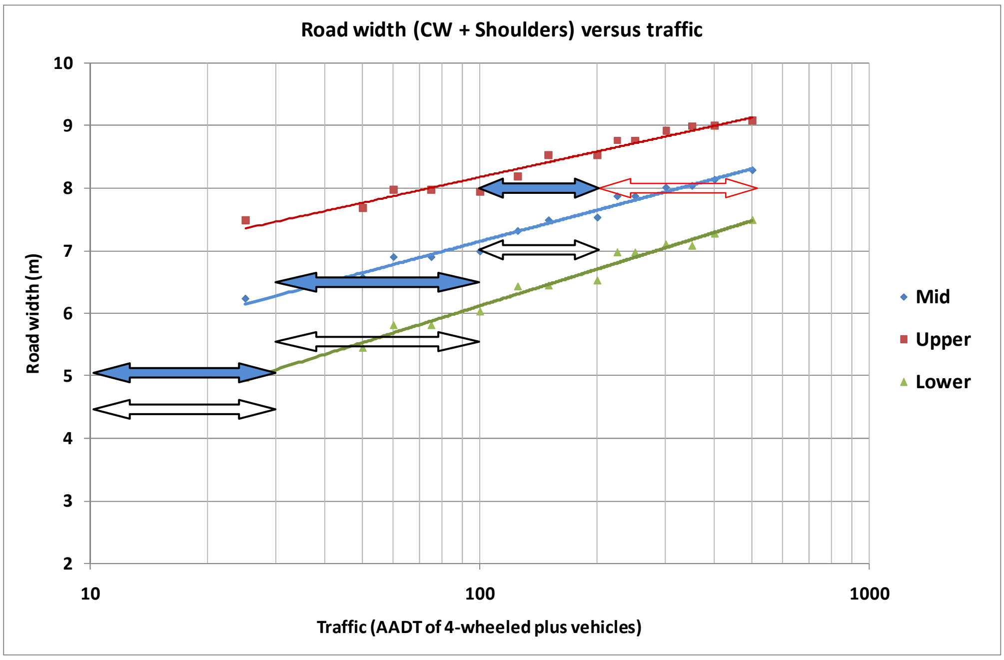

Figure 4.3 Road width showing possible traffic ranges for different width standards

4.2 Width designs for smaller vehicles

Designing the road width for a smaller design vehicle is straightforward. If a smaller truck is used, say with a width of 1.8m, i.e. 0.7m narrower than the design vehicle used in the preceding Figures, then the road width can simply be reduced by 0.7m to give the same spacing between vehicles for passing each other.

4.3 Single lane designs

For single lane roads there is good international agreement about the minimum carriageway width, namely 3.0 metres, but there is less agreement about the width of shoulders. This is because some countries do not have the number or range of other road users that are prevalent in many Asian countries. The recommended shoulder width for such roads depends on the other road users. Where these are primarily pedestrians, the width of the shoulder can be relatively low but where the numbers of non four-wheeled vehicles is high, as is usual in Cambodia, shoulder widths of 1.5m are recommended. In a recent study in Lao[1], shoulders of 1.5 m were recommended if the number of non 4-wheeled vehicles exceeded 150 per day. Below this level, 1.0 m shoulders were recommended. It is recommended that a similar standard is adopted in Cambodia.

4.3.1 Passing places

Single lane roads do not allow the larger vehicles to pass in opposite directions or to overtake hence passing places have to be provided. The increased width at passing places should allow two vehicles to pass at slow speed and hence depends on the design vehicle. For trucks or buses of 2.5m width, the safe minimum is 6.0m.

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

The length of passing places is dictated by the maximum length of vehicles expected to use the road, again indicating the need to define a design vehicle. In most cases a length of 20m will be sufficient for rural roads.

5 Basic Geometric Principles

5.1 Design Speed

Design speed is normally defined as the maximum safe speed that can be maintained over a specified section of road when conditions are so favourable that the road design features of the road govern the speed. The concept of design speed is most useful because it allows the key elements of geometric design to be selected for each standard of road in a consistent and logical way.. Thus design speed is relatively low in mountainous terrain to reflect the necessary reductions in standards required to keep road costs to manageable proportions. It is higher in rolling terrain and highest of all in flat terrain. The question that must be answered by the designer is simply the selection of design speed for each.

There seems to be a general reluctance amongst authors of geometric design manuals to actually recommend design speeds although it is agreed amongst the majority that design speed should be related to traffic level and terrain. Table 5.1 illustrates the situation. However the World Bank document does introduce the additional issue of safety in mixed traffic conditions as a modifying factor.

Table 5.1 Recommended design speeds

Author	Traffic (ADT of 4-wheeled vehicles)				
	<20	20-100	100-400	400-1000	>1000
ORN 6	-	60/50/40	70/60/50	85/70/60	100/85/70
ARRB unsealed	Minimum 70/70/40; Maximum 120/100/70				
SFRDP		70/70/50	70/70/50		
Thailand		Minimum 60/50/30 Maximum 80/60/50			
Cambodia based on Australian recommendations[1]		40/30/20	60/50/40	60/50/40	70/60/50
Lao	50/40/30	50/40/30			
Other	25				

Notes 1. Source not acknowledged by authors

Comparisons are difficult because of the different nature of the overall traffic amongst the various countries. In view of the mixed traffic that occupies the rural roads of Cambodia and the cost and safety benefits of selecting lower design speeds, it is prudent to select lower values of design speed.

5.2 Stopping sight distance

In order to ensure that the design speed is safe, the geometric properties of the road must meet certain minimum or maximum values to ensure that drivers can see far enough ahead to carry out normal manoeuvres such as overtaking another vehicle or stopping if there is an object in the road. The distance a vehicle requires to stop safely is called the stopping sight distance. It mainly affects the shape of the road on the brow of a hill (vertical alignment) but if there are objects near the edge of the road that restrict a driver's vision on approaching a bend, then it also affects the horizontal curvature.

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

In order to calculate the stopping sight distance, assumptions have to be made about all of these factors. Table 5.2 shows the range of values that have been assumed by different authorities (ARRB, TRL, DoT/RSA).

Table 5.2 Assumptions used for calculating stopping distances

Parameter	Values used
Drivers reaction time	2.0 – 2.5 seconds
Drivers eye height	1.0 – 1.15m
Object height for stopping	0.1 – 0.2m
Object height for passing	1.0 – 1.3m
Longitudinal friction factor[1]	0.43 – 0.60

Note 1 Depends on speed

As a result of these assumptions, the ranges of stopping sight distances in Table 5.3 are obtained. It can be seen that, for each speed, the range is not trivial. Values towards the higher and the lower end of these ranges are recommended for unsealed and sealed roads respectively as shown in the Table.

Table 5.3 Stopping sight distances (m)

Design speed (km/h)	**30**	**40**	**50**	**60**	**70**	**80**
Stopping distance (m)	25-35	35 -55	50 -75	65-100	85-130	115-160
Recommendations: unsealed (m)	35	50	70	93	120	150
Recommendations: sealed (m)	30	40	55	72	95	120

5.3 Camber and Cross-fall

Camber or cross-fall is essential to promote surface drainage. Ponding of water on a road surface quickly leads to deterioration. There is general agreement that camber or cross-fall should be 3 - 4% on sealed roads.

Drainage is less efficient on rough surfaces and therefore the camber or cross-fall needs to be higher on earth and gravel roads. However, if the soil or gravel is susceptible to erosion, high values of camber or cross-fall can cause erosion problems. Values that are too high can also cause driving problems, but on the lower standards of rural roads where traffic is low and the road is single carriageway, vehicles will generally travel in the middle of the road thus high levels of camber are not such a problem as high levels of cross-fall. The design of unsealed rural roads should make use of this fact so that higher camber is used where appropriate. Thus the optimum value of cross-fall/camber varies considerably but normally lies between 4% and 7% with 6% being the usual recommendation in the absence of additional information concerning the erosion potential of the soil/gravel.

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

5.4 Adverse cross-fall

Adverse cross-fall arises on curves when the cross-fall or camber causes vehicles to lean outwards when negotiating a curve. This affects the cornering stability of vehicles and is uncomfortable for drivers, thereby affecting safety. The severity of its effect depends on vehicle speed, the horizontal radius of curvature of the road and the side friction between tyres and road surface. For reasons of safety it is recommended that adverse cross-fall is removed where necessary (Table 5.4) on all roads regardless of traffic.

Table 5.4 Adverse cross-fall to be removed if radii are less than shown

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

Some cross-fall is necessary for drainage and hence flat sections are not acceptable. Instead, a single value of cross-fall is designed in the proper direction (i.e. all camber is removed) (Figure 5.1) such that the cross sectional shape of the road is straight with the cross slope being the same as that of the inner side of the cambered two-lane road, usually 3 or 4% for sealed roads. For unpaved roads the recommended cross-fall should also be the same as the normal camber or cross-fall values of 6%.

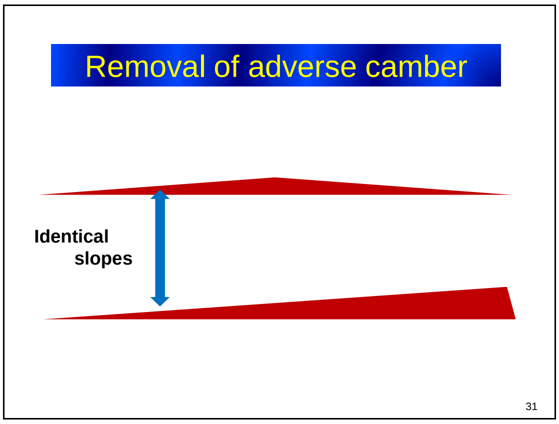

Figure 5.1 Removal of adverse camber

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

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

5.5 Horizontal curvature

Horizontal curves are designed to ensure that vehicles can negotiate them safely. The main factor is the radius of curvature. The design criterion is its minimum value. This is determined by two main considerations namely the design speed and the cross-fall or super-elevation (see Section 5.4). The friction between the road surface and the vehicle wheels also has an effect hence the minimum values of curvature are higher for unsealed roads than for sealed roads because the friction is lower.

The design speed is one of the main design parameters and has been set for each class of road. Thus for each design speed, the minimum horizontal radius is determined only by the cross-fall or super-elevation - the higher the cross-fall, the smaller the radius of curvature that can be negotiated safely by the vehicles

For both sealed and unsealed roads there are also constraints on the maximum cross-fall, as described in Section 5.3. For sealed roads the preferable maximum value of cross-fall or super-elevation (SE) is normally set at 6 - 8% with an absolute maximum of 10%. For unsealed roads the upper limit is 6 or 7%. These constraints translate directly into minimum values of horizontal radii of curvature.

The values obtained from the international references in Table 5.5 and Table 5.7 show a range because of the slightly different assumptions that were made in their derivation. Values in the middle of the ranges are recommended as shown in Table 5.6 and Table 5.8.

As indicated in the Tables, the use of a higher value of super-elevation makes it possible to introduce a smaller horizontal curve based on the same design speed. This can be used for sealed roads but not for unsealed roads

Table 5.5 Range of minimum values of horizontal radii of curvature for sealed roads

Design speed (km/h)	**30**	**40**	**50**	**60**	**70**	**80**
Minimum horizontal radius for SE = 4% (m)	30 - 34	55 -63	95 - 99	150	204 - 215	280
Minimum horizontal radius for SE = 7% (m)	17	35	70	105	180	240
Minimum horizontal radius for SE = 10% (m)	15 - 25	30 - 45	60 - 75	85 - 115	130 - 165	210

Table 5.6 Recommended minimum horizontal radii of curvature for sealed roads (m)

Design speed (km/h)	**30**	**40**	**50**	**60**	**70**	**80**
Minimum horizontal radius for SE = 4% (m)	32	60	97	150	210	280
Minimum horizontal radius for SE = 7% (m)	20	40	70	112	170	240
Minimum horizontal radius for SE = 10% (m)	18	35	63	97	145	210

Table 5.7 Range of minimum values of horizontal radii of curvature for unsealed roads

Design speed (km/h)	**30**	**40**	**50**	**60**	**70**
Minimum horizontal radius for SE = 4% (m)	35	63 - 70	99 - 120	150 - 180	204 - 260
Minimum horizontal radius for SE = 7% (m)	31	60	100	150	215

Table 5.8 Recommended minimum horizontal radii of curvature for unsealed roads

Design speed (km/h)	**30**	**40**	**50**	**60**	**70**
Minimum horizontal radius for SE = 4% (m)	35	67	110	165	235
Minimum horizontal radius for SE = 7% (m)	30	60	100	150	215

5.5.1 Curve widening

Widening of the carriageway where the horizontal curve is tight is usually necessary to ensure that the rear wheels of the largest vehicles remain on the road when negotiating the curve and, on two lane roads, to ensure that the front overhang of the vehicle does not encroach on the opposite lane. Thus widening is also important for reasons of safety. Vehicles need to remain centred in their lane to reduce the likelihood of colliding with an oncoming vehicle or driving on the shoulder. Sight distances should be maintained as discussed in Section 5.2. The levels of widening shown in Table 5.9 are recommended.

Table 5.9 Widening recommendations

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

5.6 Gradient

Gradient is a major aspect of vertical alignment and is related to vehicle performance and level of service. For the low levels of traffic flow, with only a few four-wheel drive vehicles, the maximum traversable gradient is reported as 20% and two-wheel drive trucks are similarly recorded as successfully tackling gradients of 15%, except when heavily laden (TRL ORN 6, 1988). Bearing in mind the likelihood of heavily laden small trucks and animal drawn carts, the rural road standards have a proposed general recommended limit of 10%, but with an increase to 15% for short sections in areas of difficult terrain.

Regional experience indicates that unsealed road sections in excess of 6% gradient are unsustainable in terms of erosion and material loss in the medium to long-term.

5.7 Vertical alignment

The vertical alignment of a road seems more complicated than horizontal alignment but this is simply because of difficulties in presentation due to the fact that an extra variable is involved namely the algebraic difference in gradient (G%) between the uphill and downhill sides. The required sight distance for safety is the basic stopping sight distance discussed in Section 5.2.

5.7.1 Crest curves

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

The minimum value of the L/G ratio can be tabulated against the stopping sight distance, and therefore the design speed, to provide the designer with a value of L for any specific value of G. The international comparisons give the values shown in Table 5.10

Table 5.10, Minimum values of L/G for crest curves

Design speed (km/h)	**30**	**40**	**50**	**60**	**70**	**80**
Sealed roads	2	4	7	12	21	34
Unsealed roads	3	6	11	20	34	53

5.7.2 Sag curves

Sag curves are the opposite of crest curves – vehicles first travel downhill and then uphill. In daylight the sight distance is normally adequate for safety and the design criterion is based on minimising the discomforting forces that act upon the driver and passengers when the direction of travel changes from downhill to uphill. On rural roads such considerations are somewhat less important than road safety issues. However, at night time the problem on sag curves is the illumination provided by headlights to see far enough ahead. To provide road curvature that allows the driver to see sufficiently far ahead using headlights while driving at the design speed at night is usually too expensive for rural roads. In any case, the driving speed should be much lower at night on such roads. As a result of these considerations it is recommended that the minimum length of curve is determined by the driver discomfort criterion. The results are shown in Table 5.11.

Table 5.11 Minimum values of L/G for sag curves

Design speed (km/h)	**30**	**40**	**50**	**60**	**70**	**80**
Minimum L/G	0.7	1.3	2.2	3.5	4.8	7.5

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

5.8 Shoulders

The shoulders of a road must fulfil the following functions:

- Allow wide vehicles to pass one another without causing damage to the shoulder
- Provide safe room for temporarily stopped or broken down vehicles

- Allow pedestrians, cyclists and other vulnerable road users to travel with increased safety
- Allow water to drain from within the pavement layers
- Reduce the extent to which water flowing off the surface can penetrate into the pavement, often by extending the seal over the shoulder.

Thus the increase in width will vary with the relative amounts of traffic, their characteristics, the terrain and location (e.g. in village areas).

6 Recommended Geometric Standards for Cambodian Rural Roads.

6.1 Classification of Cambodian rural roads

The roads for which the MRD have responsibility are based on administrative classes rather than traffic level, hence it is likely that some busy roads linking district centres will fall outside the range of roads that are normally defined as low volume (< 200 four-wheeled vehicles per day). In terms of geometric design and the methodology described in this report, this does not pose a problem. A geometric classification appropriate to higher traffic levels is proposed together with those for lower traffic levels. However, for higher traffic levels, particularly when the proportion of heavy vehicles is also high, the performance of the road becomes very dependent on the traffic load. For example the thickness of the pavement layers needs to increase and the quality of the materials from which it is made must meet higher strength specifications. The traffic is also counted in terms of the number of cumulative standard axles rather than the AADT of 4-wheeled vehicles. For such roads there are several appropriate pavement structural design methods in common use but most countries introduce their own modifications to suit their particular circumstances. It is beyond the scope of this project to review these methods and to propose a structural design method for Cambodia for such roads.

6.1.1 Traffic classification

The proposed rural road classification in terms of traffic is shown in Table 6.1. It should be remembered that the traffic is that which is estimated to be using the road in mid-life, namely in about seven years from construction or upgrading, not the traffic expected immediately after construction. Normally a general growth rate is assumed or is provided by government based on the growth in registered vehicles during previous years. However, local development plans may indicate higher growth rates in some places. The class of 4-wheeled vehicles includes Koyun and Sarmlor types of local vehicle because these are of comparable size to more conventional 4-wheeled vehicles such as cars, small buses, trucks and pick-ups. The number of PCUs of non 4-wheeled vehicles (i.e. all vehicles not included in the ADT classification) is used in the classification.

The standards for each classification are summarised in Table 6.3 through to Table 6.7 and discussed in the following paragraphs.

Table 6.1 Proposed classification of rural roads

Class	AADT of 4-wheeled vehicles	Width of running surface (m)	Sub class	PCUs of non 4-wheeled vehicles	Width of shoulders (m)	Total width (m)
RR 1	200 to 500	6.0	A	>300	1.5	9.0
		6.0	B	< 300	1.0	8.0
RR 2	100 to 200	5.0	A	> 300	1.5	8.0
		5.0	B	< 300	1.0	7.0
RR 3	30 to 100	3.5	A	> 300	1.5	6.5
		3.5	B	< 300	1.0	5.5
RR 4	5 to 30	3.0	A	> 300	1.0	5.0
		3.0	B	< 300	0.75	4.5
RR 5	< 5	2.5	A	>300	1.0	4.5
		2.5	B	<300	0.75	4.0

6.2 Road width

There are five main classes based on the number of 4-wheeled vehicles. It is the 4-wheeled vehicles that determine the width of the running surface (see Section 3.4). The rural roads in Cambodia often carry high volumes of motorcycles, bicycles and other two or three-wheeled vehicles as well as many pedestrians. These do not require as much road *width* as 4-wheeled vehicles but they do require road *space*. Also many of them do not mix well with 4-wheeled vehicles. Therefore, on grounds of road space and safety, whenever the roads in the classification are required to carry high levels of such vehicles, the width of the shoulders is increased. These 'vehicles' are assessed in terms of PCUs using Table 3.1.

For the lowest traffic categories of rural roads (RR3, RR4 and RR5) single lane operation is adequate because there will be only a very low probability of vehicles meeting each other and the few passing manoeuvres can be undertaken at much reduced speeds. Provided sight distances are adequate for safe stopping, these manoeuvres can be performed without hazard, and the overall loss in efficiency brought about by the reduced speeds will be small.

RR5, with a 2.5m wide carriageway, is typically for roads from village to fields or a few dwellings. Such roads are designed for extremely low traffic and will generally be only connect to other roads at one end. They will be fairly short and the probability of meeting another 4-wheeled vehicle is extremely low. The geometric standards other than width should follow those for RR4.

6.3 Design speeds

Design speed controls many of the geometric parameters (see Chapter 5) and ensures a uniform and consistent standard for the whole road. Based on the arguments in Chapter 5 the recommended values are shown in Table 6.2

Table 6.2 Recommended design speeds

Classification	**Flat** (km/h)	**Rolling** (km/h)	**Mountainous** (km/h)
Rural Road RR 1	60	50	40
Rural Road RR 2	50	40	30
Rural Road RR 3	50	40	30
Rural Road RR 4	50	40	30
Rural Road RR 5	30	30	20

6.4 Super-elevation

It is recommended that adverse cross-fall or camber is always removed on horizontal curves below 700m radius. Since the recommended cross-fall or camber is 6%, the effective 'super-elevation' when adverse cross-fall is removed will be 6% and this therefore determines the minimum radius of horizontal curvature for each design speed in the same way as for genuine super-elevation. In practice it may not be possible to maintain such a value of cross-fall during the life of an unsealed road and therefore it is recommended that minimum radii are based on the lower level of 4% cross-fall.

For sealed roads the removal of adverse cross-fall will result in an effective super-elevation of 3-4% and this should be used to determine minimum radii of curvature for such roads. However, if these radii are difficult to achieve, genuine super-elevation of up to 7% (or, in exceptional circumstances, up to 10%) can be used with a resulting decrease in horizontal radius of curvature.

6.5 Road Curvature

The minimum horizontal radii of curvature for all the road classes except RR5 are determined from the design speed and cross-fall/super-elevation as indicated in Section 5.5. For RR5 an overall limit of 35m is recommended

Widening the carriageway on low radius curves for road classes RR1, RR2 RR3 and RR4 is as recommended in Table 5.9.

6.6 Gradient

The recommended maximum gradients are as discussed in Section 5.6.

Table 6.3 Rural Roads Class RR 5 (ADT<5)

Design Parameter	Comments	Definition		
Carriageway width		2.5m		
Shoulder width	Depends on number of non 4-wheeled vehicles	> 300 PCUs 1.0 m < 300 PCUs 0.75 m		
Notional design speed	Defined by terrain	Flat	Rolling	Mountainous
		30 km/h	30 km/h	20 km/h
Minimum horizontal curve radius (m)		35	35	35
Maximum gradient	A limit of 6% for gravel	6%	8%	10%(1)

1. Gradients up to 15% permitted in cases where lower gradients would incur excessive earthworks and construction cost and where lengths of alignment >10% are kept to <300m.
2. Gravel cross-fall must be maintained at between 4 and 6%.

Table 6.4, Rural Roads Class RR 4 (ADT < 30)

Design Parameter	Comments	Definition		
Carriageway width		3.0 m		
Shoulder width	Depends on number of non 4-wheeled vehicles	> 300 PCUs 1.0 m < 300 PCUs 0.75 m with passing places		
Design speed	Defined by terrain	Flat	Rolling	Mountainous
		50 km/h	40 km/h	30 km/h
Maximum gradient	A limit of 6% for gravel	6%	8%	10%(1)
Stopping sight distance (m)	Gravel	70	50	35
	Sealed	55	40	30
Minimum horizontal curve radius (m) SE=4%	Gravel(2)(recommended)	110	67	35
	Sealed	97	60	32
Minimum horizontal curve radius (m) SE=7%	Gravel(2)	100	60	30
	Sealed	70	40	20
Minimum value of L/G for vertical curves	Gravel	12	6	3
	Sealed	7	4	2
Sag	Gravel or sealed	2.2	1.3	0.7
Cross-fall	Gravel	6%[2]		
	Sealed	4%		

1. Gradients up to 15% permitted in cases where lower gradients would incur excessive earthworks and construction cost and where lengths of alignment >10% are kept to <300m.
2. Gravel cross-fall must be maintained at between 4 and 6%.

Table 6.5, Rural Roads Class RR 3 (ADT 30-100)

Design Parameter	**Comments**	**Definition**		
Carriageway width		3.5 m		
Shoulder width	Depends on number of non 4-wheeled vehicles	> 300 PCUs 1.5 m < 300 PCUs 1.0 m		
Design speed	Defined by terrain	Flat	Rolling	Mountainous
		50 km/h	40 km/h	30 km/h
Maximum gradient	A limit of 6% for gravel	6%	8%	10%(1)
Stopping sight distance (m)	Gravel	70	50	35
	Sealed	55	40	30
Minimum horizontal curve radius (m) SE=4%	Gravel(2)(recommended)	110	67	35
	Sealed	97	60	32
Minimum horizontal curve radius (m) SE=7%	Gravel(2)	100	60	30
	Sealed	70	40	20
Minimum value of L/G for vertical curves	Gravel	12	6	3
	Sealed	7	4	2
Sag	Gravel or sealed	2.2	1.3	0.7
Cross fall	Gravel	6 %[2]		
	Sealed	4 %		

1. Gradients up to 15% permitted in cases where lower gradients would incur excessive earthworks and construction cost and where lengths of alignment >10% are kept to <300m.
2. Gravel cross-fall must be maintained at between 4 and 6%.

Table 6.6, Rural Roads Class RR 2 (ADT 100-200)

Design Parameter	Comments	Definition		
Carriageway width		5.5 m		
Shoulder width	Depends on number of non 4-wheeled vehicles	> 300 PCUs 1.5 m < 300 PCUs 1.0 m		
Design speed	Defined by terrain	Flat	Rolling	Mountainous
		50 km/h	40 km/h	30 km/h
Maximum gradient	A limit of 6% for gravel	6%	8%	10%(1)
Stopping sight distance (m)	Gravel	70	50	35
	Sealed	55	40	30
Minimum horizontal curve radius (m) SE=4%	Gravel(2)(recommended)	110	67	35
	Sealed	97	60	32
Minimum horizontal curve radius (m) SE=7%	Gravel(2)	100	60	30
	Sealed	70	40	20
Minimum value of L/G for vertical curves	Gravel	12	6	3
	Sealed	7	4	2
Sag	Gravel or sealed	2.2	1.3	0.7
Cross fall	Gravel	6 %[2]		
	Sealed	4 %		

1. Gradients up to 15% permitted in cases where lower gradients would incur excessive earthworks and construction cost and where lengths of alignment >10% are kept to <300m.
2. Gravel cross-fall must be maintained at between 4 and 6%.

Table 6.7, Rural Roads Class RR 1 (ADT 200-500)

Design Parameter	Comments	Definition		
Carriageway width		6.0 m		
Shoulder width	Depends on number of non 4-wheeled vehicles	> 300 PCUs 1.5 m < 300 PCUs 0.75 m		
Design speed	Defined by terrain	Flat	Rolling	Mountainous
		60 km/h	50 km/h	40 km/h
Maximum gradient	A limit of 6% for gravel	6%	8%	10%(1)
Stopping sight distance (m)	Gravel	93	70	50
	Sealed	72	55	40
Minimum horizontal curve radius (m) SE=4%	Gravel(2, 3) (recommended)	165	110	67
	Sealed	150	97	60
Minimum horizontal curve radius (m) SE=7%	Gravel (2, 3)	150	100	60
	Sealed	112	70	40
Minimum value of L/G for vertical curves	Gravel (2)	20	11	6
	Sealed	12	7	4
Sag	Gravel or sealed	3.5	2.2	1.3
Cross fall	Gravel (see notes 2, 3)	6%		
	Sealed	4%		

1. Gradients up to 15% permitted in cases where lower gradients would incur excessive earthworks and construction cost and where lengths of alignment >10% are kept to <300m.
2 Gravel surfaces are not usually suitable for this traffic level.
3. Gravel cross-fall must be maintained at between 4 and 6%.

7 Discussion: Geometric Standards

7.1 Data Gaps

Better information always allows better decisions to be made. The standards described in this report are minimum standards and hence poor information could result in overdesign or, possibly more importantly, under design. Under design will result in higher vehicle operating costs, extra maintenance needs and less safety for the road users.

Traffic

Information about the volume and composition of traffic using the rural roads at the present time is sparse and unreliable. Information about traffic growth is also unavailable and therefore estimating the traffic for which the roads should be designed is difficult. As far as the authors are aware, no formal system for obtaining such information is in use in Cambodia, nevertheless it is something that most governments see as valuable for a variety of reasons.

For selecting the appropriate standard for rural roads, the level of accuracy required is not high. Indeed, traffic growth rates are difficult to predict and hence high accuracy cannot be achieved. Nevertheless it is recommended that a system for obtaining and storing traffic data is set up by RGC.

A second issue concerns the size of the “design vehicles” on which the rural; roads are designed. The designs in this report are based on a truck size that has been used by many authorities but may be larger than is necessary for Cambodia. A truck or bus of 2.5 or 2.6m width and a length of between 9 and 12m has been used but in neighbouring Lao, for example, most of the trucks using the rural roads are relatively small. It is possible that in Cambodia road widths for some classes of rural roads could also be reduced.

Traffic information will provide the means for selecting the most appropriate road class for any situation and, equally importantly, such information will, potentially, allow refinements in the recommended standards to be made which will reduce whole life costs.

7.2 Classification

There is usually an upper limit to the roads that may be included within the LVRR approach to rural road design and construction. In general terms this limit is taken as being one below which traffic is not the dominant factor influencing road deterioration and that other road environment factors have a significant influence. This limiting figure needs to be interpreted and adapted for specific regions bearing in mind their particular characteristics but it is normally between 150-200 4-wheel ADT. The nature of the current SEACAP 19.03 project has limited the amount of research possible into the Cambodian road environment on this specific issue but as noted previously the classifications RR2 to RR5 can be reasonably assumed to be within the LVRR envelope whilst RR1 is outside it.

It is important to note that the LVRR designation does not imply that all Rural Roads or Community Roads (CRs) in Cambodia must comply with a set upper limit; only that roads to be designed under the LVRR principles must do so. Rural Roads that are deemed to require a higher axle load or higher traffic standard must be dealt with under standard road design approaches.

7.3 Shoulder widths

The point at which shoulders should be widened to cope safely with the volume of non 4-wheeled vehicles has been set at 300 PCUs. This value is based on judgements but could be refined based on better data. It is anticipated that the important figure for this is the peak flow during the day rather than the total daily flow but the two are likely to be closely related.

8 Matrix of Pavement and Surfacing Options

8.1 Introduction

A number of LVRR pavement trials programmes have been undertaken in the last few years in the Cambodia, Lao and Vietnam. Only one trial programme so far in Cambodia has involved performance monitoring and hence there has been limited input to determining appropriate pavement upgrade options specifically for Cambodia. However a recent review of research in the region has been undertaken as part of the SEACAP programme summarising the status of the ongoing research programme. The review relies heavily on the extensive SEACAP trials of over 140 km of roads in Vietnam. Although the research has not been completed, there is sufficient evidence to identify the most effective solutions and, just as importantly, those that should not be used until more evidence is available of long-term performance.

8.2 Road pavement performance

Road pavements are surprisingly complex structures that can deteriorate in many different ways. The main reason for this is that, unlike most civil engineering structures, roads are not designed with a large factor of safety. This is because, first of all, they are relatively expensive (and most countries need quite a lot of them) and, secondly and most importantly, their slow deterioration and subsequent failure is not a major life-threatening event. Therefore 100% reliability is not mandatory. Indeed, economic analysis shows that the optimum design of roads will guarantee that some roads will deteriorate much faster than we would like but, conversely, others will last longer than we expect. This is because the very nature of roads and the materials that we use to construct them means that their performance is extremely variable. Designing for high levels of reliability increases their costs considerably and designing for no failures is prohibitively expensive. Nevertheless, for the most important roads in a country the level of reliability is usually set to a high level commensurate with what can be afforded, often 98% reliability. In other words, about 2% of the roads will reach the defined failure condition before the design life is reached. For such roads many of the potential causes of deterioration are eliminated. For low volume rural roads (carrying low levels of traffic) such high levels of reliability are not economically justified. Thus the ‘safety factor’ for the design of rural roads is relatively low and this means that there are more ways in which they can deteriorate. In particular, the impact of environmental factors is greater.

The design of road pavements can be conveniently considered separately in terms of the surfacing and the structure. The surfacing is primarily designed to keep the pavement dry and waterproof whereas the main structure underneath the surfacing is designed to spread the loads from traffic to protect the subgrade from deformation and failure. As a result, the selection of surfacings and basic structure are often independent of one another and a large number of combinations are possible. Some surfacings such as penetration macadam also contribute to the overall structural strength. In the case of concrete slabs, the surfacing is also the main structural component.

8.3 Selecting the best option

In order to design rural roads economically it is important to understand how and why they deteriorate so that the design and construction procedures can be tailored to minimise deterioration. Some structures will naturally last longer than others and some will be better suited to particular conditions. In principle, the least cost option that is available in a particular location should be selected but this should be based on whole life costs so that the durability of a particular option and maintenance costs are taken properly into account. As a result, the best available solution will vary with the environmental conditions. A low cost option suitable for a straight, level stretch of road that is not subject to seasonal flooding (i.e. a favourable location) will not be suitable for a steep hill in a high rainfall area. Similarly a design suitable for the latter will almost certainly be a conservative high cost option for more favourable conditions.

8.4 Proposed options

A limited range of proposed rural road options are included in this document and is shown in Table 8.4 and discussed below.

Table 8.1, Summary of components of a pavement

	Pavement Options	**Description**
	UN SEALED SURFACES	
US1	Gravel wearing course	A layer of compacted natural earth or added gravel wearing course (typically 15-20cm thick)
	NON STRUCTURAL SEALED SURFACES	
NS1	SBST and DBST – single and double bituminous surface treatment (stone chip sealed surface)	A seal consisting of a hand or machine applied film of bitumen (straight run, cutback or emulsion) followed by the application of a layer of single sized (9-20mm) stone chippings, lightly rolled in the bitumen. Two layers are normally used with the second layer consisting of smaller chippings.
NS2	Otta seals	A layer consisting of a hand or machine applied film of relatively soft bitumen (usually straight run or cutback) followed by the application of graded natural gravel or crushed stone aggregate (typically 16mm downwards), rolled into the bitumen using heavy pneumatic-tyred rollers.
	STRUCTURAL SURFACES	
SS1	Concrete Surface	Jointed slabs of structural quality concrete reinforced with a mild steel rod grid. Joints with steel weight transfer dowels and bitumen seal
SS2	Penetration Macadam Surface	Two or three layers of single sized crushed stone (of deceasing nominal aggregate size, e.g. 63mm downwards) each compacted and with bitumen (straight run, cutback or emulsion) sprayed between each stone application.
	BLOCK TYPE SURFACES	
BS1	Dressed Stone Surface	A layer (typically 15-20cm thick) of stone blocks cut (dressed) to a cubic shape by hand and laid by hand. Joints mortared/sealed or tightly packed and wedged with stone chips rammed into place with remaining voids filled with sand. The Dressed Stone is normally bedded on a thin layer of sand/gravel.
	PAVEMENT LAYERS	
L1	Water Bound Macadam roadbase or sub-base	A layer of nominal single size (typically up to 50mm) crushed stone compacted and fully blinded with well-graded fine aggregate which is watered into the voids and compacted to produce a dense stable material. Layer thickness up to twice the nominal stone size. Material may be hand or machine crushed and laid.
L2	Dry Bound Macadam roadbase or sub-base	A layer of nominal single sized (typically up to 50mm) crushed stone compacted and fully blinded with angular sand or fine crushed stone material, which is then vibro-compacted to produce a dense stable material. Layer thickness up to twice the nominal stone size. Material may be hand or machine crushed and laid. Suitable in areas short of water.
L3	Graded Crushed Stone roadbase	A layer (usually up to 20cm thick) of graded crushed stone material (typically 50mm downwards) usually derived from fresh sound quarried rock, boulders or granular material. Material may be hand or machine crushed.
L4	Chemical Stabilised roadbase	Addition and mixing of a stabiliser (lime or cement) to a material to increase its strength and achieve the properties required of a roadbase. Mixing and compaction by appropriate equipment.

The opportunity to include additional options in the Cambodia Standards in future is available from trials undertaken in Cambodia. However, these trials are not part of a current research programme and hence long-term monitoring and performance analysis is not currently scheduled. Proposals have been made in Technical Report 4 entitled ‘Low volume rural road upgrade options’ of SEACAP 19 for a research programme that is designed to include such trials.

The above options are discussed under the headings of surfacings and structure. The options are assessed in relation to key construction, performance and sustainability criteria and to some typical Cambodian road environments.

8.5 Un-sealed roads

8.5.1 Engineered natural surfaces.

A research study of the performance of ENS roads was carried out in Cambodia as part of SEACAP 19. The results essentially confirmed that if the basic soil has sufficient plastic fines for cohesion and sufficient coarse aggregate it would perform adequately as a LVRR capable of carrying many non 4-wheeled vehicles and a limited number of 4-wheeled vehicles.

8.5.2 Gravel roads

Gravel is, of course, the traditional material for surfacing LVRRs. However, relatively recent research has shown that it is not a sustainable road surfacing in many parts of SEA. Several key research reports have reached this conclusion, most notably the major 12-country study in southern Africa (SADC) and SEACAP research in Vietnam and elsewhere.

The conditions under which gravel is an acceptable surfacing in Vietnam have been outlined in Cook and Petts (2004) and more recently key aspects have been highlighted in a short study in Lao (LTEC-OtB, 2009). In short, rainfall must be low, gradients must be low, traffic must be low and the gravel material should meet certain specifications. Attempts at using better engineered materials such as Water Bound Macadam, Dry Bound Macadam and Graded Crushed Stone without a seal have not, in general, proved successful or cost-effective.

8.6 Sealed roads

The surfacings that are used to seal road pavements to make them waterproof are classified in two types namely those that are merely seals and those that also add to the structural strength of the road.

8.6.1 Non structural

Surface dressings – single and double seals

Surface dressings, sometimes known as chip seals, have been developed as surfacings for LVRRs by many authorities and there is no doubt that they have been successful. The standard design is a two-layer design requiring two sizes of chippings and two applications of a sprayed bitumen film. Single layers have also been used successfully but usually simply as a maintenance seal on top of an old existing double seal or asphalt surfacing.

Indications from SEACAP research in Vietnam are that the addition of a sand seal on top of the single seal is not an effective option. On the other hand the double seals performed well. The few examples of poor performance were often clearly associated with structural problems with the underlying pavement and therefore the surfacing was not to blame.

Otta seals

Construction trials of Otta seals have been undertaken in Cambodia. Unfortunately, at the time of writing, there is no programme to monitor their performance but visual inspections in early life indicate that they could perform well. Initial results from the monitoring of Otta seals in Lao indicate satisfactory performance in a low volume traffic environment (LTEC-OtB, 2009). Experience in other countries supports this view hence Otta seals should be considered for regular use in Cambodia.

8.6.2 Structural surfacings

Concrete

Concrete is used as the main form of construction for rural roads in the Philippines and has been trialled in Cambodia. Concrete has also been trialled extensively in Vietnam..

The research has indicated clearly that good performance depends on a suitable sub-base and that the use of concrete without good engineering will not guarantee a long maintenance free life. However, when built to acceptable standards, a long low maintenance life should be achieved. The research also showed that bamboo was not a suitable material for reinforcing concrete roads

Penetration Macadam

Penetration Macadam is a very traditional road building material in SEA. If made with a reasonable level of quality control, it performs well. The penetration macadam trials in Vietnam showed that it was the most reliable of the bituminous surfacings.

8.7 Structure

The structural layers of a pavement fall into the follow categories,

- Unbound pavement layers
- Stabilised pavement layers
- Block type paving.

8.7.1 Unbound layers

Unbound layers have evolved from using as-dug gravels, the ‘large-stone’ designs of Thomas Telford, the ‘locked’ stone methods of Macadam to the continuously graded high quality crushed stones often used today. The most common methods for roads other than the most heavily trafficked are Macadams. Two types are commonly used, Water Bound Macadam (WBM) and Dry Bound Macadam (DBM). Both are methods of making a good mechanically stable layer and both can work well. For use in LVRRs where the traffic is relatively light, their internal strength should always be sufficient provided the aggregates meet standard strength specifications. Their load spreading properties should also be adequate provided they are laid to adequate thicknesses for the subgrades encountered. Dangers arise when the standard methods of construction are modified without adequate research but using well proven methods should provide long lasting roads.

Graded crushed stone is likely to be more expensive than Macadams but it works in a similar way and should provide good performance if constructed to normal standards.

Where the strength of the aggregates and pavement layers fall below normal standards, Macadams can still be used but the structural designs need to be developed specifically for the strengths available. This is beyond the scope of this report.

8.7.2 Stabilised layers

Unbound materials can be stabilised with various stabilising agents. The most common and the most reliable are bitumen, cement, and lime and the materials that can be stabilised cover a wide range. The principal specifications for each type of stabilisation have evolved over time and are reliable.

The properties of stabilised layers also cover a wide range from quite weak materials for sub-bases through to very strong cemented layers suitable for very heavy traffic. There should be few problems in using these well known techniques. However, research plays a major part in *extending* the specifications to cover specific materials that do not meet the principal specifications. Finding ways of using such materials is important for providing rural roads at low cost and therefore local research and experience is important in areas where local materials are outside normal specifications. Some trials have been built in Cambodia but at the time of writing no long-term monitoring for research purposes has been implemented. At this time it is recommended that only materials meeting specifications are used.

8.7.3 Block 'type' paving

This category includes concrete blocks, clay bricks, dressed stone, mortared stone, and cobble stones. Building roads with these materials is a labour intensive activity and has been done successfully throughout the world. The research in SEA has highlighted the problems created by intense rainfall and has demonstrated the value of using mortar between the blocks instead of traditional sand but the number of trials of each of the different types has been small. The experiences have shown the way forward but there is insufficient data to recommend the best option.

8.8 Suitable combinations

Table 8.2 shows the recommended combinations. These potentially fall into just four thickness designs for each traffic level although the more expensive options will not be suitable for the lowest categories of road. The basic gravel wearing course is not recommended for the highest traffic levels.

Table 8.2, Structural options

Layer	Structure 1	Structure 2	Structure 3	Structure 4
Surface	Gravel	DBST or Otta	Pen Mac	Concrete
Road base		WBM, DBM, GCS, Stabilised	WBM, DBM, GCS, Stabilised	-
Sub-base		Gravel	Gravel	Gravel
Selected Fill[1] where required		CBR > 10%	CBR > 10%	CBR > 10%

Notes 1 If suitable material is not available a stabilisation option is required and sub-base thicknesses can be reduced.

9 Structural Designs

Fundamental to the approach to cost-effective and appropriate LVRR design is the use of local materials with engineering properties that may be outside the limits of normal specifications. The use of these materials is dependant on locally based research into their marginal properties and the nature of the traffic loads they would have to withstand. This approach has allowed, for example, the use of local natural gravels and aggregates in LVRR layer designs in the Lao Standards and Specifications.

Such designs using materials of marginal quality can also be developed for Cambodia on similar principles based on the specific quality of materials and the environmental conditions in different parts of the country, but this is beyond the scope of the current project. The following structural designs are therefore not specific “LVRR” designs but are based on the materials meeting ‘normal’ or international standards. They are primarily based on international research carried out by TRL and by ARRB.

9.1 Traffic

The classification of rural roads is shown in Table 6.1. The classification is based on the number of 4-wheeled vehicles.

Structural design, for sealed roads at least, depends on the weight of vehicle axles and the number of times the road has to support these axles. Thus it is the cumulative traffic throughout the design life of the road that is important and this is measured in terms of ‘equivalent standard axles’ according to the formula;.

$$esa = \sum \left(\frac{Axle\,load\ in\ kilo\ grams}{8160} \right)^{4.5}$$

where the summation is over all the axles of the vehicles.

Applying the relationship shows that only heavy vehicles are important. For major roads a survey of axle loads is normally required but this is not usually practicable for LVRRs. Instead, assumptions have to be made about the proportion of the 4-wheeled (plus) vehicles in the traffic stream that are likely to be heavily loaded and their average esa values. Such vehicles are large buses, large 2-axle trucks and all trucks of more than two axles. It is likely that there is some information available in Cambodia from other road projects but in the absence of a systematic review it is assumed that 20% of the 4-wheeled vehicles fall into this category. Unfortunately the loads on these vehicles are not known and therefore neither is the likely value of the number of esas per vehicle. Experience in the region indicates that the average on different roads could cover a very wide range from very low (<0.5) to a high value (e.g. >5) representing regular overloading. The latter is very likely where building works are being carried out, but such overloading may be only temporary.

This poses a design dilemma. It has been resolved by assuming two basic levels of loading for such vehicles, low or high. It will therefore be the responsibility of the designer to estimate which category of loading is likely to apply to the road he is designing, remembering that it is the traffic in seven years time that is most representative of the overall traffic on the road during its design life.

The two levels are

Low = 20% heavy vehicles with average esa values of 1.0 esa per vehicle.
High = 20% heavy vehicles with average esa of 5.0 esa per vehicle.

The consequences of these assumptions is that the ADT values used for road classification translate directly into cumulative esa values over a 15-year design life. Using rounded values, the results are shown in Table 9.1 and indicate that a maximum of four thickness designs will be sufficient for each of the four structures shown in Table 8.2. However, the design methods often indicate minimum thickness values which will cater for a wide range of traffic hence the number of actual designs is less.

It should be emphasised that the traffic levels for RR1 lie outside the normally accepted limits of LVRR design. Although RR1 designs are currently included in this document, some aspects of LVVR engineering would not be applicable, for example, the future use of marginal materials, as discussed above, would not normally apply to this group.

Table 9.1, Cumulative traffic loading for design

Class	**ADT (sum of both directions)**	**Cumulative mesa (one direction)**	
		High load option	Low load option
RR 1	200 - 500	1.3	0.5
RR 2	100 - 200	0.5	0.1
RR 3	30-100	0.25	0.05
RR 4	5 - 30	0.1	0.02
RR 5	0 - 5	0.02	Very low

Thus structural designs are needed for traffic levels of 0.02, 0.05, 0.10, 0.25, 0.50, and 1.3 mesas, or six options. These are shown in the following Tables.

Most structural design charts for pavements do not take into account the width of the wheelpaths. These are relatively narrow on major roads but much wider on rural roads where the heavy vehicles tend to run in the middle of the road and are also frequently moving about to overtake slower vehicles. As a result, the effective loading of the vulnerable parts of the road is less than expected from a direct calculation based on vehicle numbers. This effect is difficult to include in the design method because it has rarely been measured. Ignoring it means that there is an additional element of safety in the designs suggested here.

For single lane roads, traffic in both directions uses the same wheelpaths hence the road loading is potentially higher than normal. Conflicts with other road users increases the effective width of the wheelpaths and counteracts this effect slightly. However, the traffic loading on single lane roads is very low and these effects can essentially be ignored.

9.2 Structure 1: Gravel wearing courses

Table 9.2 gives details of the designs for gravel wearing courses. Gravel can wear away quite quickly and therefore allowance has to be made for this, particularly where the traffic is high and heavy vehicles are likely to be present. For low subgrade strengths a ‘fill’ layer is recommended to protect the subgrade. The thickness of gravel wearing course also helps for low strength subgrades. For the higher strength subgrades the thickness of gravel is designed to minimise re-gravelling frequencies as far as is practicable. Thinner gravel courses will require more frequent re-gravelling.

Table 9.2, Designs with a gravel wearing course

Subgrade CBR%	Layer	Cumulative traffic in mesa					
		0.02	**0 05**	**0.10**	**0.3**	**0.5**	**1.3**
S1 = 2%	Gravel (mm)	200	200	250	250	250	NS
	Fill (mm)	150	200	200	200	200	
S2 = 3, 4%	Gravel (mm)	200	200	250	250	250	NS
	Fill (mm)	100	150	150	150	150	
S3 = 5 -7%	Gravel (mm)	225	250	250	250	250	NS
S4 = 8 -14%	Gravel (mm)	200	200	250	250	250	NS
S5 = 15 -29%	Gravel (mm)	200	200	250	250	250	NS
S6= >30%	Gravel (mm)	200	200	250	250	250	NS

NS = Not suitable

9.3 Structure 2: Unbound bases

The possible roadbases are WBM, DBM, and Graded Crushed Stone. The sub-bases are normally gravel meeting a soaked CBR criterion of > 25%. If suitable gravel is not available a stabilised material can be used. Stabilisation to give a similar strength to that of a suitable unstabilised sub-base allows the designs shown in Table 9.3 to be used. This is a CBR of >25% or an unconfined compressive strength of 0.75MN/m^2. Stabilisation also permits a stronger layer to be constructed and this will allow a reduction in thickness as shown in Table 9.4, where the stabilisation provides a material at least equivalent to a CBR of 40% or unconfined compressive strength of 1.5MN/m^2.

Table 9.3, Structures with unbound roadbases

Subgrade CBR%	Layer	Cumulative traffic in mesa					
		0.02	**0 05**	**0.10**	**0.3**	**0.5**	**1.3**
S1 = 2%	Surface	DBST or Otta					
	Roadbase (mm)	125	150	150	150	150	200
	Sub-base (mm)	150	150	150	200	200	225
	Fill (mm)	200	225	250	300	350	325
S2 = 3, 4%	Surface	DBST or Otta					
	Roadbase (mm)	125	125	150	150	150	200
	Sub-base (mm)	125	150	150	200	200	225
	Fill (mm)	150	175	150	200	250	225
S3 = 5 -7%	Surface	DBST or Otta					
	Roadbase (mm)	125	125	125	125	150	175
	Sub-base (mm)	100	125	150	150	150	175
	Fill (mm)	75	100	100	100	175	175
S4 = 8 -14%	Surface	DBST or Otta					
	Roadbase (mm)	125	125	125	150	150	175
	Sub-base (mm)	100	125	150	175	200	225
S5 = 15 -29%	Surface	DBST or Otta					
	Roadbase (mm)	100	100	125	150	150	175
	Sub-base (mm)	75	100	100	100	125	150
S6= >30%	Surface	DBST or Otta					
	Roadbase (mm)	100	100	125	150	150	175

9.3.1 *Unbound roadbases and stabilised sub-bases*

If suitable sub-base material is not available, stabilised material can be used instead. See Section 9.3 above for details of the strength of the stabilised layer.

Table 9.4 Stabilised sub-bases

Subgrade CBR%	**Layer**	**Cumulative traffic in mesa**					
		0.02	**0.05**	**0.1**	**0.3**	**0.5**	**1.3**
S1 = 2%	Surface	DBST or Otta					
	Roadbase (mm)	125	150	150	150	150	200
	Sub-base (mm)	125	150	150	200	200	200
	Fill (mm)	200	200	225	250	300	325
S2 = 3, 4%	Surface	DBST or Otta					
	Roadbase (mm)	125	125	150	150	150	200
	Sub-base (mm)	125	150	150	175	175	200
	Fill (mm)	125	150	150	200	250	225
S3 = 5 -7%	Surface	DBST or Otta					
	Roadbase (mm)	100	125	125	150	150	175
	Sub-base (mm)	100	100	125	150	150	150
	Fill (mm)	75	100	100	100	150	175
S4 = 8 -14%	Surface	DBST or Otta					
	Roadbase (mm)	100	100	125	150	150	175
	Sub-base (mm)	100	125	125	150	175	200
S5 = 15 -29%	Surface	DBST or Otta					
	Roadbase (mm)	75	100	100	125	150	175
	Sub-base (mm)	75	75	100	125	125	125
S6 = >30%	Surface	DBST or Otta					
	Roadbase (mm)	100	100	125	150	150	175

9.4 Structure 3: Bituminous roadbases

Penetration Macadam has performed well in rural trials in Vietnam. The designs are shown in Table 9.5.

Table 9.5, Penetration macadam designs

<table>
<tr><th rowspan="2">Subgrade CBR%</th><th rowspan="2">Layer</th><th colspan="6">Cumulative traffic in mesa</th></tr>
<tr><th>0.02</th><th>0 05</th><th>0.1</th><th>0.3</th><th>0.5</th><th>1.3</th></tr>
<tr><td rowspan="4">S1 = 2%</td><td>Pen mac (mm)</td><td colspan="6">65</td></tr>
<tr><td>Roadbase (mm)</td><td>75</td><td>100</td><td>125</td><td>150</td><td>175</td><td>200</td></tr>
<tr><td>Sub-base (mm)</td><td>100</td><td>125</td><td>175</td><td>200</td><td>200</td><td>250</td></tr>
<tr><td>Fill (mm)</td><td>200</td><td>200</td><td>200</td><td>250</td><td>300</td><td>300</td></tr>
<tr><td colspan="8"></td></tr>
<tr><td rowspan="4">S2 =
3, 4%</td><td>Pen mac (mm)</td><td colspan="6">65</td></tr>
<tr><td>Roadbase (mm)</td><td>75</td><td>100</td><td>125</td><td>150</td><td>175</td><td>200</td></tr>
<tr><td>Sub-base (mm)</td><td>100</td><td>125</td><td>125</td><td>150</td><td>175</td><td>200</td></tr>
<tr><td>Fill (mm)</td><td>100</td><td>125</td><td>150</td><td>200</td><td>200</td><td>250</td></tr>
<tr><td colspan="8"></td></tr>
<tr><td rowspan="4">S3 =
5 -7%</td><td>Pen mac (mm)</td><td colspan="6">65</td></tr>
<tr><td>Roadbase (mm)</td><td>75</td><td>100</td><td>125</td><td>150</td><td>150</td><td>175</td></tr>
<tr><td>Sub-base (mm)</td><td>100</td><td>125</td><td>150</td><td>200</td><td>150</td><td>175</td></tr>
<tr><td>Fill (mm)</td><td></td><td></td><td></td><td></td><td>150</td><td>175</td></tr>
<tr><td colspan="8"></td></tr>
<tr><td rowspan="3">S4 =
8 -14%</td><td>Pen mac (mm)</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Roadbase (mm)</td><td>100</td><td>75</td><td>100</td><td>125</td><td>125</td><td>175</td></tr>
<tr><td>Sub-base (mm)</td><td></td><td>100</td><td>100</td><td>150</td><td>200</td><td>200</td></tr>
<tr><td colspan="8"></td></tr>
<tr><td rowspan="3">S5 =
15 -29%</td><td>Pen mac (mm)</td><td colspan="6">65</td></tr>
<tr><td>Roadbase (mm)</td><td>75</td><td>100</td><td>125</td><td>100</td><td>125</td><td>150</td></tr>
<tr><td>Sub-base (mm)</td><td></td><td></td><td></td><td>100</td><td>100</td><td>125</td></tr>
<tr><td colspan="8"></td></tr>
<tr><td rowspan="2">S6 =
>30%</td><td>Pen mac (mm)</td><td colspan="6">65</td></tr>
<tr><td>Roadbase (mm)</td><td>75</td><td>75</td><td>100</td><td>100</td><td>125</td><td>150</td></tr>
</table>

9.5 Structure 4: concrete pavements

The concrete pavement designs are shown in Table 9.6. Concrete pavements are constructed to a minimum thickness of 150mm and this is suitable for traffic up to quite a high level (much greater than that which would normally be defined as a low volume road) hence, for the lowest traffic categories they are likely to be expensive. However, there are many situations where the environmental conditions are severe and a concrete pavement is recommended.

The success of concrete for heavy traffic is dependent on the presence of a uniform supporting sub-base layer. This sub-base must be resistant to erosion and to the movement of fine material through the pumping action created by heavy traffic but for rural roads the amount of heavy traffic is low therefore pumping of fines should not be a problem. However subgrade movement can create large voids under slabs and so the preparation of the foundation layers under a concrete slab is just as important as for other road structures.

Table 9.6, Concrete pavements designs.

Subgrade CBR%	**Layer**	**Cumulative traffic in mesa**					
		0.02	**0.05**	**0.1**	**0.3**	**0.5**	**1.3**
S1 = 2%	Concrete (mm)	150					
	Sub-base (mm)	100	100	100	125	150	200
	Fill (mm)	100	100	100	100	150	200
S2 = 3, 4%	Concrete (mm)	150					
	Sub-base (mm)	100	100	100	125	100	125
	Fill (mm)					100	150
S3 = 5 -7%	Concrete (mm)	150					
	Sub-base (mm)	100	100	100	100	100	150
S4 = 8 -14%	Concrete (mm)	150					
	Sub-base (mm)	100	100	100	100	100	100
S5 = 15 -29%	Concrete (mm)	150					
	Sub-base (mm)	75	100	100	100	100	100
S6 = >30%	Concrete (mm)	150					
		Prepared subgrade					

9.6 Structure 5: block pavements

No formal design procedures have yet been developed for this group of options in SEA. Trial designs used in Vietnam, Lao and Cambodia were generally based on local experience and precedent. The thickness of blocks used in SEA trials are summarised in Table 9.7.

Table 9.7, Regional block layer thicknesses

Country	Block Type	Thickness (mm)	Strength
Cambodia	Stone Sett	200	Crushing strength 25 MPa
Vietnam	Fired Clay Bricks	100	Crushing strength 20-25 MPa
	Concrete Blocks	70	Crushing strength 25 MPa
	Stone Setts	200	Stone compressive strength>75MPa
	Stone Cobbles	150	Crushing strength 25 MPa
Lao	Concrete Blocks	65	Crushing strength 25 MPa

As a general guide the underlying layers for LVRRs (excluding classification RR1) would normally be in line with recommendations for sub-base and capping layer fill as shown in Table 9.3 and 9.4.

10 Drainage

10.1 General Principles

One of the most important aspects of the design of a road is the provision made for protecting the road from surface water or ground water. If water is allowed to enter the structure of the road, the pavement will be weakened and it will be much more susceptible to damage by traffic. Water can enter the road as a result of rain penetrating the surface or as a result of the infiltration of ground water. The road surface must be constructed with a camber so that it sheds rain water quickly and the formation of the road must be raised above the level of the local water table to prevent it being soaked by ground water.

Water can also have a harmful effect on shoulders, slopes, ditches and other features. High water velocities can cause erosion which, when severe, can lead to the road being cut. Conversely, low velocities in drainage facilities can lead to silt being deposited which, in turn, can lead to a blockage. Blockages often result in further erosion.

A good road drainage system, which is properly maintained, is vital to the successful operation of a road. It has four main functions:

- To convey rainwater from the surface of the carriageway to outfalls (streams and turn- outs)
- To control the level of the water table in the subgrade beneath the carriageway
- To intercept surface water flowing towards the road
- To convey water across the line of the road in a controlled fashion.

The first three functions are performed by side drains and the fourth by culverts, drifts and bridges.

Attention is required to ensure that all water discharges do not risk erosion downstream or on adjacent land.

10.2 Existing Drainage Standards

The MRD’s draft Works Specifications and Technical Standards for Rural Roads and Bridges includes drainage standards that are considered applicable to rural roads.

11 Recommendations: The Way Forward

11.1 Classification and Geometric Standards

The proposed rural road Classification and Geometric Standards have been developed in close consultation with relevant personnel within the Ministry of Rural Development (MRD). The principal contents were also presented at a Workshop in Phnom Penh in June 2009 at which there was a general agreement on their suitability.

It is believed therefore that the proposals contained within this document comprise a sensible and appropriate basis for a revised Rural Road Classification and Geometric Standards for Cambodia. The following steps are therefore now recommended:

1. Translation of the document into Khmer
2. Review and formal approval by the MRD
3. Edit the contents of this document into an appropriate official format
4. Formal legal acceptance as the official Rural Roads Classification and Geometric Standards Document for Cambodia.

It is firmly recommend that there should be a separation of Classification and Standards from the Pavement Option elements of this current document. The latter should **not** be included within the official standards but should be kept as a separate but associated document that can be updated without the need for formal government approval.

11.2 Pavement Options

As noted above, the Pavement Options elements of this document should be kept as a separate technical document associated with the formal standards. In the short term there is need to adapt the currently proposed design charts in Chapter 9 of this document into specific LVRR charts for use with specific Cambodian materials within Cambodian road environments; particularly with respect to traffic loads.

In the longer term there is additional work required to prepare a wider matrix of LVRR design options for Cambodia, as indicated in the associated SEACAP 19 Technical Papers. Much of this work should centre around the monitoring of existing trials or the developing of new research trials. Some additional applied research into local construction material properties is also recommended.

11.3 Data Collection

It was apparent from discussions held with key stakeholders that there is no clear consensus on the nature of rural traffic patterns nor the types of vehicles in use throughout the various rural environments of Cambodia. This is an extremely serious knowledge gap and one which should be urgently addressed.

There is a reasonable argument for not finalising the Classification and Geometric Standards until at least the issue of typical design vehicles is clarified by appropriate studies. This is not a major undertaking by any means but one which can be addressed by locally-based studies coordinated by the MRD.

In the slightly longer term there is a clear need to obtain reliable data on the types of traffic currently utilising Cambodian rural roads and its regional variation. In particular, there is need to identify the percentages of larger trucks (and axle loads) that are likely to use the rural network in the foreseeable future.

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Appendix A. Summary Tables: classification and geometric standards

The following tables are recommended as the basis for the recommended new rural road Classification and Geometric Standards for Cambodia.

Proposed classification of rural roads

Class	AADT of 4-wheeled vehicles	Width of running surface (m)	Sub class	PCUs of non 4-wheeled vehicles	Width of shoulders (m)	Total width (m)
RR 1	200 to 500	6.0	A	>300	1.5	9.0
		6.0	B	< 300	1.0	8.0
RR 2	100 to 200	5.0	A	> 300	1.5	8.0
		5.0	B	< 300	1.0	7.0
RR 3	30 to 100	3.5	A	> 300	1.5	6.5
		3.5	B	< 300	1.0	5.5
RR 4	5 to 30	3.0	A	> 300	1.0	5.0
		3.0	B	< 300	0.75	4.5
RR 5	< 5	2.5	A	>300	1.0	4.5
		2.5	B	<300	0.75	4.0

Rural Roads Class RR 5 (ADT<5)

Design Parameter	Comments	Definition		
Carriageway width		2.5m		
Shoulder width	Depends on number of non 4-wheeled vehicles	> 300 PCUs 1.0 m < 300 PCUs 0.75 m		
Notional design speed	Defined by terrain	Flat	Rolling	Mountainous
		30 km/h	30 km/h	20 km/h
Minimum horizontal curve radius (m)		35	35	35
Maximum gradient	A limit of 6% for gravel	6%	8%	10%(1)
Stopping sight distance (m)	Gravel	70	50	35
	Sealed	55	40	30
Minimum horizontal curve radius (m) SE=4%	Gravel(2)(recommended)	110	67	35
	Sealed	97	60	32
Minimum horizontal curve radius (m) SE=7%	Gravel(2)	100	60	30
	Sealed	70	40	20
Minimum value of L/G for vertical curves	Gravel	12	6	3
	Sealed	7	4	2
Sag	Gravel or sealed	2.2	1.3	0.7
Cross-fall	Gravel	6%[2]		
	Sealed	4%		

2. Gradients up to 15% permitted in cases where lower gradients would incur excessive earthworks and construction cost and where lengths of alignment >10% are kept to <300m.

2. Gravel cross-fall must be maintained at between 4 and 6%.

Rural Roads Class RR 4 (ADT < 30)

Design Parameter	**Comments**	**Definition**		
Carriageway width		3.0 m		
Shoulder width	Depends on number of non 4-wheeled vehicles	> 300 PCUs 1.0 m < 300 PCUs 0.75 m with passing places		
Design speed	Defined by terrain	Flat	Rolling	Mountainous
		50 km/h	40 km/h	30 km/h
Maximum gradient	A limit of 6% for gravel	6%	8%	10%**(1)**
Stopping sight distance (m)	Gravel	70	50	35
	Sealed	55	40	30
Minimum horizontal curve radius (m) SE=4%	Gravel(2)(recommended)	110	67	35
	Sealed	97	60	32
Minimum horizontal curve radius (m) SE=7%	Gravel(2)	100	60	30
	Sealed	70	40	20
Minimum value of L/G for vertical curves	Gravel	12	6	3
	Sealed	7	4	2
Sag	Gravel or sealed	2.2	1.3	0.7
Cross-fall	Gravel	6%[2]		
	Sealed	4%		

1. Gradients up to 15% permitted in cases where lower gradients would incur excessive earthworks and construction cost and where lengths of alignment >10% are kept to <300m.
2. Gravel cross-fall must be maintained at between 4 and 6%.

Rural Roads Class RR 3 (ADT 30-100)

Design Parameter	**Comments**	**Definition**		
Carriageway width		3.5 m		
Shoulder width	Depends on number of non 4-wheeled vehicles	> 300 PCUs 1.5 m < 300 PCUs 1.0 m		
Design speed	Defined by terrain	Flat	Rolling	Mountainous
		50 km/h	40 km/h	30 km/h
Maximum gradient	A limit of 6% for gravel	6%	8%	10%(1)
Stopping sight distance (m)	Gravel	70	50	35
	Sealed	55	40	30
Minimum horizontal curve radius (m) SE=4%	Gravel(2)(recommended)	110	67	35
	Sealed	97	60	32
Minimum horizontal curve radius (m) SE=7%	Gravel(2)	100	60	30
	Sealed	70	40	20
Minimum value of L/G for vertical curves	Gravel	12	6	3
	Sealed	7	4	2
Sag	Gravel or sealed	2.2	1.3	0.7
Cross fall	Gravel	6 %[2]		
	Sealed	4 %		

1. Gradients up to 15% permitted in cases where lower gradients would incur excessive earthworks and construction cost and where lengths of alignment >10% are kept to <300m.
2. Gravel cross-fall must be maintained at between 4 and 6%.

Rural Roads Class RR 2 (ADT 100-200)

Design Parameter	Comments	Definition		
Carriageway width		5.5 m		
Shoulder width	Depends on number of non 4-wheeled vehicles	> 300 PCUs 1.5 m < 300 PCUs 1.0 m		
Design speed	Defined by terrain	Flat	Rolling	Mountainous
		50 km/h	40 km/h	30 km/h
Maximum gradient	A limit of 6% for gravel	6%	8%	10%**(1)**
Stopping sight distance (m)	Gravel	70	50	35
	Sealed	55	40	30
Minimum horizontal curve radius (m) SE=4%	Gravel(2)(recommended)	110	67	35
	Sealed	97	60	32
Minimum horizontal curve radius (m) SE=7%	Gravel(2)	100	60	30
	Sealed	70	40	20
Minimum value of L/G for vertical curves	Gravel	12	6	3
	Sealed	7	4	2
Sag	Gravel or sealed	2.2	1.3	0.7
Cross fall	Gravel	6 %**2**		
	Sealed	4 %		

1. Gradients up to 15% permitted in cases where lower gradients would incur excessive earthworks and construction cost and where lengths of alignment >10% are kept to <300m.
2. Gravel cross-fall must be maintained at between 4 and 6%.

Rural Roads Class RR 1 (ADT 200-500)

Design Parameter	**Comments**	**Definition**		
Carriageway width		6.0 m		
Shoulder width	Depends on number of non 4-wheeled vehicles	> 300 PCUs 1.5 m < 300 PCUs 0.75 m		
Design speed	Defined by terrain	Flat	Rolling	Mountainous
		60 km/h	50 km/h	40 km/h
Maximum gradient	A limit of 6% for gravel	6%	8%	10%(1)
Stopping sight distance (m)	Gravel	93	70	50
	Sealed	72	55	40
Minimum horizontal curve radius (m) SE=4%	Gravel(2, 3) (recommended)	165	110	67
	Sealed	150	97	60
Minimum horizontal curve radius (m) SE=7%	Gravel (2, 3)	150	100	60
	Sealed	112	70	40
Minimum value of L/G for vertical curves	Gravel (2)	20	11	6
	Sealed	12	7	4
Sag	Gravel or sealed	3.5	2.2	1.3
Cross fall	Gravel (see notes 2, 3)	6%		
	Sealed	4%		

1. Gradients up to 15% permitted in cases where lower gradients would incur excessive earthworks and construction cost and where lengths of alignment >10% are kept to <300m.

2 Gravel surfaces are not usually suitable for this traffic level.

3. Gravel cross-fall must be maintained at between 4 and 6%.

Appendix B. Summary Tables of proposed pavement structural designs.

Designs with a gravel wearing course

Subgrade CBR%	**Layer**	**Cumulative traffic in mesa**					
		0.02	**0 05**	**0.10**	**0.3**	**0.5**	**1.3**
S1 = 2%	Gravel (mm)	200	200	250	250	250	NS
	Fill (mm)	150	200	200	200	200	
S2 = 3, 4%	Gravel (mm)	200	200	250	250	250	NS
	Fill (mm)	100	150	150	150	150	
S3 = 5 -7%	Gravel (mm)	225	250	250	250	250	NS
S4 = 8 -14%	Gravel (mm)	200	200	250	250	250	NS
S5 = 15 -29%	Gravel (mm)	200	200	250	250	250	NS
S6= >30%	Gravel (mm)	200	200	250	250	250	NS

Structures with unbound roadbases

Subgrade CBR%	**Layer**	**Cumulative traffic in mesa**					
		0.02	**0 05**	**0.10**	**0.3**	**0.5**	**1.3**
S1 = 2%	Surface	DBST or Otta					
	Roadbase (mm)	125	150	150	150	150	200
	Sub-base (mm)	150	150	150	200	200	225
	Fill (mm)	200	225	250	300	350	325
S2 = 3, 4%	Surface	DBST or Otta					
	Roadbase (mm)	125	125	150	150	150	200
	Sub-base (mm)	125	150	150	200	200	225
	Fill (mm)	150	175	150	200	250	225
S3 = 5 -7%	Surface	DBST or Otta					
	Roadbase (mm)	125	125	125	125	150	175
	Sub-base (mm)	100	125	150	150	150	175
	Fill (mm)	75	100	100	100	175	175
S4 = 8 -14%	Surface	DBST or Otta					
	Roadbase (mm)	125	125	125	150	150	175
	Sub-base (mm)	100	125	150	175	200	225
S5 = 15 -29%	Surface	DBST or Otta					
	Roadbase (mm)	100	100	125	150	150	175
	Sub-base (mm)	75	100	100	100	125	150
S6= >30%	Surface	DBST or Otta					
	Roadbase (mm)	100	100	125	150	150	175

Stabilised sub-bases

Subgrade CBR%	**Layer**	**Cumulative traffic in mesa**					
		0.02	**0.05**	**0.1**	**0.3**	**0.5**	**1.3**
S1 = 2%	Surface	DBST or Otta					
	Roadbase (mm)	125	150	150	150	150	200
	Sub-base (mm)	125	150	150	200	200	200
	Fill (mm)	200	200	225	250	300	325
S2 = 3, 4%	Surface	DBST or Otta					
	Roadbase (mm)	125	125	150	150	150	200
	Sub-base (mm)	125	150	150	175	175	200
	Fill (mm)	125	150	150	200	250	225
S3 = 5 -7%	Surface	DBST or Otta					
	Roadbase (mm)	100	125	125	150	150	175
	Sub-base (mm)	100	100	125	150	150	150
	Fill (mm)	75	100	100	100	150	175
S4 = 8 -14%	Surface	DBST or Otta					
	Roadbase (mm)	100	100	125	150	150	175
	Sub-base (mm)	100	125	125	150	175	200
S5 = 15 -29%	Surface	DBST or Otta					
	Roadbase (mm)	75	100	100	125	150	175
	Sub-base (mm)	75	75	100	125	125	125
S6 = >30%	Surface	DBST or Otta					
	Roadbase (mm)	100	100	125	150	150	175

Penetration macadam designs

Subgrade CBR%	**Layer**	**Cumulative traffic in mesa**					
		0.02	**0 05**	**0.1**	**0.3**	**0.5**	**1.3**
S1 = 2%	Pen mac (mm)	65					
	Roadbase (mm)	75	100	125	150	175	200
	Sub-base (mm)	100	125	175	200	200	250
	Fill (mm)	200	200	200	250	300	300
S2 = 3, 4%	Pen mac (mm)	65					
	Roadbase (mm)	75	100	125	150	175	200
	Sub-base (mm)	100	125	125	150	175	200
	Fill (mm)	100	125	150	200	200	250
S3 = 5 -7%	Pen mac (mm)	65					
	Roadbase (mm)	75	100	125	150	150	175
	Sub-base (mm)	100	125	150	200	150	175
	Fill (mm)					150	175
S4 = 8 -14%	Pen mac (mm)						
	Roadbase (mm)	100	75	100	125	125	175
	Sub-base (mm)		100	100	150	200	200
S5 = 15 -29%	Pen mac (mm)	65					
	Roadbase (mm)	75	100	125	100	125	150
	Sub-base (mm)				100	100	125
S6 = >30%	Pen mac (mm)	65					
	Roadbase (mm)	75	75	100	100	125	150

Concrete pavements designs.

Subgrade CBR%	**Layer**	**Cumulative traffic in mesa**					
		0.02	**0.05**	**0.1**	**0.3**	**0.5**	**1.3**
S1 = 2%	Concrete (mm)	150					
	Sub-base (mm)	100	100	100	125	150	200
	Fill (mm)	100	100	100	100	150	200
S2 = 3, 4%	Concrete (mm)	150					
	Sub-base (mm)	100	100	100	125	100	125
	Fill (mm)					100	150
S3 = 5 -7%	Concrete (mm)	150					
	Sub-base (mm)	100	100	100	100	100	150
S4 = 8 -14%	Concrete (mm)	150					
	Sub-base (mm)	100	100	100	100	100	100
S5 = 15 -29%	Concrete (mm)	150					
	Sub-base (mm)	75	100	100	100	100	100
S6 = >30%	Concrete (mm)	150					
		Prepared subgrade					

Drainage of road pavements (from current MRD works specifications and technical standards for rural roads and bridges