MINISTRY OF PUBLIC WORKS AND TRANSPORT

Low Volume Rural Road
Environmentally Optimised Design Manual

April 2009

Typical low volume rural road in Lao PDR

CONTENTS

Glossary

Access	The ability to travel, for which adequate vehicles and infrastructure are required.
Armoured gravel	Specified natural gravel laid to camber and compacted overlain by a protective armouring (usually 75mm thick) of crushed stone aggregate laid to camber and compacted
Base	A pavement layer of medium to high strength material and on which the surface is constructed.
Bituminous seal	A thin surface comprising bitumen and either single sized chips (giving DBST) or graded aggregate (giving an Otta seal).
Budget	The funding available for the construction or maintenance of a road.
Capping	A low strength soil which can be placed onto a subgrade in order to reduce the required thicknesses of the pavement layers above and to provide a working platform for the construction
Chainage	The measurement of distance along the road, normally starting from 0+000.
Cross section	A section of road and terrain taken right angles to the longitudinal alignment.
Design life	The expected life of the road for which the road is designed. Roads designed using this manual will have a design life of between 8 to 12 years.
Environment	Either the green environment, comprising vegetation and water sources, or a more general term referring to the various technical, social and institutional features of where and how the road will be constructed.
Flat terrain	Terrain with minimal gradient and minimal restriction on horizontal and vertical alignment.
Gaz 66	A medium truck, common in Lao PDR, for which the LVRR Standards are suitable.
Geometric cross section	The transverse shape of a road, including the carriageway and shoulders.
Geometry	The nature of the alignment of the road in terms of curves, crests, dips and gradients.
Gravel	A natural well graded material with plasticity and a good particle structure and which is suitable as a base layer and a

	wearing course.
Infrastructure	Constructed works, such as roads and bridges, in order to provide access and allow road users to travel.
Isuzu	A medium truck, common in Lao PDR, for which the LVRR Standards are suitable.
Kolao	A small truck, common in Lao PDR, for which the LVRR Standards are suitable.
LVRR Standards	A set of design requirements which are suitable for low volume rural roads in Lao PDR.
Mountainous terrain	Terrain with steep hills and substantial restrictions on horizontal and vertical alignment.
Pavement	One or more layers of imported material which are compacted onto a subgrade in order to allow vehicles to travel more easily.
Prioritisation	Selection of the sections to be improved using priority criteria.
Priority criteria	Criteria which are given to a length of road on the basis of its current passability and safety in order to select the most important sections when funding is limited.
Rolling terrain	Terrain with low hills and some restrictions on horizontal and vertical alignment.
Screening	A decision, made using initial information, to go ahead with or cease work in order to prevent wasted effort on an unrealistic project.
Sub-base	A pavement layer of low to medium strength material which is constructed on a capping layer or subgrade and on which the roadbase is constructed.
Subgrade	The surface of natural material on which an improved pavement will be constructed.
Subgrade design strength	The strength of the subgrade which is used when designing the layers of the improved pavement.
Surface	The top layer of a pavement, a thin bituminous seal, concrete or gravel wearing course.
Travel	Movement from place to place, typically using vehicles and on constructed paths and road.
Uniform section	A length of road which is similar in several aspects and which may be improved in its entirety with a single design.

Abbreviations

AADT	Average Annual Daily Traffic
BoQ	Bill of Quantities
CBR	California Bearing Ratio
DBST	Double Bituminous Surface Treatment
DCP	Dynamic Cone Penetrometer
DPWT	Department of Public Works and Transport
EOD	Environmentally Optimised Design
GPS	Global Positioning System
LRD	Local Roads Division
LRDM	Lao Road Design Manual
LVRR	Low Volume Rural Road
MPa	Mega Pascals
MPWT	Ministry of Public Works and Transport
OPWT	Office of Public Works and Transport
ORN	Overseas Road Note
PI	Plasticity Index
VMC	Village Management Committee

1 Introduction

1.1 Rural travel and infrastructure

Travel is necessary for economic, government, employment, agricultural, commercial, health, schooling and social purposes and is vital for development and poverty reduction.

There are four aspects of rural travel, all of which need to be addressed if development is to be sustainable and equitable: durable infrastructure, efficient and affordable transport services, vehicles which are appropriate for the conditions and travel reduction measures such as the relocation of services close to communities.

This manual is concerned with the improvement of rural infrastructure with a focus on improved pavements and surfaces. It provides a range of low cost designs which are adequate for typical traffic on rural roads.

1.2 The Environmentally Optimised Design (EOD) approach

This manual is based on the EOD approach. With this approach, the road is designed to suit a variety of task and environmental factors such as rainfall, available materials, construction capacity, gradient, flood risk and so on.

Some of these factors vary from road to road and even from site to site along a road. Therefore a road design may vary along the length of a road with, for example, a sealed surface up a hill or gravel along a level section. This variable nature is referred to as ‘variable longitudinal design’.

Whereas the priority of those using national highways is to travel fast and comfortably, the priority of those using low volume rural roads is on safe and reliable travel, being confident that one will arrive at one’s destination safely and without the route being blocked. When funds are limited, therefore, they should be used to improve sites which do not currently provide safe and reliable access, for example a badly damaged or flooded section. Sites which do provide this level of access can be left without improvement, for example a length of track which is not eroding, slippery or damaged, allowing the funds to be used to improve access on other roads. Sites which are improved in such a way are referred to as ‘spot improvements’.

The EOD approach combines variable longitudinal design with, when funds are limited, spot improvements.

This manual is based on the guidance in Low Volume Rural Road Standards and Specifications Part I-III, which were produced under the SEACAP 3.01 project in the South East Asia Community Access Programme (SEACAP).

This manual has been written by a team of road researchers and engineers from LTEC, OtB and TRL.

1.3 Structure and use of the manual

Chapter 2 describes the steps in the design of improvements to a road or track which has deteriorated and is now in poor condition.

Chapter 3 briefly describes the steps in the design of new road, where they differ from those in Chapter 2.

The Appendices give design tables and technical guidance to support the steps in Chapters 2 and 3 and exercises and examples in several important topics.

It is impossible to produce guidance for every example of path, track and road and the condition in which they may be found. Therefore the steps may need to be amended to suit the specific circumstances of each case.

The design process will normally include a first site visit for a rapid survey, a second visit for the main survey and a possible third visit to collect additional data. The design process may take two to six months.

2 Improvement of an existing road

Figure 1 is a flowchart showing the design steps to improve a road or track in poor condition.

2.1 Screening	Screen out unrealistic projects where funding is too low, traffic is too heavy or maintenance capacity is inadequate.
2.2 Site visit and rapid survey	Collect general information and form an initial opinion of the problems and likely improvements along the road.
2.3 Assessments	Assess the traffic, terrain, rainfall, available materials and the construction and maintenance capacity that will affect the design.
2.4 Initial design work	Use the results of the assessments to design the geometric cross section and geometry of the road.
2.5 Main survey	Collect more design information, identify required improvements and determine the relative importance of each improvement.
2.6 Data collection	Collect data relating to the strength of the surface on which improved pavements may be constructed and the quality of materials that will be used in these pavements.
2.7 Selection of improvements	Use the collected survey information and other data to select the most appropriate improvements for each section of the road.
2.8 Pavement and surface design	Select the pavement and surface type and use subgrade strength and traffic to determine the layer thicknesses and strengths of the required pavement.
2.9 Estimation of costs	Calculate the cost of the improvements over their design life – their whole life asset costs –and, if necessary, compare them with alternatives.
2.10 Prioritisation	Select the sections of the road that will be improved if funds are restricted.
2.11 Contract documents	Prepare technical documents relating to the road and the improvements that are required in the contract.

Figure 1 Design steps

2.1 Screening

The design process can be time consuming and expensive. Time and money can be saved by identifying and screening out projects which should not be undertaken or where this manual is inapplicable.

Fund screening

It is essential that adequate funds are available for construction and future maintenance of any improvements.

Typical minimum construction and maintenance costs should be obtained from LRD, taking into account the location of the road and the likely nature of the improvements. If the available construction funds are less than these typical minimum construction costs, it is very unlikely that the current level of access will be noticeably improved. If the available maintenance funds are less than the typical minimum maintenance costs, it is very likely that the improvements will deteriorate within 3-5 years and all benefits will be lost. In either case, more funding should be sought or another project should be chosen.

Traffic screening

If it is obvious from a brief visit or discussion with communities or DPWT or OPWT staff that any of the following are likely, this manual should not be used and the Lao Road Design Manual (LRDM) should be used instead.

- Trucks with axle loads more than 4.5 tonnes will use the road
- More than 150 motorised 4 wheel vehicles will be the road every day
- Vehicles from logging, mining or other development activities will use the road

Maintenance screening

All improvements must be maintained if they are to provide access for more than 3-5 years. If the required technical capacity (skills and equipment) is not available locally to the road, it is unlikely that maintenance will be carried out. Either another project should be chosen or the user of this manual should carefully check that only those pavements and surfaces for which capacity is available are chosen.

2.2 Site visit and rapid survey

Unless the designer is very familiar with the road, it is strongly recommended that a visit is made to the road before the main survey is carried out. The entire road should be seen during the visit, either walking or driving. This visit allows the designer to form an initial opinion of the nature of the problems and the likely improvements. The designer should be accompanied by someone who has walked or driven along the road in wet and dry seasons.

It is recommended that the Rapid Survey Form is used to collect general information during this site visit. This Form is given and explained below. A tape measure is required for the rapid survey and a hand level or inclinometer should be taken if available.

For the rapid survey, if it is possible, chainage posts should be fixed every 50 metres along the road using a long tape measure or other means, either before or during the survey. These posts should remain for the duration of the design and construction work. If these chainage posts are not possible at this stage, the odometer of a vehicle can be used and reference points, such as villages and junctions, should be recorded so that the rapid survey can be matched to the more accurate chainage posts after they have been fixed.

The Rapid Survey Form is given below and should be expanded on a photocopier to give a form of usable size. It can also be obtained from LRD. Complete one row every 100 metres with the observed condition at that exact point.

- Road name, Start point, Province, District, Surveyor, Date – complete as normal.
- Chainage – complete with 0+000, 0+100, 0+200, etc.
- Cross section – complete with 1-6 depending on whether the road is flat, embanked, across sidelong ground, etc.
- Driveable width (m) – complete with the width which motorised vehicles can use.
- Surface – complete with E, G, S, B or C according to the surface material.
- Gradient – complete with 1-5 according to the estimated gradient. Include + for uphill and – for downhill.
- Village – tick if the point is close to houses or is a site of increased pedestrian activity.
- Flooding frequency. – complete with 1-3 according to the frequency with which the road surface is covered with water during the wet season.

- Water course – tick if a water course crosses the road in the preceding 100 metres.
- Condition – complete with 1-3 according to the passability of the road.
- Remarks – record any additional information relating to nearby material sources or landmarks such as junctions or village names.

LVRR Rapid Survey Form

Road name............ Province............. Surveyor.................

Start point........... District.............. Date.....................

Chainage	Cross section	Driveable width (m)	Surface	Gradient (+/-)	Village (√)	Flooding freq.	Water course (√)	Condition	Remarks - material sources, landmarks

Cross section
1
2
3
4
5
6

Surface
- E Earth
- G Gravel
- S Stones
- B Bitumen
- C Concrete

Gradient
1. 0-1 %
2. 2-5 %
3. 6-10 %
4. >10 %
5. crest/sag

Flooding frequency
1. Never
2. < 1 / year
3. ≥ 1 / year

Condition
1. Passable all year
2. Passable dry only
3. Impassable all year

2.3 Assessments

After the site visit and rapid survey, a series of assessments should be carried out. These assessments are required for the later design work.

2.3.1 Traffic assessment

Design life

All roads are designed to last for a defined design life. If the design life is very short, repeated construction costs will be very high; if the design life is very long, traffic may grow to the extent that the road is no longer adequate. Roads designed using this manual will have a design life of between 8 and 12 years.

Objective of traffic counting

In order to design a road, it is necessary to estimate the traffic that will be using the road at the end of the design life. To do this, it is necessary to count the current levels of traffic and then estimate how it will increase when the improvements are completed and then how it will grow over the following years.

The expected traffic has already been screened in order to prevent unnecessary design work on roads that are likely to carry traffic that is beyond the capacity of the designs in this manual.

Traffic categories

In this manual all vehicles are grouped into one of the five categories shown in Table 1.

Table 1 Traffic categories

Traffic Category	Description	Vehicles	Remarks	
1	Non-motorised vehicles and pedestrians	Pedestrian Bicycle Animal	LVRR Standards should ensure that these road users are not in danger from motorised vehicles	
2	2&3-wheeled motorised vehicles	Motorcycle Tuk-tuk Jambo Farm tractor	LVRR Standards are specifically suited to roads carrying vehicles in Categories 2 and 3	
3	Light 4-wheeled motorised vehicles: Width ≤ 1.8 metres & Axle load ≤ 2.5 tonnes	Car Pick-up 4WD Minibus Kolao	LVRR Standards are specifically suited to roads carrying vehicles in Categories 2 and 3	
4	Medium 4-wheeled motorised vehicles: Width = 1.8-2.3 metres & Axle load = 2.5-4.5 tonnes	Isuzu Gaz 66 Medium bus	LVRR Standards suit roads carrying small numbers of vehicles in Category 4	
5	Heavy 4+-wheeled motorised vehicles: Width > 2.3 metres or Axle load > 4.5 tonnes	Large truck Large bus	Large vehicles in Category 5 are beyond the scope of LVRR Standards	

Traffic counts

The traffic should be counted at defined locations so that variations along the road are recorded. The sites defined in Table 2 are the recommended minimum. If the counts at different locations are significantly different, the road may be divided into separate lengths, each with a different count.

Table 2 Traffic count locations

Description of road	Traffic count locations
Shorter than 10 km and does not pass through any villages	One location mid way along the road
Longer than 10 km	Two non-village * locations, one near each end For other locations, interpolate between these figures
Has a major junction	One non-village * location on either side of the junction
Passes through one or more villages	One village location and one non-village * location
Passes through villages of different size and level of activity	In the largest village and in the smallest village For other villages, interpolate between these figures

* Non-village locations should be beyond the limits of normal village activity so that the count is not affected by short distance village journeys. 'Village' can refer to any site of increased pedestrian activity.

At each location traffic should be counted in both directions from 06:00 to 18:00 using the LVRR Traffic Counting Form below, which should be expanded on a photocopier to give a form of usable size. This Traffic Counting Form can also be obtained from LRD.

Ideally the traffic should be counted on 7 consecutive days but if this is not possible, 3 consecutive days are acceptable. Unusual days, such as local festivals, should be avoided. If the road is impassable during the wet season, the count should take place in the dry season. A traffic counting team should have two or more people so that they can work in shifts and count all vehicles. The counts should be added up for each vehicle type and then the totals for each of the five categories calculated. The totals for each category should then be averaged over the total counting days.

LVRR Traffic Counting Form

Road name.................. Province........................... Surveyor.........................

Survey point................. District............................. Date.............................

Traffic Category	Vehicles	06:00 - 09:00	09:00 - 12:00	12:00 - 15:00	15:00 - 18:00	Total two-way count	
1	**Pedestrian**						
	Bicycle						
	Animal						**Category 1**
2	**Motorcycle**						
	3-wheeler						
	Farm tractor						**Category 2**
3	**Car**						
	Pick-up						
	4WD						
	Minibus						
	Kolao						**Category 3**
4	**Isuzu**						
	Gaz 66						
	Medium bus						**Category 4**
5	**Large truck**						
	Large bus						**Category 5**

Traffic increase and growth

This manual is normally used for improving roads in poor condition, in which case the traffic levels are likely to increase immediately after the improvements are completed and the level of access improved. This increase depends upon the current level of access and the current level of economic activity in the region. The increase can be estimated by surveying road users' origins and destinations and identifying how many road users are likely to use the improved road, comparing the road with one nearby with similar populations and economic activity or by asking for guidance from LRD.

After a road has been rehabilitated or opened traffic volume is likely to grow and vehicle usage change over future years as social and economic activity increases. This growth is estimated by applying a constant growth factor for the remaining years of the design life.

Traffic analysis

Traffic counts should be analysed as follows using the LVRR Traffic Analysis Form below, which should be expanded on a photocopier to give a form of usable size. This Traffic Analysis Form can also be obtained from LRD.

1. Transfer the total daily counts on the LVRR Traffic Counting Form into the five grey cells on the Analysis Form.
2. Multiply these counts by a Daily factor to include traffic which may have passed by the count site during the night. The Daily factors can be found on the Analysis Form.
3. Multiply these values by a Seasonal factor (obtained from MPWT) to convert the count into a daily average over the year.
4. Estimate the likely traffic increase after completion of the improvements for each category and add this to the daily average.
5. Use the table on the Analysis Form, the annual economic growth rate and the design life to derive the Traffic growth factor over the design life. Multiply the daily average after completion of the improvement by this Traffic growth factor to derive the daily traffic at the end of the design life (Average Annual Daily Traffic – AADT) in each category.

LVRR Traffic Analysis Form

Road name……………… Province……………………….. Surveyor…………………….. Count duration: from……..……to……..…….

Traffic count location……………… District………………………… Date………………………… Design Life (yr)…………………….….

Traffic Category	1	2	3	4	5	
Vehicles	Pedestrian Bicycle Animal	Motorcycle Tuk-tuk Jambo Farm tractor	Car Pick-up 4WD Minibus Kolao	Isuzu Gaz 66 Med bus	Large truck Large bus	
Total two-way count = A						from LVRR Traffic Counting Form
Daily factor = B						
A x B = C						
Seasonal factor = D						
C x D = AADT						
Add 2 way traffic increase on completion = E						
AADT + E = F						
Annual growth rate (%) = G						
Traffic growth factor = H						
F x H = Final year AADT						

Traffic growth factors over the Design Life

Annual growth rate (%)	1	2	3	4	5	6	7	8	9	10
DL = 10 yr	1.10	1.22	1.34	1.48	1.63	1.79	1.97	2.16	2.37	2.59
DL = 12 yr	1.13	1.27	1.43	1.60	1.80	2.01	2.25	2.52	2.81	3.14
DL = 15 yr	1.16	1.35	1.56	1.80	2.08	2.40	2.76	3.17	3.64	4.18
DL = 20 yr	1.22	1.49	1.81	2.19	2.65	3.21	3.87	4.66	5.60	6.73

Count duration	6.00 - 18.00	0.00 - 24.00
Daily factor	1.2	1

Month in which count was made	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Seasonal factor	x	x	x	x	x	x	x	x	x	x	x	x

Traffic analysis is required for three decisions: the applicability of the LVRR standards, the design of the geometric cross section of the road and the allocation of Traffic Group for pavement design

LVRR standards

If there are any vehicles in Traffic Category 5, LVRR standards do not apply and the LRDM should be used
If the sum of the final year AADTs of Traffic Categories 3 and 4 is 150 or more, LVRR standards do not apply and the LRDM should be used

Traffic Group

If the final year AADT of Traffic Category 4 is less than 10, the traffic is in Traffic Group A
If the final year AADT of Traffic Category 4 is 10 or more, the traffic is in Traffic Group B

Design of the cross section

If there are any vehicles in Traffic Category 4, the carriageway is 3.5 metres wide and each shoulder is 1 metre wide
If there are no vehicles in Traffic Category 4 and the final year AADT of Category 1 is 150 or more, the carriageway is 2.5 metres wide and each shoulder is 1.5 metres wide
If there are no vehicles in Traffic Category 4 and the final year AADT of Category 1 is less than 150, the carriageway is 2.5 metres wide and each shoulder is 1 metre wide

Traffic decisions

The final year daily traffic figures are used in three decisions in the design process. Two are described here; a third is described in a later section.

Firstly, use the final year AADTs of traffic categories 3, 4 and 5 and Table 3 to determine if the LVRR Standards are applicable. If the LVRR Standards are not applicable, the LRDM should be used instead. If the road has been divided into separate lengths, each with a different count, and the manual is not applicable for one or more lengths, the LRDM should be used for the entire road. This Table is a more accurate check of the traffic screening carried out earlier.

Table 3 Applicability of the LVRR standards

Category 5 vehicles in any year	**Sum of the final year AADTs of Categories 3 and 4**	
	< 150	**≥ 150**
None	LVRR standards are applicable **Continue using this manual**	LVRR standards are not applicable The LRDM should be used
Some	LVRR standards are not applicable The LRDM should be used	LVRR standards are not applicable The LRDM should be used

Secondly, use the figure for traffic category 4 and Table 4 to allocate the traffic into a Traffic Group for use during pavement design.

Table 4 Traffic Groups

Final year AADT of Category 4	**Traffic Group**
< 10	A
≥ 10	B

An example of traffic analysis and decisions is given in Appendix 10.1.

Traffic restriction

In order for this manual to be applicable and to benefit from its low cost designs, it is possible to use posts, barriers or gates to prevent large or heavy vehicles using a road. If so, it must be done with the agreement of the DPWT and local communities.

Goalpost barrier

Concrete side posts

2.3.2 Terrain assessment

Terrain refers to the nature of the land that the road passes through. It does not refer to each specific curve and hill. If the terrain changes along the length of the road, for example a hill road descending to a valley floor, the terrain for each part can be assessed separately.

Use Table 5 to determine if the terrain is flat, rolling or mountainous. The number of 5 metre contours crossed can be estimated in the following ways.

- Use a GPS instrument to measure the height of each rise and fall. However, it is important to check the accuracy of altitude measurements with the GPS before using this method.
- Use a map with 25 or 50 metre contours and interpolate between contour lines
- Carry out a longitudinal level survey along the road

If these methods are not possible, the descriptions in Table 5 or the experience of the surveyor can be used instead.

Table 5 Terrain classes

Number of 5 metre contours crossed per km	Description	Terrain	
0-10	Terrain with minimal gradient and minimal restriction on horizontal and vertical alignment	Flat	
11-25	Terrain with low hills and some restrictions on horizontal and vertical alignment	Rolling	
>25	Terrain with steep hills and substantial restrictions on horizontal and vertical alignment	Mount-ainous	

2.3.3 Rainfall assessment

The climate of a region affects the design of a road, from the materials that can be used to the need to seal a gravel surface on a hill. Although there are many aspects of climate – total rainfall, duration of wet season, rainfall intensity, etc – in this manual climate is represented by the total annual rainfall.

The total annual rainfall in the area of the road should be established from DPWT or OPWT records and the area should be classed using Table 6. The rainfall class will be used during the design process.

Table 6 Rainfall classes

Total annual rainfall (mm/year)	Rainfall class
1000-1500	Moderate
1500-2000	High
> 2000	Very high

2.3.4 Materials assessment

An assessment of available materials will give important indications as to the feasibility and costs of pavement types and associated earthworks and drainage. Table 7 lists common material groupings encountered in Lao PDR with potential uses. Note that the economic use of materials in Groups I and VI may depend upon whether or not processing equipment is available (extraction, crushing and screening).

Table 7 Common material groupings in Lao PDR

Material Group	Description	Possible uses
I Hard rock	Strong to very strong igneous (granite, basalt), sedimentary (crystalline limestone) and metamorphic (schist) rock types. Will require processing.	Filter and drainage aggregate Concrete aggregate Pavement sub-base and base material Surfacing aggregate
II Weak rock	Weak to very weak mainly sedimentary rocks such as shale, mudstone and non-crystalline limestone. Also includes weathered Type I rock types	Common fill and capping Pavement sub-base material Unsealed surfacing wearing course
III Hill gravels	Hill gravels (colluvium) derived from a combination of hard rock weathering and down-slope accumulation.	Common fill and capping Shoulders Pavement sub-base Pavement base material (high quality only) Unsealed surfacing wearing course
IV Laterite gravel	Soil-like materials with a clay-silt-sand-gravel nature with small nodules or concretions. Occasional forms more continuous hardened layers	Common fill and capping Shoulders Pavement sub-base Pavement base material (high quality only) Unsealed surfacing wearing course.
V Residual soil (laterite soil)	Formed by the in situ weathering of Group I and II materials, no significant granular material.	Common fill Capping
VI Alluvial materials	Sand, gravel and cobble derived mainly from Group I materials. Will require some processing (screening/crushing)	Filter and drainage aggregate Concrete aggregate Pavement sub-base and base material Surfacing aggregate

2.3.5 Construction and maintenance capacity assessment

There are three aspects to the capacity to construct and maintain an improvement: technical ability, resources and maintenance management. In most cases this assessment focuses on pavement type options such as gravel, bituminous seal or concrete.

If the capacity does not exist for a particular pavement type, a different type should be selected and designed. If the capacity does not exist for any pavement type, the project may not be feasible.

Technical ability

Construction and maintenance work must meet the LVRR specifications. The experience and technical knowledge of the contractors should be assessed. Some of the pavement types in the LVRR standards are technically more difficult than others. Only those who are able to meet the specifications should be allowed to tender for the work. Technical training may be required for contractors and other parties before a programme of improvements can begin.

Resources

It is important that contractors have the correct resources for the required work and that they are able to complete the work within the required period, this often being a single dry season. These resources include unskilled and skilled labourers, gang leaders, supervisors, technicians, engineers, management, materials, tools, equipment and plant. Only those with sufficient resources should be allowed to tender for the work. Appropriate resources are also required for maintenance work whether it is carried out by contractors or VMCs.

Maintenance management

In addition to meeting the LVRR specifications, it is essential that maintenance is reliable and is carried out when required. A common reason for the deterioration of low volume roads is the failure to carry out maintenance when it is required, particularly for gravel roads but also for all other pavement types. Maintenance management includes adequate funding, availability of contractors or VMCs and a system which sets up a regular cycle of routine maintenance, identifies the need for additional maintenance when required and ensures that all work is carried out.

Cutting grass

Clearing drains

Different pavement types require different skills, materials, resources and activity types. The required maintenance activities of different pavement types and the importance of the maintenance are summarised in Table 8, adapted from Table A1.1 in Low Volume Rural Road Standards and Specifications Part III.

Table 8 Summary of LVRR maintenance requirements

Pavement type	**Routine maintenance requirement**	**Periodic maintenance requirement**	**Importance of maintenance**
Gravel	Basic maintenance * plus pothole repairs and camber reshaping	Regravelling to replace material lost due to traffic and weather	Very high
Sealed granular	Basic maintenance * plus pothole repairs	Reseal of the surface after 8-12 years	Moderate
Unreinforced concrete	Basic maintenance * only	Crack sealing and joint repairs	Low

* Basic maintenance includes all off-surface items such as shoulder repairs, vegetation control, cleaning the drainage system and erosion repairs, which will be of similar quantity for all surfaces on low volume rural roads

These three aspects should be assessed for each possible pavement type through discussion with communities and OPWT staff. The conclusion of the assessment should be whether or not a particular pavement type can be constructed well and maintained well.

2.4 Initial design work

The geometric cross section and the geometry of the road should be designed using the results of the above assessments. Geometric cross section refers to the width and camber of the carriageway and shoulders and the height of the road above ground or flood water. Geometry refers to the horizontal and vertical curvature, super-elevation, sight distance and gradient.

2.4.1 Width of carriageway and shoulders

The width of the carriageway and shoulders should allow the expected numbers and types of vehicles and other road users to travel in safety. Use Table 9 to determine the required widths.

Table 9 Width of carriageway and shoulders

Final Year AADT of Category 4 Traffic	Final year AADT of Category 1 Traffic	
	< 150	≥ 150
None	Carriageway width = 2.5 m Shoulder width = 1 m	Carriageway width = 2.5 m Shoulder width = 1.5 m
Some	Carriageway width = 3.5 m Shoulder width = 1 m	Carriageway width = 3.5 m Shoulder width = 1 m

2.4.2 Camber of carriageway and shoulders

The camber of the carriageway and shoulders should shed rain water falling on the road into the side ditches. Use Table 10 to determine the required cambers.

Table 10 Camber of carriageway and shoulder

	Surface type [1]		
	Gravel	Bituminous	Concrete
Camber of carriageway [2]	6% [3]	4%	1-2%
Camber of shoulders	6%	6%	6%

1 This design decision will be completed when the surface type has been determined
2 All lower pavement layers should have the same camber as the carriageway
3 The camber of a gravel surface should be maintained at no less than 4%

2.4.3 Height of the subgrade above ground or flood water

The height of the top of the subgrade above ground or flood water should prevent the water excessively weakening the pavement layers of the road. Use Table 11 to determine the minimum allowable subgrade height.

Table 11 Minimum height of the subgrade above ground or flood water

Highest water level in the last 5 years [1]	Minimum height of the top of the subgrade
Surrounding land floods	0.65 m above the highest flood level
Surrounding land does not flood but ground water is above the base of the side ditches	0.65 m above the water level in the side ditch
Ground water is below the base of the side ditches but within 0.5 m of ground level	0.65 m above the base of the side ditch
Ground water is always more than 0.5 m below ground level	0.45 m above the base of the side ditch

1 The water level will be recorded during the main survey

Flooding covering a rural road

2.4.4 Radius of horizontal curvature

The radius of horizontal curvature of the road should allow vehicles travelling at typical speeds for the terrain to travel safely around curves without sliding off the road. Use Table 12 to determine the minimum allowable radius of horizontal curvature.

Table 12 Minimum radius of horizontal curvature

		Terrain		
		Flat	**Rolling**	**Mountainous**
Surface type [1]	**Gravel**	$H_{min} = 110$	$H_{min} = 70$	$H_{min} = 40$
	Bituminous or concrete	$H_{min} = 95$	$H_{min} = 60$	$H_{min} = 35$

H_{min} is the minimum horizontal radius of a curve (m)
1 This design decision will be completed when the surface type has been determined

An exception can be made to the limits in Table 12 if all of the following apply. All exemptions must be agreed with the DPWT.

- Compliance would require expensive earthworks or land purchase.
- The radius is made as high as practical.
- Visual obstructions inside the curve are removed.
- Warning signs are placed before the curve in both directions.

Horizontal curve

2.4.5 Super-elevation

The LVRR design speeds of 30 and 40 km/h are below those for which super elevation is generally recommended. However, the removal of crossfall on the outer half of the carriageway on horizontal curves below 500 metre radius is recommended.

If super-elevation is to be applied for 40-50 km/h roads then it should follow recommended practice with a maximum of normal crossfall (4-6%) and be applied over the distances recommended in the LRDM.

2.4.6 Radius of vertical curvature

The radius of vertical curvature of the road should allow vehicles travelling at typical speeds for the terrain to travel safely over crests and sags without losing traction or control and with adequate sight distance. Use Table 13 to determine the minimum allowable radius of vertical curvature.

Table 13 Minimum radius of vertical curvature

		Terrain		
		Flat	**Rolling**	**Mountainous**
Surface type [1]	**Gravel**	VC_{min} = 1500 VS_{min} = 400	VC_{min} = 900 VS_{min} = 250	VC_{min} = 400 VS_{min} = 150
	Bituminous or concrete	VC_{min} = 1000 VS_{min} = 400	VC_{min} = 500 VS_{min} = 250	VC_{min} = 300 VS_{min} = 150

VC_{min} is the minimum vertical radius of a crest (m)
VS_{min} is the minimum vertical radius of a sag (m)
Values of VC_{min} and VS_{min} have been rounded from those given in the LVRR Standards
1 This design decision will be completed when the surface type has been determined

An exception can be made to the limits in Table 13 if all of the following apply. All exemptions must be agreed with the DPWT.

- Compliance would require expensive earthworks.
- Crests are removed as much as possible.
- Warning signs are placed before the crest or sag in both directions.

Vertical crest

2.4.7 Combined curves

The above sections have given limits for horizontal and vertical curvature. However, it is also important to consider how curves should be combined. Within practical limits, horizontal and vertical curves should be kept separate by lengths of straight road with constant gradient. When this is not possible, warning signs should be used wherever one curve follows closely after another.

2.4.8 Sight distance

The sight distance along the road should allow two vehicles approaching one another at typical speeds for the terrain to stop before hitting each other. Use Table 14 to determine the minimum allowable sight distance.

Table 14 Minimum sight distance

		Terrain		
		Flat	**Rolling**	**Mountainous**
Surface type [1]	**Gravel**	$SD_{min} = 130$	$SD_{min} = 100$	$SD_{min} = 60$
	Bituminous or concrete	$SD_{min} = 100$	$SD_{min} = 70$	$SD_{min} = 50$

SD_{min} is the minimum sight distance along the road (m)
1 This design decision will be completed when the surface type has been determined

An exception can be made to the limits in Table 14 if all of the following apply. All exemptions must be agreed with the DPWT.

- Compliance would require expensive earthworks or land purchase.
- The sight distance is made as high as possible.
- Warning signs are placed before the restriction in both directions.

2.4.9 Gradient

The gradient of the hills along the road should allow vehicles travelling at typical speeds for the terrain to travel safely up and down hills without losing traction or control. Use Table 15 to determine the maximum allowable gradient.

Table 15 Maximum gradient

			Terrain		
		Annual rainfall (mm/year)	**Flat**	**Rolling**	**Mountainous**
Surface type [1]	**Gravel**	1000-1500	G_{max} = 6%	G_{max} = 6%	G_{max} = 6%
		1500-2000	G_{max} = 4%	G_{max} = 4%	G_{max} = 4%
		>2000	G_{max} = 1%	G_{max} = 1%	G_{max} = 1%
	Bituminous or concrete		G_{max} = 6%	G_{max} = 8%	G_{max} = 10%

G_{max} is the maximum gradient of a hill
1 This design decision will be completed when the surface type has been determined

An exception can be made to the limits for bituminous and concrete surfaces in Table 15 by allowing gradients up to 15% if all of the following apply. All exemptions must be agreed with the DPWT.

- Compliance would require expensive earthworks or land purchase.
- The length of slope is less than 300 metres.
- Warning signs are placed before the hill in both directions.

Steep hill

2.5 Main survey

The site visit and rapid survey are used to form an initial opinion of the problems and likely improvements along the road and to collect general information. However, it is also necessary for a survey team to walk the entire site and carry out a more detailed survey, possibly also taking samples and carrying out tests. The objectives of this main survey are to collect most of the required information, identify the required improvements and determine the relative importance of each in case not all can be constructed with available funds. The Main Survey Form below should be expanded on a photocopier and used for the survey. It can also be obtained from LRD.

It is important to note that the main survey is not a maintenance survey.

2.5.1 Survey steps

The steps in the main survey are as follows:

1. Assemble the team and equipment
2. Establish chainages
3. Record initial information
4. Identify uniform sections
5. Collect survey information
6. Select priority criteria
7. Collect supporting information

LVRR Main Survey Form

Road name.............................. Province.............................. Surveyor..............................

Start point.............................. District.............................. Date..............................

Chainage	Change of uniform section	Cross section	Driveable width (m)	Shoulder width - total (m)	Surface	Gradient (+/-)	Plan view	Village (√)	Flooding freq	Height in flood (+/-)	Water course (√)	Missing structure (√)	Surface in poor condition	Drainage in poor condition	Dusty when dry	Slippery when wet	Unstable slope (A/B)	Safety concerns	Environmental concerns	Cross section below standard	Geometry below standard	Surface below standard	Pavement below standard	Priority criteria	Supporting information - materials, samples, test pits, material sources, landmarks, villages, tight curves, safety concerns, environmental concerns, water courses, flooding frequency, realignments

Uniform section criteria
Road appearance
Gradient
Village
Risk of flooding
Overall condition
Water crossing

Cross section
1
2
3
4
5
6

Surface	
E	Earth
G	Gravel
S	Stones
B	Bitumen
C	Concrete

Flooding frequency	
1	Never
2	< 1 / year
3	≥ 1 / year

Priority criteria	
1 Unsafe - high risk	8 Unstable slope
2 Impassable at any time	9 Environmental concerns
3 Impassable in wet only	10 Very slow travel
4 Condition likely to deteriorate	11 Geom cross sect below standard
5 Health risk	12 Geometry below standard
6 Drainage in poor condition	13 Surface below standard
7 Unsafe - medium risk	14 Pavement below standard

2.5.2 Team and equipment

The survey team should include an engineer or technician from DPWT or OPWT and at least one road user or member of the local community who has experience of the road and its condition throughout the year and for the last five years.

Table 16 shows what equipment is necessary for the survey and what equipment can be taken if available.

Table 16 Survey equipment

Essential	30-50 metre tape measure LVRR Main Survey Form Clipboard Spade, sample bags and cards
Recommended	Hand level or inclinometer GPS instrument Camera Compass DCP instrument Umbrella

2.5.3 Chainages

If chainages posts were not fixed during the site visit and rapid survey, they should be fixed before the main survey. They should be fixed every 50 metres along the road using a long tape measure or other means. These posts will remain for the duration of the design and construction work.

2.5.4 Reference information

At the start of the road, complete the reference information at the top of the Main Survey Form.

2.5.5 Uniform sections

The survey process is based upon identifying the start and end points of sections which are reasonably uniform in the factors listed in Table 17 and on the Main Survey Form. Uniform sections can be of variable length, from 100 metres or less in mountainous terrain to several hundred metres in flat terrain. For each uniform section, measurements and assessments will be made. In most cases, a single improvement will be designed for each uniform section, although if further variation is found, for example in subgrade strength, uniform sections can be divided further and an improvement designed for each sub-section.

Very short uniform sections can be difficult and uneconomic for a contractor to construct. To prevent this, the guidance below should be followed.

- Minor variation in the factors should be allowed, as indicated in Table 17.
- A uniform section with a less arduous sub-section within it, for example a steep hill with a short flat sub-section half way up or a section in poor condition with a short sub-section in better condition half way along, should be considered as a single section with the improvement designed for the more arduous conditions of the longer section.
- Except in unusual situations, uniform sections should not be less than 50 metres.

Table 17 Factors of a uniform section

Factor	Description
Road appearance	This factor includes aspects such as driveable width, camber, presence of side ditches, cross section (1-6 as described in 2.2 above) and surface material, all of which affect the type of problems that are likely to occur and the work required to improve the road. Some variation within these aspects should be allowed in order to prevent uniform sections being too short.
Gradient	Gradient affects the likelihood of erosion and the severity of any slipperiness, as well as the suitability of different surfaces. The following categories, as used in 2.2, should be used: 0-1%; 2-5%; 6-10%; >10%. If measurement is not possible, gradient should be estimated as flat, gentle or steep.
Village	The increased presence of pedestrians alongside the road increases the need for safety measures and surfaces which prevent dust.
Risk of flooding	Risk of flooding affects the required improvements and their importance. The following ranges, as used in 2.2, should be used: never; < 1 per year; ≥ 1 per year.
Overall condition	Overall condition affects the passability of the road and the importance of the improvements. The following ranges, as used in 2.2, should be used: passable all year; passable dry season only; impassable all year.
Water crossing	A defined water course should be considered as a separate section of road. This should not include a crossing across a wide flood plain without a defined water course.

Low volume road passing through a village

2.5.6 Survey information

Before the survey begins, it is useful to review the Rapid Survey Form and recall the nature and variability of the road and the problems along it.

For the main survey, complete one row of the Main Survey Form every 50 metres along the road using the guidance on the Form and in Table 18. In addition and on a separate row, record the chainage at which one uniform section changes to another. In this way, the regularity of information collection is maintained but the start and end points of each uniform section are also identified.

Table 18 Main Survey Form items

Item	Description
Chainage	Record the chainages as 0+000, 0+050, 0+100, etc.
Change of uniform section	Record the chainage where one uniform section changes to another.
Cross section	Complete with complete with 1-6 depending on whether the road is flat, formed, embanked, across sidelong ground or in a cutting.
Driveable width	Record the width of the road which motorised vehicles can use.
Shoulder width	Record the total width of both shoulders, if present.
Surface	Complete with E, G, S, B or C according to the current surface material.
Gradient	Record the gradient. It is recommended that a hand level or inclinometer is used. Use "+" for uphill and "-" for downhill going up-chainage. Gradient can be measured after the main survey and added to the Form later if necessary.
Plan view	Draw a small sketch of the road to indicate if there are any tight curves nearby.
Village	Tick if the point is close to houses or is a site of increased pedestrian activity.
Flooding frequency	Complete with 1-3 according to the frequency with which the road surface is covered with water during the wet season.
Height in flood	Record the height of the subgrade above the ground or flood water (+) or the height of water above the subgrade (-) when in flood. If the ground water is deeper than 0.5 metres, it is not necessary to measure it – record with '0.5+'.
Water course	Tick if the uniform section is a defined water course but not if it crosses a wide flood plain without a defined water course.
Missing structure	Tick if the water course is missing a structure or if a structure is in very poor condition.
Surface in poor condition	Tick if the road surface is in poor condition and passability is reduced.
Drainage in poor condition	Tick if the drains are in poor condition and drainage capacity or performance is reduced.

Dusty when dry	Tick if the surface is dusty when dry.
Slippery when wet	Tick if the surface is slippery when wet and affects vehicle traction.
Unstable slope	Tick if the slopes above or below the road are unstable and at risk of slipping. Alternatively record with an A for slopes above the road or B for slopes below the road.
Safety concerns	Tick if there are any safety concerns along the road, as given in Table 19.
Environmental concerns	Tick if construction or future usage may cause environmental concerns along the road such as erosion of bare soil, disruption of a water course or contamination of a water supply.
Geometric cross section below standard *	Tick if the width or camber of the carriageway or shoulders or the heights of the subgrade above ground or flood water do not meet those determined in 2.4 above.
Geometry below standard *	Tick if the curvature, sight distance or gradient of the road do not meet those determined in 2.4 above.
Surface below standard	Tick if the surface is dusty, slippery or gravel on a steep hill
Pavement below standard *	Tick if the pavement thickness and strength is not adequate for expected traffic, as described in 2.6.2.
Priority criteria	Complete with the priority criteria for the section, as described in 2.5.7.
Supporting information	Complete with necessary supporting information, as described in 2.5.8.

* It may not be possible to make these three assessments until after the main survey has been completed and other tests have been made

Table 19 Safety concerns

Typical safety concerns
• Unstable slope above a village
• Unprotected steep or high drop alongside the road
• Slippery surface, particularly a hill
• Motorised traffic near a village, school or place of work
• Narrow road with risk of sliding off
• Dust with risk to health
• Poor visibility around curve
• Tight curve with risk of leaving the road
• Poor visibility over a crest
• Area next to the road used as a bus stop with risk of accidents
• Area next to the road used by market traders with risk of accidents
• Dangerous sites without warning signs

2.5.7 Priority criteria

An important objective of the main survey is to determine the relative importance of each improvement in case not all can be constructed with available funds. This is done by assigning each uniform section a priority criteria from Table 20 based on the impact of the condition on the safety and reliability of the access along the road. If only some improvements can be constructed, those sections with the most severe criteria will be improved first. If more than one criteria applies to a section, that which is highest in Table 20 should be used on the Form.

Table 20 Priority criteria

Priority criteria	Description
1 Unsafe – high risk	Safety concerns put road users or others at high risk of injury or death.
2 Impassable at any time	Road users are unable to pass along the road at any time of the year.
3 Impassable in wet season only	Road users are unable to pass along the road in the wet season, although closures up to 24 hours after rainfall are accepted.
4 Condition likely to deteriorate	Vehicles or rainfall are likely to cause significant deterioration of the road in the next year.
5 Health risk	The health of road users and others is at risk, typically due to dust from a gravel road.
6 Drainage in poor condition	Drainage capacity or performance is reduced and retained water is likely to damage the road.
7 Unsafe – medium risk	Safety concerns put road users or others at medium risk of injury.
8 Unstable slope	The slopes above or below the road are unstable and at risk of slipping.
9 Environmental concerns	Construction or future usage may cause environmental concerns along the road such as erosion of bare soil, disruption of a water course or contamination of a water supply.
10 Very slow travel	Vehicles travel very slowly along the road due to its poor condition.
11 Geometric cross section below standard *	The width and camber of the carriageway and shoulders do not meet those determined in 2.4 above.
12 Geometry below standard *	The curvature, sight distance or gradient of the road do not meet those determined in 2.4 above.
13 Surface below standard	The surface is dusty, slippery or gravel on a steep hill.
14 Pavement below standard *	The pavement does not meet the requirements specified in 2.6.2 below.

* It may not be possible to select these priority criteria until after the main survey has been completed and other tests and comparisons with standards have been made.

2.5.8 Supporting information

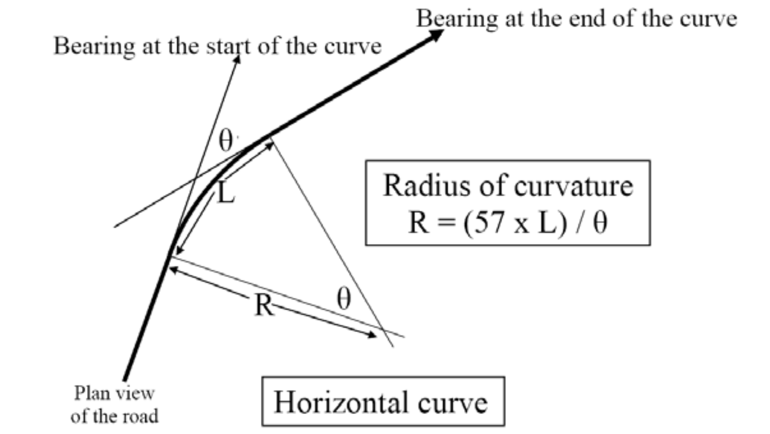
Although most of the required information will be recorded on the preceding columns of the Main Survey Form, there will be some information to support the analysis and design that cannot be collected with simple ticks and measurements. This information should be written in the final column. Table 21 lists what is likely to be required but is not exclusive and any other information that might be relevant should also be recorded.

Table 21 Supporting information

Supporting information	**Description**
Materials	Record the current road surface material and, if observed, the material below the surface.
Samples	Record the chainage and details of any material samples taken or planned.
Test pits	Record the chainage of any test pits dug or planned.
Material sources	Record the location and material type of any sources close to the road.
Landmarks	Record the chainage of any landmarks for help with referencing and reinstatement if required.
Villages	Record the start chainage and names of villages or other sites of increased pedestrian activity.
Tight curves	Record the chainage and an estimated radius of any tight horizontal and vertical curves, as shown in Figure 2.
Safety concerns	Record the chainage and type of any safety concerns.
Environmental concerns	Record the chainage and type of any environmental concerns.
Water courses	Record the approximate width and depth of any water courses.
Flooding frequency	Record the frequency of flooding of the section of road.
Realignments	Record any sites where short realignments might simplify the required improvements.

Take a bearing with a compass at the start of the curve and the end of the curve. The difference in the bearings, measured in degrees, is θ. Measure the distance along the road between the two points. This distance is L. The radius of curvature is given by R = (57 x L) / θ.

The same equation can also be used for vertical crests and sags where θ is the angle between the approach slope and the leaving slope.



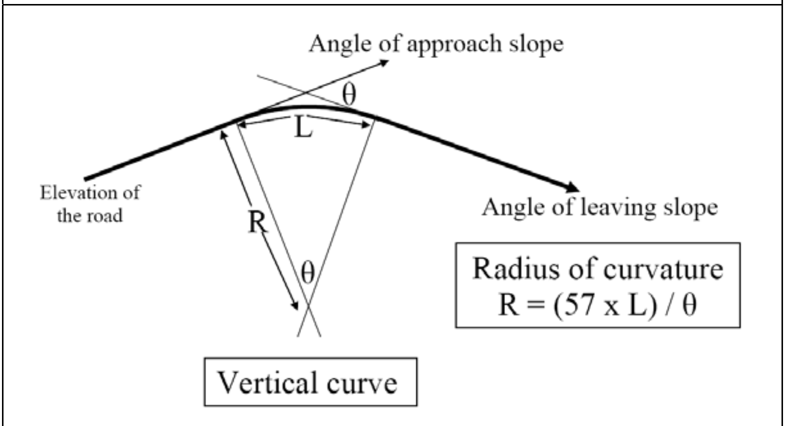


Figure 2 Estimating the radius of horizontal and vertical curvature

2.6 Data collection

During the main survey, information on the nature of the road, the problems along the road and their relative importance is collected. In most cases it is also necessary to collect more specific data relating to the strength of the surface on which improved pavements may be constructed, the strength and thickness of a previously constructed pavement and the quality of materials that will be used in these pavements.

2.6.1 Subgrade strength

The focus of this manual is on the selection and design of improved pavements and surfaces. Two inputs are required for their design: the traffic which is expected to use the road and which was assessed in 2.3.1 and the strength of the surface on which the pavements will be constructed. Although this surface may range from a deteriorated pavement to natural material, it is referred to here in all cases as ‘subgrade’.

Extent of the subgrade assessment

It is recommended that the subgrade of the entire road is assessed and that only if budgets for testing and construction are extremely restricted should limited sections of the subgrade be assessed, with emphasis on sections with obvious surface damage.

Some roads are constructed across hillsides, in which case one side is often cut into the slope while the other side is formed by placing and compacting the excavated material. Compacted fill is often much weaker than a cut slope, particularly if compaction was poor. In other cases, road construction can be variable from one side to another. It is therefore recommended that the subgrade is assessed on either side of the road, typically in each wheeltrack.

Measuring subgrade strength

Subgrade strength can be measured in two ways. It is recommended that both are carried out when possible and that the results are compared, as described below.

It should be noted that the surface of a road which has been subjected to light traffic and wetting and drying cycles can appear very strong, although lower layers can be much weaker and unable to support higher levels of traffic. It is therefore important to test the top 500 mm to ensure that a strong surface does not give an incorrect impression.

Laboratory soaked test

This test measures the strength of a sample of soil that is removed from the site, processed to remove particles larger than 20 mm, compacted into a mould and soaked for 4 days. This soaked condition represents the state that the subgrade may be in when saturated and possibly weakened during a wet season.

The soaked test can be carried out in most DPWT laboratories but is slow and expensive and is typically carried out at a spacing of 500 metres along a road. In most cases, the CBR is assessed at 95% of the maximum dry density obtained under AASHTO modified compaction.

Dynamic Cone Penetrometer (DCP) test

The DCP is an instrument comprising a cone on the end of a rod which is driven into the subgrade by successive blows of a falling weight. The rate of penetration can be used to estimate the strength of the subgrade down to a depth of around 800 mm. The test is carried out on the subgrade in its current condition and indicates the strength on the day of the test. Even if the DCP test is carried out at the end of the wet season when the subgrade is at its wettest, it is still subject to daily variation in moisture content and so, unless some allowance is made, the designs may still fail when the subgrade is saturated. Making allowance for this is described below.

DCP tests take 10-20 minutes and can be carried out at a much closer spacing than soaked laboratory tests, typically 50-100 metres. Each test should penetrate to 800 mm or refusal.

Estimating subgrade design strength

It is recommended that laboratory soaked tests and DCP tests are both carried out. The results should then be correlated so that the pattern from the more closely spaced DCP results can be interpolated between the more accurate but less closely spaced soaked results and hence estimate the subgrade design strength. The ways in which the results should be correlated and the subgrade design strength estimated are given in Appendix A1.

2.6.2 Pavement strength and thickness

If the improved pavement is to be constructed on natural material or a deteriorated pavement, the guidance in 2.6.1 should be followed, a subgrade design strength estimated and a new pavement constructed.

However, if the surface is a pavement in fair or good condition, it may be necessary to make a careful assessment of the pavement and the subgrade below. DPWT or OPWT staff should make this assessment, following the general principles in 2.6.1 and the following paragraphs. There are two situations in which this assessment may be useful.

Firstly, it may be possible to use these layers in an improved pavement. For example, the surface may be a gravel pavement and it may be possible to simply thicken the base and add a bituminous seal to provide a sealed gravel pavement.

Secondly, the current pavement may be adequate for increased traffic levels without further improvement.

Layer thicknesses should be estimated by using a DCP and observing the depths at which the penetration rate changes. Test pits at a greater spacing can confirm the thicknesses. Test pits should be at least 500 mm deep.

DCP tests can also estimate the strength of each layer, including the subgrade, but soaked tests of each layer are also recommended so that the results can be correlated, patterns interpolated and soaked strengths estimated at a close spacing. Correlation should follow the guidance in Appendix A1.

It is important to ensure that any changes in the pavement along the road are detected.

The strength and thickness of each pavement layer should be estimated. The pavement should be compared with the designs in Appendix A3 for the required Traffic Group. If the pavement is equivalent to the relevant design, no further improvement is required; if the pavement is not equivalent to the relevant design, DPWT or OPWT staff should determine what additional thicknesses and layers are required for the pavement to be equivalent.

2.6.3 Material quality

The LVRR pavement and surfacing types in this manual are derived from those described in Appendix A of LVRR Standards and Specifications Part II. These specifications also define the required materials characteristics that should be complied with in terms of standard laboratory tests. The requirements for earthworks and drainage materials are similarly defined in the standard documents associated with the LRDM.

The suitability of materials for identified tasks within a road design is assessed by a combination of field and laboratory procedures.

Field assessment

Field assessment of potential materials resources should be undertaken under three headings:

- Location
- Quantity
- Quality

Location should be considered by answering the following important questions:

- How far is the source from the road sections where it is likely to be used?
- Is the source already in use? If not, how much preparation or development is required?
- What is the condition of the access road to the source?
- Are there any environmental impacts associated with using this source?

The potential **quantity** should be estimated by considered the surface extent of the source and its likely thickness. This estimation is best done by considering the surface extent as a simple geometric shape or a combination of shapes. The size of the geometric shapes can be calculated by using a GPS to measure distance from key points. If no GPS is available then estimation by "pacing out" can be undertaken. When estimating volume the following should be taken into account:

- Reduction in volume due to unusable materials (eg overburden)
- A "bulking factor" from in situ volumes to loose excavated volumes.
- A factor for loose excavated to compacted volume in the road

An early and very useful indication of likely materials **quality** can be obtained by field assessment using a number of simple techniques, as follows:

- *Visual assessment*: apart from identifying general material type it is relatively easy to obtain a general idea of grain size and shape. This may be aided by the use of standard charts or cards.
- *Fines content*: can be roughly assessed by the "hand shake" dilatancy test and the jar settlement test.
- *Schmidt Hammer*: can be used to estimate the strength of rock in outcrop or large boulders
- *Hand Sample Index Strength*: for smaller rock samples
- *Field Durability*: to assess the likely erodibility or disintegration potential of soils or weak rocks
- *Aggregate Pliers Test:* may be used to asses the strength of potential aggregate
- *Field Plasticity Test:* can give a very useful indication of likely plasticity

Further detail on field assessment techniques is included in Appendix A2.

Laboratory assessment

It is essential that some laboratory testing is undertaken to identify the characteristics of proposed materials and to assess how they can be best utilised in the road, remembering that an important EOD principle is to design the road to suit available materials rather than find the materials to suit a standard design.

The key materials characteristics and associated laboratory tests are summarised in Table 22 below and further detail is included in Appendix A2.

Table 22 General tests for assessing natural construction materials

	Material characteristic	Description of the material property	Main laboratory tests designed to evaluate the property
1	Particle size distribution	The relative proportions of each size fraction from gravel to clay size	Sieve analysis Hydrometer analysis
2	Plasticity of the fine fraction	The plasticity characteristics of the particles < 0.425 mm – indication of "slipperiness"; swell-shrink and general behaviour under different moisture condition	Liquid Limit Test Plastic Limit Test Linear Shrinkage Test
3	Load bearing capacity of compacted material	The capacity of the compacted materials to support imposed loads under saturated conditions	4-day soaked CBR
4	Volume stability	Volumetric response of the compacted material to swell-shrinkage on soaking-drying.	Swell measurement during 4-day soaked CBR
5	Particle strength and durability (granular materials)	The existing strength of individual particles and the ability of the particles to maintain this strength during the life of the road.	10% Fines Aggregate Crushing Test (10% FACT) and wet/dry ratio Los Angeles Abrasion Test (LAA) Magnesium or Sodium Sulphate Soundness Test
6	Particle shape (granular materials)	The angularity and flakiness of the aggregate particles and their ability to interlock together	Visual description Flakiness Index Test Elongation Index Test

Sampling

The recovery of representative samples, either from potential source or existing road pavement, is a pre-requisite for effective laboratory testing. Recommended sample sizes for common tests on materials used on low volume rural roads are listed in Table 23.

Table 23 Standard material tests and required sample sizes

Test	ASTM	Minimum Sample Required (kg)		
		Clay-silt size maximum	Sand size maximum	Gravel size maximum
Moisture Content	D2216	0.05	0.35	4.0
Liquid Limit (Cone /Casagrande))	D4318	0.50	1.0	2.0
Liquid Limit (one point cone)	D4318	0.10	0.20	0.40
Plastic Limit	D4318	0.05	0.10	0.20
Linear Shrinkage	(BS1377)	0.50	0.80	1.50
Particle Size (Sieve)	C136 -117	0.15	2.50	17.00
Particle Size (Hydrometer)		0.25		
Particle density	D854	0.30	0.60	0.60
Compaction – CBR (Modified)	D1883	80	80	80
Mg/Na Soundness	C88	0.15	0.60	0.85
Point Load Test	(ISRM)	Ten identical samples		
Los Angeles Abrasion (LAA)	C131	5.0-10.0		

It is important to clearly mark all samples with a unique reference number and to ensure their safe transport to the designated laboratory accompanied by a complete inventory list of samples and the required testing.

2.7 Selection of improvements

The survey information relating to the road and its problems and data relating to the strength of the subgrade should be analysed in order to select the most appropriate improvements for each uniform section.

It may be appropriate to subdivide the uniform sections if the survey information and subgrade strength data indicate variation within a uniform section. However, any sub-sections should still comply with the guidance on minimum length in 2.5.5.

The following paragraphs list potential solutions for each issue identified on the Main Survey Form. It is important to identify the fundamental causes of any engineering problems before an improvement is selected. Applying solutions to superficially apparent problems without addressing the underlying cause will lead to failure of the spot improvement. For example, poor road surface condition may be the result of a number factors ranging from poor maintenance to more complex pavement layer, sub-grade or cross-drainage issues. Treating sub-grade failure as a maintenance problem will only lead to a short improvement at best. Some improvements may be required in isolation, others in combination.

These paragraphs describe the appropriate improvements for each condition or defect. The priority criteria assigned to each uniform section will then determine which improvements can be constructed if funds are restricted.

Village

If people live, work or go to school near to the road, the following improvements should be considered:

- An improved pavement with a bituminous or concrete surface if a gravel surface is currently causing health and safety problems – see 2.8.
- Safety measures – see Appendix A8.

Flooding

If the road floods or if flood water rises to within the minimum allowable subgrade heights given above in Section 2.4.3, the following improvements should be considered:

- A road surface which is resistant to flooding if long term closures are acceptable to the local community. Such surfaces are not covered by this manual.
- An embankment to the required level – see Appendix A5 – with an improved pavement and surface – see 2.8.
- A short realignment around the site – see Appendix A7.

Missing structure

If a water course is missing a structure or if a structure is in very poor condition, the following improvement should be considered:
- A water crossing structure – see Appendix A6.

Surface in poor condition

If the road surface is in poor condition and passability is reduced, the following improvements should be considered:
- An improved pavement and surface – see 2.8.
- An embankment if the height of the subgrade above ground or flood water is within the minimum allowable heights – see Appendix A5.

Drainage in poor condition

If the drains are in poor condition and drainage capacity or performance is reduced, retained water is likely to damage the road and the following improvements should be considered:
- Drainage improvements – see Appendix A6.

Dusty when dry

If the surface is dusty when dry and causes health problems to high numbers of people living alongside and using the road, the following improvements should be considered:
- An improved pavement and surface – see 2.8.
- Safety measures since improved surfaces often cause traffic speeds to increase – see Appendix A8.

Slippery when wet

If the surface is slippery when wet, the following improvement should be considered:

- An improved pavement and surface – see 2.8.

Unstable slope

If the slopes above or below the road are unstable and at risk of failure, the following improvements should be considered:

- Slope stabilisation measures – see references in Appendix A9. For these measures, it will be necessary to return to the site to carry out a more detailed survey of the slopes.
- A short realignment around the site – see Appendix A7.

Safety concerns

If there are safety concerns, with supporting information recorded on the Main Survey Form, the following improvements should be considered:

- Safety measures – see Appendix A8. For these measures, it will be necessary to return to the site to carry out a more detailed survey of the concerns.

Environmental concerns

If there are environmental concerns, with supporting information recorded on the Main Survey Form, the following improvements should be considered:

- Environmental mitigation or protection measures, as described in appropriate MPWT guidance. For these measures, it will be necessary to return to the site to carry out a more detailed survey of the concerns.

Geometric cross section below standard

If the width or camber of the carriageway or shoulders or the height of the subgrade above ground or flood water do not meet those determined in 2.4 above, the following improvements should be considered:

- A reconstructed pavement and surface – see 2.8.

Geometry below standard

If the horizontal and vertical curvature, super elevation, sight distance and gradient do not meet those determined in 2.4 above, the following improvements should be considered:

- A reconstructed pavement and surface with improved geometry – see 2.8.
- A bituminous or concrete surface on steep hills – see 2.8.
- A short realignment around the site – see Appendix A7.

Surface below standard

If the surface is inappropriate for the site, for example if it is erodible on a steep hill, dusty through a village or slippery when wet, the following improvements should be considered:

- An improved surface on a reconstructed pavement – see 2.8.

Pavement below standard

If the pavement is inadequate for the traffic that is expected to use it, by comparison with pavement designs in this manual as described in 2.6.2, the following improvements should be considered:

- An improved pavement and surface – see 2.8.

After improvements have been selected for each uniform section, it is useful to produce a summary for discussion with colleagues in DPWT and OPWT offices. This summary should include a general description of the road, the typical problems along it and improvements selected, the materials which will probably be used in the construction and the likely proportion of the road that will be improved.

2.8 Pavement and surface design

The design of an improved pavement and surface has two steps: the selection of the most appropriate pavement and surface type, and the detailed design of that selection.

2.8.1 Selection of pavement and surface type

Available pavement and surface options are shown in Table 24.

Table 24 Pavement and surface types

Unsealed Gravel	Gravel Wearing Course
	Capping as required
Sealed Natural Gravel	Seal
	Base/Sub-base of specified natural gravel
	Capping as required
Sealed Armoured Gravel	Seal
	Stone aggregate armouring
	Base/Sub-base of specified natural gravel
	Capping as required
Sealed Macadam	Seal
	Macadam base and sub-base
	Capping as required
Non Reinforced Concrete	Concrete surface
	Sub-base of specified gravel or macadam

Tables 25 to 27 may be used to select the most appropriate pavement options. These are based on assessments of the key factors: material availability, maintenance and gradient-rainfall that have been made earlier in this design process. Table 28 may use as guidance for the selection of seal option.

Options that are listed as being "NOT recommended" carry with them a significantly high risk of failure within their design life. In addition there is an over-riding recommendation that unsealed option should not be used where there is a specific health or safety risk; for example: within villages, or adjacent to health centres or schools.

If two or more pavement and surface types appear to be appropriate, it is recommended that designs are completed for both and the whole life asset costs for both are compared, as described in 2.9. The cost comparison should be balanced with a consideration of aspects such as construction complexity and maintenance capacity and the most appropriate type should be selected.

Since some factors, such as gradient, flood risk, presence of people, and material availability, can vary from site to site along a road, the most appropriate pavement and surface type may also vary along a road, for example gravel along a flat section and unreinforced concrete up a hill. However, it should also be noted that an excessively varied design will increase the complexity of construction for the contractor and should therefore be carefully considered.

An increase in pavement choice is likely as more surface and pavement types are trialled and proven in Lao road environments.

Table 25 Option selection by Available Material

MATERIALS SCENARIOS

SPECIFICALLY **NOT** RECOMMENDED	Materials available close to road	RECOMMENDED
	Good quality gravel	Unsealed gravel; sealed gravel; armoured gravel
	Moderate quality gravel	Unsealed gravel; armoured gravel
Unsealed gravel, sealed gravel	Poor quality gravel only	Sealed stabilisation options.
	Processed crushed aggregate	Sealed macadam options
	Non-processed hard rock	Cobbles, stone setts, hand packed stone
Unsealed gravel, sealed gravel	Non processed sand and gravel	Sealed mechanically stabilised options
Unsealed options	Sandy soil only	Sealed stabilised (cement) options
Unsealed options	Clayey soil only	Sealed stabilised (lime) options; clay brick

Table 26 Option selection by Maintenance Regime

MAINTENANCE SCENARIOS

SPECIFICALLY **NOT** RECOMMENDED	MAINTENANCE SCENARIOS	RECOMMENDATION
	Fully funded maintenance regime	No restriction on options
	Routine Maintenance only (with shaping)	Unsealed gravel at risk within 3-5 years
	Routine Maintenance only (no shaping)	Unsealed gravel at risk within 1-5 years.
Unsealed gravel	Occasional intermittent maintenance	Sealed flexible, block, or concrete options
Unsealed gravel	No foreseeable maintenance at all	Concrete best option

Table 27 Option selection by Gradient-Rainfall

GRADIENT-RAINFALL-FLOOD SCENARIOS

SPECIFICALLY **NOT** RECOMMENDED		RECOMMENDATAION
Unsealed gravel	Gradient > 6% Rainfall >1000mm/year	Sealed flexible, block or concrete
Unsealed gravel	Gradient > 4% Rainfall 1500-2000mm/year	Sealed flexible, block or concrete
Unsealed gravel	Any Gradient Tropical Storms - rainfall >2000mm/yr	Sealed flexible, block or concrete
Unsealed gravel	Occasional flood	Sealed flexible, block or concrete
Unsealed gravel,+ (Seals at risk)	Regular yearly flood	Concrete options

Table 28 Seal Option Selection

SEAL OPTIONS

SPECIFICALLY **NOT** RECOMMENDED	Scenario	RECOMMENDATION
	Good fine aggregate available	DBST
	Some limitation on aggregate, but sand available - low traffic group only	Sand seal on SBST
Sand seal	Flood Risk or Gradient >4%	
	Some limitation on aggregate, but graded sand-gravel available	Double Otta Seal

2.8.2 Design method

Two inputs are required for the design of improved pavements and surfaces: the traffic which is expected to use the road and which was assessed in 2.3.1 and the strength of the subgrade on which the pavements will be constructed and which was measured in 2.6.1 and Appendix A1.

For each of the pavement and surface types, Tables are provided in Appendix A3, as shown in Table 29, which give the required pavement design, in terms of layer thicknesses and strengths, for a defined subgrade strength and Traffic Group. In some cases alternative Tables are provided for the use of a capping layer of low strength material which allows the thickness of the other pavement layers to be reduced. These alternative designs can be compared using whole life asset costs and other considerations and the most appropriate design selected.

Table 29 Pavement and surface appendices

Pavement and surface type	Appendix
Gravel	A3.1
Sealed granular	A3.2
Sealed armoured gravel	A3.3
Unreinforced concrete	A3.4

If the subgrade is very strong or if a pavement has already been constructed, it may be possible to use material that is already in place as one or more layers of the pavement design, reducing the quantity and cost of additional construction. Decisions regarding layer substitution must be made by the DPWT or OPWT and should comply with the following principles.

- Sufficient DCP tests, test pits and laboratory soaked tests should be carried out to ensure that the thickness and strength of any layer is equal to or greater than the layer which is to be substituted.
- The combined structure of additional layers, substituted pavement layers and the resulting subgrade (assessed using the guidance in 2.6.1 and 2.6.2) is adequate for the expected traffic.

- Adjustments to the thickness or strength of any layer in a pavement design are not permitted, unless amended designs are discussed in detail with LRD.

After improvements have been designed for each uniform section, it is useful to summarise them for discussion with colleagues in DPWT and OPWT offices and with any interested outside parties. This summary can be done either as a list of improvements, similar to a Bill of Quantities, or as a map, similar to a strip map of the road.

2.9 Estimation of costs

The costs of the selected and designed improvements should now be estimated. There are two reasons for estimating the costs.

1. It is important to make sure that the improvements can be completed within the available budget
2. It may be necessary to compare the costs of two or more alternative improvements for a section in order to select the cheapest. In most cases this will be between different pavement types, although it may be necessary to compare a short realignment with reconstructing a road up a steep hill or to compare two different water crossing structures.

Some improvements are cheap to construct but expensive to maintain. Selecting these improvements can cause long term financial problems for OPWTs and VMCs. It is therefore recommended that the expected costs over the design life of the road are estimated. These are referred to as whole life asset costs and can then be used to compare costs with available budgets and compare alternative pavement types.

Whole life asset costs have three elements: construction costs, maintenance costs and residual value.

Construction costs

These are the costs of constructing the work and include materials, labour, equipment, transport, fuel, supervision, management, insurance, site camp, land purchase, commercial profit, overheads and tax. Construction costs can be estimated in three ways. Firstly, by using the cost of similar work constructed recently nearby using similar methods and materials. Secondly, by using MPWT figures for the typical costs of various improvements. Thirdly, by multiplying the quantity of each input into the work by the unit costs of that input in a Bill of Quantities (BoQ).

Maintenance costs

These are the costs of maintaining the improvements over the design life. They can be estimated in a similar way to construction costs, by comparison with similar work or by multiplying quantities by unit costs, and using information on the likely frequency and content of required maintenance cycles. Maintenance that happens in future years should be multiplied by a discount factor, referred to as discounting, in order to indicate the effect of that cost on the current budget. Discount factors depend on the annual growth rate and the year in which the work is carried out and can be found in Table 30 below. It should be noted that most pavement types require routine maintenance annually and periodic maintenance every 4-8 years.

Residual value

At the end of the design life, some improvements need to be completely reconstructed but others are still in reasonable condition. The repair of these improvements is normally cheaper than reconstruction. These improvements have residual value which can be estimated by calculating the difference between reconstruction and the required repair work.

The whole life asset cost of an improvement is estimated by adding the discounted maintenance costs to the construction cost and then subtracting the discounted residual value.

Table 30 Discount factors

Design life (years)	Discount rate (%)										
	5	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
1	0.95	0.94	0.93	0.93	0.92	0.91	0.90	0.89	0.88	0.88	0.87
2	0.91	0.89	0.87	0.86	0.84	0.83	0.81	0.80	0.78	0.77	0.76
3	0.86	0.84	0.82	0.79	0.77	0.75	0.73	0.71	0.69	0.67	0.66
4	0.82	0.79	0.76	0.74	0.71	0.68	0.66	0.64	0.61	0.59	0.57
5	0.78	0.75	0.71	0.68	0.65	0.62	0.59	0.57	0.54	0.52	0.50
6	0.75	0.70	0.67	0.63	0.60	0.56	0.53	0.51	0.48	0.46	0.43
7	0.71	0.67	0.62	0.58	0.55	0.51	0.48	0.45	0.43	0.40	0.38
8	0.68	0.63	0.58	0.54	0.50	0.47	0.43	0.40	0.38	0.35	0.33
9	0.64	0.59	0.54	0.50	0.46	0.42	0.39	0.36	0.33	0.31	0.28
10	0.61	0.56	0.51	0.46	0.42	0.39	0.35	0.32	0.29	0.27	0.25
11	0.58	0.53	0.48	0.43	0.39	0.35	0.32	0.29	0.26	0.24	0.21
12	0.56	0.50	0.44	0.40	0.36	0.32	0.29	0.26	0.23	0.21	0.19
13	0.53	0.47	0.41	0.37	0.33	0.29	0.26	0.23	0.20	0.18	0.16
14	0.51	0.44	0.39	0.34	0.30	0.26	0.23	0.20	0.18	0.16	0.14
15	0.48	0.42	0.36	0.32	0.27	0.24	0.21	0.18	0.16	0.14	0.12

The estimated whole life asset costs should allow the costs of two or more alternative improvements for a section to be compared and the improvement with the lowest whole life asset costs to be selected.

An example in Appendix A10.4 shows how whole life asset costs are calculated and how two alternative pavements can be compared.

The comparison of the improvement costs against the available budget is explained below.

2.10 Prioritisation

Improvements have now been selected and designed for each uniform section along the road. The construction and whole life costs of the improvements have been estimated.

However, in most cases the budget available for the improvements is less than the estimated costs. The options are to cancel the project and wait until enough funding is available for the entire road, or to construct some of the improvements to the limit of the budget. Cancelling the project is unrealistic because additional funding is unlikely to become available. It is therefore necessary to select which improvements can be constructed within the construction budget.

Improvements that are important to those who use and rely on the road should be prioritised for construction and those improvements which are less important should be omitted. This process is called prioritisation and is why each uniform section was given a priority criteria. The selected improvements will be referred to as ‘spot improvements’.

In addition to priority criteria, the way in which the road connects at either end affects its priority. On a road which is equally used along its length, all uniform sections of similar priority should be prioritised and improved together. However, for a road such as one from a village into farmland with no onward connection, one end is more used than the other and sections there have greater priority.

Improvements should be prioritised using the following procedure.

Define the connection of the road

Decide if the road connects two significant locations, such as a District centre with a main road, or connects one significant location, such as a kum ban, with, for example, farmland, as shown in Table 31. Prioritisation of the two types of road is described in the paragraphs below.

Table 31 Connection of the road

Description	Connection of the road
Road connects two significant locations	Double entry road
Connection with network at both ends	
Road connects only one significant location	Single entry road
No exit at the far end	

Prioritisation of a double entry road

The objective when prioritising improvements on a double entry road is to improve the entire road equally along its entire length. Improvements are therefore prioritised by firstly constructing all selected improvements on the uniform sections with a priority criteria of 1, then all the improvements on the sections with a priority criteria of 2 and so on until the construction costs are almost equal to the available construction budget.

If it is not possible to address all uniform sections that have, for example, a priority criteria of 7, within the budget, the sections should be improved starting at the end with the higher traffic and moving towards the other end.

The sections which the available budget does not cover will remain unimproved until additional funding can be obtained.

Prioritisation of a single entry road

The emphasis when prioritising improvements on a single entry road is on achieving a balance between the priority criteria and the higher traffic at one end of the road.

The dominant end of the road is defined as the end with the higher traffic, the significant location or the connection with the network. In most cases these will all occur at the same end.

Improvements are therefore prioritised by grouping together all uniform sections with a priority criteria of 1-5. These sections are improved starting at the dominant end and moving towards the other end. If it is possible to address all these uniform sections within the budget, those with a priority criteria 6-10 should be grouped together and improved starting from the dominant end. If these can be addressed within the budget, the remaining sections with a priority criteria 11-14 should be grouped together and improved starting from the dominant end. The sections which the available budget does not cover will remain unimproved until additional funding can be obtained.

Completion of prioritisation

Table 32 lists possible outcomes of the prioritisation process, depending on the available budget.

Table 32 Possible outcomes of the prioritisation process

Available budget	Outcome
High	Entire road improved with a pavement and a bituminous or concrete surface
Medium	Gravel surface with spot improvements of a bituminous or concrete surface on steep hills, through villages and at other dangerous sites
Low	Spot improvements at dangerous sites; the remainder of the road is unimproved

A small amount of funding should be retained to carry out low cost measures, as indicated in Table 33, on the uniform sections which will not be improved. These measures are intended to reduce the rate at which these sections deteriorate. They are all described briefly in Appendix A6.

Table 33 Low cost measures on unimproved sections

Improvement	Description
Drainage humps on unformed tracks	Diagonal humps across a track should be constructed to remove water from the surface and reduce erosion
Mitre drains	Additional mitre drains should be dug wherever possible to reduce the water flow in side ditches
Scour checks	Small dams should be constructed in side ditches to reduce water velocity and erosion

After the improvements have been prioritised, it should be checked that the likely maintenance costs will be within the available annual maintenance budget. If it is not, fewer improvements should be constructed in order to reduce the future maintenance requirement.

The summary list or map of improvements should now be amended to show those which have been prioritised for construction.

2.11 Contract documents

The final part of the design process is to incorporate adequate information on the selected, designed and prioritised improvements into contract documentation so that the work can be tendered.

Table 33 recommends the information that should be included in the contract documentation, which should also comply with standard Lao contract procedures.

Table 34 Design information to be included in the contract

Information that is required in a single package for the contract	• List or strip map of the prioritised improvements • Overall alignment of the road • Landmarks used for referencing chainages • List of villages along the road • List of required safety measures • List of required environmental measures • List of available material sources • Standard paragraphs from the LVRR Specifications • LVRR Specifications for all required pavement types
Information that is required for each uniform section	• Start and end chainages and length • Geometric cross section information, including carriageway and shoulder width, camber and freeboard • Geometry, including gradient, horizontal and vertical curvature and super elevation • Pavement type, layer strengths and thicknesses • Shoulder design • Subgrade preparation • Embankment design • Drainage design • Slope protection works • List of low cost measures on all unimproved sections • Water crossing structure designs

3 Construction of a new road

The design steps for a new road are the same as those for improving a road in poor condition, with the following exceptions.

1. An initial step is to establish the alignment of the road. This manual gives brief guidance on short realignments around difficult sites. Additional guidance should therefore be used when establishing the alignment of a new road. However, determining the alignment of a new road offers the opportunity to avoid areas with many problems, such as wide valley floors or wide flood plains.

2. It is possible that some portions of the agreed alignment will be passable with minimal improvement, for example a length with a flat cross section in gentle terrain which is unlikely to erode, weaken or become slippery.

3. During the rapid survey of the agreed alignment, some items such as width, surface and condition may not be relevant.

4. There will be no traffic to count and it will therefore be necessary to make careful estimates of the traffic that will use the road soon after opening and the rate at which the traffic will grow after that.

5. When identifying uniform sections, road appearance and overall condition will not be relevant.

6. A number of the main survey items, such as width, surface, surface and drainage in poor condition and geometric cross section, geometry, surface and pavement below standard, may not be relevant. It will therefore be more necessary to record conditions such as gradient, flooding and so on which are likely to lead to poor condition when traffic starts to use the road.

7. Safety concerns may be difficult to anticipate on a route which traffic is not yet using.

8. Priority criteria 1-10 are relevant although they may be more difficult to define on a route which traffic is not yet using and which has not yet fallen into poor condition at problem sites.

9. DCP tests are unlikely to be used in their normal role for subgrade assessment but can be used to assess relative strengths and depths. It will therefore be necessary to carry out laboratory soaked tests.

10. Subsequent steps – improvement selection, design, costing and prioritisation – remain similar to those or a road in poor condition.

4 Acknowledgements

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Appendices

A1. Subgrade design strength

A2. Material testing

A3. Pavement design tables
- A3.1 Gravel pavement
- A3.2 Sealed granular pavement
- A3.3 Sealed armoured gravel pavement
- A3.4 Unreinforced concrete pavement

A4. Shoulder design

A5. Earthworks

A6. Drainage and water crossing design

A7. Realignment

A8. Safety measures

A9. Slope stabilisation

A10. Exercises and examples
- A10.1 Traffic analysis exercise
- A10.2 Subgrade design strength and pavement design example
- A10.3 Road and pavement design exercise
- A10.4 Whole life asset cost exercise

A1. Subgrade design strength

The detailed pavement designs in this manual are based upon the traffic that is likely to use the road and the strength of the subgrade on which the pavement will be constructed, which may be either: prepared and compacted in situ material; compacted imported material or layers of an existing pavement.

Subgrade strength may be obtained from one or more of the following sources:

1. Soaked laboratory CBR tests on samples taken of the materials to be used as the subgrade

2. Previous laboratory tests on material similar to that being used for the subgrade

3. In situ DCP-CBR testing on the material forming the subgrade

4. In situ DCP-CBR testing on adjacent roads or sections of road constructed with similar materials

5. Correlation of CBR strength with standard soil index properties

Apart from (5) the options are associated with either laboratory testing or in situ testing; both have their advantages and disadvantages with respect to practical LVRR pavement design.

The laboratory test approach is one which is normally adopted for higher grade road pavement design. The disadvantages the laboratory testing approach for LVRRS are:

1. The difficulty of obtaining reliable CBR results reasonably quickly from remote areas.
2. CBR testing is undertaken only on material <20mm. Material >20mm is removed prior to testing and hence for coarser soils the laboratory value may not be truly representative.
3. Using the laboratory CBR assumes that subgrade will be compacted uniformly to the required standard and hence also relies on site control and/or in situ density testing, (activities which are not necessarily carried out effectively on LVRR projects).

In situ DCP-CBR testing provides an assessment of actual in situ strength at the time and road condition of testing and because of the speed and cheapness of operation can provide a representative number of values within most LVRR investigation budgets. A DCP programme therefore provides a reliable assessment of relative strength along and across alignments at low cost. The principal drawback to its application for design work is that DCP testing provides a snapshot assessment of in situ strength at the existing conditions of moisture and density. An evaluation therefore has to be made as to how this DCP-CBR relates to the strength of the investigated layers under any future conditions of moisture and density.

It is clear from experience with regional LVRR projects that the ideal situation is where a combination of laboratory and in situ testing provide both an adequate coverage of all subgrade variations and good correlations are available between the in situ and laboratory testing. Frequently this will not be the case for LVRR projects and engineering judgement and assessment will have to be used.

This Appendix therefore indicates how the subgrade design strength may be estimated under typical LVRR conditions.

If DCP and laboratory test results are both available for a section whose surface has been well compacted by traffic or weather, the subgrade design strength should be estimated using the steps below. Other situations are covered in the subsequent notes.

1. Take samples of the subgrade or pavement surface along the road at a recommended spacing of 500 metres (or at least two tests per section). In a laboratory determine the soaked CBR strength at 95% of modified AASHTO maximum dry density. If the surface has more than one distinct layer in the top 300 mm, take a separate sample of each layer and determine the soaked strength of each.

2. Carry out in situ DCP tests at a recommended spacing of 100 metres in each wheeltrack and also within 1 metre of every sample site. Plot the penetration data of each DCP test on graph paper and identify the weakest layer within the top 300 mm that is thicker than 50 mm. For this layer, use the following penetration equation to estimate the in situ strength in terms of CBR.

$$\text{Log}_{10}(\text{CBR}) = 2.48 - 1.057\ \text{Log}_{10}(\text{mm/blow})$$

3. If possible, measure the moisture content and density of the subgrade where each DCP test was carried out.

4. Try to establish a correlation between the soaked laboratory CBRs and the DCP-CBRs, taking into account any situ moisture-density condition at each sample site. Note that the ASSHTO testing procedure requires CBR testing at different compaction levels for each sample, thus allowing CBR interpolation for a range of moisture-density conditions.

5. Plot the strengths against chainage along the road or each section of road, indicating separately the in situ strengths from each wheeltrack and the soaked strengths. Try to interpolate the pattern in the in situ strengths into the gaps between the soaked strengths, if possible using the correlation from step 4.

6. Compare the strengths from each wheeltrack. A consistent difference from one side to the other, particularly if the road crosses a steep hillside, might indicate problems with the site or with initial preparation work and should be carefully checked. A low strength on the downhill side across a hillside might be because the road has been formed on top of loose fill which would be at risk of erosion or slipping.

7. Identify and use the design charts in these Appendices which correspond to the pavement types being considered. Note the subgrade strengths which correspond to different rows in the charts.

8. Divide the road into sub-sections if there is a significant change in strength along the road and the strength of one sub-section is in a different row of the design chart to another sub-section. A sub-section should not be less than 100m in length and must include DCP tests on at least 2 chainages.

9. Estimate the design subgrade strength within each section or sub-section. If there are 5 or less soaked strengths (either real or correlated from the in situ strengths), the design subgrade strength is the lowest value; if there are 6-9 strengths, this is the second lowest value, and so on.

10. Overseas Road Note (ORN) 31 is a pavement design document written by TRL for use in tropical and sub-tropical countries. It contains Table A1, which correlates estimated subgrade strength with soil plasticity and water-table position. Although likely to be conservative it is a valid correlation to use in the absence of other data from laboratory or in situ subgrade strength testing.

Table A1 Soil plasticity and subgrade strength

Depth of water table (m)	Subgrade strength (CBR %)				
	Non-plastic sand	**Sandy clay (PI = 10)**	**Sandy clay (PI = 20)**	**Silty clay (PI = 30)**	**Heavy clay (PI > 40)**
0.5	8-14	8-14	3-4	3-4	2
1	15-29	8-14	5-7	3-4	2
2	15-29	15-29	8-14	5-7	3-4
3	30	15-29	8-14	5-7	3-4

PI – Plasticity Index

Additional Notes

If the road is along a new section of alignment with an as-yet uncompacted surface DCP-CBRs will only relate to this existing condition and should therefore not be used for pavement design purposes. Samples should be taken of the material (either in situ or imported) that is likely to form the subgrade and the laboratory soaked CBR strength determined.

If DCP results are not available additional soaked CBR strengths should be determined. Reduce the spacing between tests if possible. Ideally, at least two tests will be carried out on each uniform section.

If laboratory test results are not available, it may be possible to compare in situ strengths with soaked strengths from nearby roads, but this should be done with very careful consideration of soil types, drainage conditions and terrain.

If neither DCP results nor laboratory test results are available, the lowest strength in the suggested range in the above Table should be used as the subgrade design strength.

A2. Material testing

Tables A2 and A3 provide examples of useful on-site material tests.

Table A2 Simple field tests

Field Test	Description
Fines Content	Relative percentages of silt/clay. • Hand shake dilatancy test – Soil dilation =high silt content • Jar settlement test – allow material to settle in jar of water and measure relative thicknesses of settled fines/sand/gravel
Hand Sample Index Strength	Use of small geological type hammer on hand or core sample • Very weak: easily broken in hand • Weak: broken by leaning on sample with hammer • Moderately weak: broken in hand by hitting with hammer • Moderately strong: broken against solid object with hammer • Strong: difficult to break against solid object with hammer • Very strong: requires many blows of hammer to break sample • Extremely strong: sample can only be chipped with hammer
Aggregate Pliers Test	Take 100-200 pieces of air dry material in the 12 to 20 mm range and attempt to break the pieces between finger and thumb, then try to break remaining pieces with a pair of 180-mm pliers. The percentage unbroken by the pliers is termed the Aggregate Pliers Value and is broadly comparable to a 10% Fines value of over 100 kN.
Field Plasticity	Prepare a ball 20 or 30 mm in diameter. Moisten so that it can be modelled without being sticky. Roll to a 3mm thread adding water if necessary. At 3 mm the material should start to break, then remould into a ball and carry out the following: • Ball is hard to crush – does not crack/crumble = high clay content • Tends to crack/crumble = low clay content • Impossible to make a ball = high sand or silt content, very little clay • The ball has a soft or spongy feel = organic soil

Table A3 Common laboratory tests

Physical Condition Tests	Standard Procedures		Advantages of Test
	BS	ASTM	
Moisture Content	1377: 2:,3.1 812:109	D2216	Simple and widely accepted test.
Water Absorption	812:109	C127 & C128	Simple test with established correlations to aggregate performance
Liquid Limit (WL)	1377:2,:4.3-6	D4318	Well established soil index and classification test
Plastic Limit (Wp)	1377:2,:5.3	D4318	Well established soil index test. Plasticity index (Ip = W_L-Wp) used as a key defining parameter in many specifications.
Linear Shrinkage (Ls)	1377:2,:6.5		Can give an estimate of Ip for soils where W_L and Ws are difficult to obtain. Better repeatability and reproducibility than plasticity test.
Particle Size Distribution	1377:9:2.3-5 812:103,1	D422	Simple and widely accepted test incorporating both sieving and sedimentation. A fundamental soil classification tool.
Sand Equivalent Value		D2419	A rapid site-lab means of determining relative fines content
Aggregate Grading (Sieve) Aggregate Sedimentation	812:103,1 812:103,1	C136 & C117	Simple and widely accepted test for defining aggregate size distribution.
Flakiness Index (If) Elongation Index (Ie)	812:105, 1 812:105, 2	D4791	Standard gauge methods of ascertaining particle shape. Parameters incorporated into coarse aggregate specifications
Soil Particle Density	1377:2, 8.2	D854	Required for use in analysis of other parameters (e.g. psd, compaction)
Compaction	1377:4, 3.3-7	D698 & D1557	Simple test. Basis of control on site compaction of fill and pavement

			materials
CBR	1377:4, 7	D1883	Quick and simple to perform. A convenient and widely established test for defining material suitability for road construction and subsequent quality control.
Vane Shear (Lab)	1377:7, 3	D4648	Very simple and rapid method for obtaining undrained shear strength. Can be used on materials in compaction or CBR moulds.
Sulphate Soundness	BS 812: 121	C88	Assesses aggregate durability as a response to repeated crystallization and rehydration stresses. Incorporated in many specifications
Los Angeles Abrasion (LAA)		C131/535	Standard combined impact and rolling abrasion test. Commonly used as a specification parameter
Aggregate – Bitumen Adhesion		D1664	Tests for assessing adhesion of bitumen to aggregate in water

A3. Pavement design tables

Design tables are provided in this Appendix for the following pavement and surface types.

Pavement and surface type	**Appendix**
Gravel pavement	A3.1
Sealed granular pavement	A3.2
Sealed armoured gravel pavement	A3.3
Unreinforced concrete pavement	A3.4

A3.1 Gravel pavement

This pavement is a layer of gravel that is used as a combined pavement layer and wearing course.

Table A4 is the design table for a gravel pavement with a capping layer. Table A5 is the design table for a gravel pavement without a capping layer in situations where gravel is locally abundant or a previously constructed gravel pavement is being used in an improved pavement. Table A6 gives the required layer strengths.

In the two design tables, the upper 100 mm is designed to wear away and be replaced during maintenance. It is important therefore to regravel the road before this upper 100 mm has worn away.

Table A4 Gravel pavement design table with a capping layer

Traffic Group A			Traffic Group B		
Subgrade soaked CBR (%)	**Pavement layer**	**Layer thickness (mm)**	**Subgrade soaked CBR (%)**	**Pavement layer**	**Layer thickness (mm)**
2-3.9	Gravel * Capping	200 250	2-3.9	Gravel * Capping	200 300
4-6.9	Gravel * Capping	200 100	4-5.9	Gravel * Capping	200 150
> 7	Gravel * Capping	200 0	6-7.9	Gravel * Capping	200 100
			> 8	Gravel * Capping	200 0

* The surface should be regravelled before the gravel thickness is less than 100 mm

Table A5 Gravel pavement design table without a capping layer

Traffic Group A			Traffic Group B		
Subgrade soaked CBR (%)	**Pavement layer**	**Layer thickness * (mm)**	**Subgrade soaked CBR (%)**	**Pavement layer**	**Layer thickness * (mm)**
2-3.9	Gravel	375 (275)	2-3.9	Gravel	400 (300)
4-6.9	Gravel	275 (175)	4-5.9	Gravel	300 (200)
> 7	Gravel	200 (100)	6-7.9	Gravel	275 (175)
			> 8	Gravel	200 (100)

* The first figure is the required construction thickness of gravel. The second figure in brackets is the minimum thickness before the surface is regravelled.

Table A6 Layer strengths for a gravel pavement

Pavement layer	Traffic Group A & B
	Soaked CBR (%)
Gravel	25
Capping	10

The specification for gravel wearing course is contained in the Low Volume Rural Road Standards and Specifications (Part II) as LVRR-1 and is based on the current Lao specification.

The specification for capping is in the current standard Lao Specification for Earthworks, with the additional strength requirement as above.

A3.2 Sealed granular pavement

This pavement consist of a bituminous sealed surface on top of a granular base which can be a medium or high strength gravel, a dry bound macadam or a water bound macadam.

Table A7 is the design guide for a sealed granular pavement with a capping layer and Table A8 is the guide in situations where a capping layer is not being used, for example: where gravel is locally abundant or a previously constructed gravel pavement is being overlain. Table A9 gives the required layer strengths.

Table A7 Sealed granular pavement design table with a capping layer

Subgrade soaked CBR (%)	Pavement layer	Layer thickness (mm)	
		Traffic Group A	Traffic Group B
2-3.9	Surface	Seal *	Seal *
	Granular base	100	100
	Granular sub-base	100	150
	Capping	200	275
4-6.9	Surface	Seal *	Seal *
	Granular base	100	100
	Granular sub-base	100	150
	Capping	100	175
7-10.9	Surface	Seal *	Seal *
	Granular base	100	100
	Granular sub-base	100	150
	Capping	0	100**
> 11	Surface	Seal *	Seal *
	Granular base	100	100
	Granular sub-base	100	150
	Capping	0	0

* Seal can be either DBST or double Otta seal

** Capping layer may be omitted if subgrade >10%

Table A8 Sealed granular pavement design table without a capping layer

Subgrade soaked CBR (%)	Pavement layer	Layer thickness (mm)	
		Traffic Group A	Traffic Group B
2-3.9	Surface	Seal *	Seal *
	Granular base	100	100
	Granular sub-base	225	325
4-6.9	Surface	Seal *	Seal *
	Granular base	100	100
	Granular sub-base	175	275
7-10.9	Surface	Seal *	Seal *
	Granular base	100	100
	Granular sub-base	100	225
> 11	Surface	Seal *	Seal *
	Granular base	100	100
	Granular sub-base	100	150

* Seal can be either DBST or double Otta seal

Table A9 Layer strengths for a sealed granular pavement

Pavement layer	Minimum Soaked CBR (%)	
	Traffic Group A	Traffic Group B
Granular base	50 *	80
Granular sub-base	25	25
Capping	10	10

* Gravel with CBR of 25% may be used if there are no trucks (including Kolaos) in the traffic

The following relevant specifications are contained in the Low Volume Rural Road Standards and Specifications (Part II) – Pavement Options and Technical Specifications:

- LVRR-1: Gravel as a base or sub-base layer
- LVRR-2: Dry-bound/water-bound base or sub-base
- LVRR-4: DBST
- LVRR-5: Otta Seal

The specification for capping is in the current standard Lao Specification for Earthworks, with the additional strength requirement as above.

A3.3 Sealed armoured gravel pavement

This pavement is a low or medium strength gravel with an armouring layer of aggregate and a bituminous sealed surface.

Table A10 is the design guide for a sealed armoured gravel pavement with a capping layer and Table A11 is the guide in situations where a capping layer is not being used, for example: where gravel is locally abundant or a previously constructed gravel pavement is being overlain. Table A12 gives the required layer strengths.

Table A10 Sealed armoured gravel pavement design table with a capping layer

Subgrade soaked CBR (%)	Pavement layer	Layer Thickness (mm)	
		Traffic Group A	Traffic Group B
2-3.9	Surface	Seal *	Seal *
	Armouring	70	70
	Gravel base	100	100
	Gravel sub-base	100	150
	Capping	200	275
4-6.9	Surface	Seal *	Seal *
	Armouring	70	70
	Gravel base	100	100
	Gravel sub-base	100	150
	Capping	100	175
7-10.9	Surface	Seal *	Seal *
	Armouring	70	70
	Gravel base	100	100
	Gravel sub-base	100	150
	Capping	0	100**
> 11	Surface	Seal *	Seal *
	Armouring	70	70
	Gravel base	100	100
	Gravel sub-base	100	150
	Capping	0	0

* Seal can be either DBST or double Otta seal
** Capping layer may be omitted if subgrade >10%

Table A11 Sealed armoured gravel pavement design table without a capping layer

Subgrade Soaked CBR%	Pavement layer	Layer Thickness (mm)	
		Traffic Group A	Traffic Group B
2-3.9	Surface	Seal *	Seal *
	Armouring	70	70
	Gravel base	100	100
	Gravel sub-base	225	325
4-6.9	Surface	Seal *	Seal *
	Armouring	70	70
	Gravel base	100	100
	Gravel sub-base	175	275
7-10.9	Surface	Seal *	Seal *
	Armouring	70	70
	Gravel base	100	100
	Gravel sub-base	100	225
> 11	Surface	Seal *	Seal *
	Armouring	70	70
	Gravel base	100	100
	Gravel sub-base	100	150

* Seal can be either DBST or double Otta seal

Table A12 Layer strengths for a sealed armoured gravel pavement

Pavement layer	Soaked CBR (%)	
	Traffic Group A	Traffic Group B
Armouring	Refer to the specification	
Gravel base	25	25
Gravel sub-base	25	25
Capping	10	10

The following relevant specifications are contained in the Low Volume Rural Road Standards and Specifications (Part II) – Pavement Options and Technical Specifications:

- LVRR-1: Gravel as a base or sub-base layer
- LVRR-3: Crushed stone aggregate
- LVRR-4: DBST
- LVRR-5: Otta Seal

The specification for capping is in the current standard Lao Specification for Earthworks, with the additional strength requirement as above.

A3.4 Unreinforced concrete pavement

This pavement is a layer of unreinforced concrete on low strength gravel.

Table A13 is the design table for a concrete pavement. Table A14 gives the required layer strengths.

Table A13 Concrete pavement design table

Subgrade soaked CBR (%)	Pavement layer	Layer thickness (mm)
		Traffic Groups A & B
2-6.9	Concrete	150
	Sub-base	150
> 7	Concrete	150
	Sub-base	100

Table A14 Layer strengths for a concrete pavement

Pavement layer	Layer strength
	Traffic Groups A & B
Concrete	28 day cube strength = 20 MPa
Sub-base *	Soaked CBR = 25%

The following relevant specifications are contained in the Low Volume Rural Road Standards and Specifications (Part II) – Pavement Options and Technical Specifications:

- LVRR-1: Gravel as a base or sub-base layer
- LVRR-2: Dry-bound/water-bound base or sub-base
- LVRR-6: Non-reinforced concrete pavement

A4. Shoulder design

Shoulders are an important part of a road, providing lateral support for the pavement layers, allowing water from the carriageway to flow into the side ditches and being occasionally trafficked by passing vehicles. In the case of LVRRs they also provide a relatively safe pathway for non-vehicular traffic.

It is generally too expensive to construct shoulders with the same material as the pavement, except in the case of a gravel wearing course. Shoulder materials that are non-plastic will tend to ravel and lack sufficient cohesion to withstand the abrasive action of traffic and hence may need to be stabilised in some way.

When the pavement construction cannot be extended into the shoulders, the shoulder material should be selected using the same principles as for a gravel surfaced road or a sub-base to carry construction traffic. Thus the material should be strong enough to carry occasional vehicles and should be as cohesive as possible without being too weak when wet. The material will normally be of sub-base quality with a minimum soaked CBR 25%.

If the base material cannot be extended into the shoulders and an impermeable material is used, it is important that water is not trapped without means of discharge. There are three ways of draining this water away. Firstly, the sub-base through the shoulder can be constructed of permeable material. Secondly, drainage grips of free draining graded granular material, 300 mm wide and extending from under the base and for the full depth of the sub-base layer under the shoulder can be constructed every 5 metres. Thirdly, a permeable subgrade can be used to drain the water away vertically.

It is very desirable if at least the outer edge of the shoulder is able to support the growth of grasses which help to bind the surface and prevent erosion.

Un-sealed shoulders often require considerable maintenance if satisfactory performance is to be guaranteed.

A5. Earthworks

Cut-slope and embankment earthwork design is currently outside the specific scope of this edition of the EOD Manual. Earthworks should be designed to comply with current Lao general specification and in line with guidance in the LRDM.

The following points should be noted, however, with specific reference to LVRR earthworks:

1. Adequate compaction of fill materials is essential. The practice of excavation and dumping to fill without adequate compaction through the whole depth of fill must be avoided. Inadequate compaction, particularly in side-long ground, will inevitably lead to erosion and road failure.

2. Excavated material must not be dumped in a location where it is either a danger to life (above a village) or the environment (above a water course).

3. Embankment and cut-slope slope angles must be constructed to be compatible with the material properties of the cut or fill concerned.

4. Adequate cross-drainage should be provided through embankments. This is particularly important on sections of long embankment on low-lying flood-prone area where earthworks can form impediments to flood dissipation and may be seriously eroded in the process.

A6. Drainage and water crossing design

The four main functions of the external drainage system are:

- 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 manner

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

In both the design and maintenance of drainage, it is important to interfere as little as possible with the natural flow of water. Culverts on natural water courses should follow the existing alignment as closely as practicable and realignment (often resulting in sharp changes in direction) should be avoided. The surface flows in ditches and culverts should also be kept to a minimum by the use of frequent turnouts where side ditches cannot be discharged to existing watercourses. In sidelong ground, where discharge from the side ditch on the high side passes to the low side, it is best to use frequent small culverts rather than occasional large ones.

A number of drainage measures are recommended for roads which are not selected for improvement during prioritisation. These measures are low cost and help to reduce the rate of continuing deterioration. They include drainage humps – shallow humps, diagonal in plan, across an unformed track which trap water flowing along and eroding the surface and divert it onto the surrounding land – mitre drains – drains which carry water from the side ditch away from the road onto the surrounding land – and scour checks – small dams in side ditches which reduce the speed of water and the erosion that it causes.

Suitable designs for LVRR side ditches and cut-off drains are given in the LRDM. These are summarised below. Designs and specifications for culverts, drifts and bridges will be contained in separate LVRR Standards and Specification documents. Currently, guidance on these topics may be obtained from the following documents:

- TRL Ltd, 1997, Principles of Low Cost Road Engineering in Mountainous Regions
- TRL Ltd, 2000, Overseas Road Note 9, A Design Manual for Small Bridges

Side ditches and cut-off drains

1 General

The following sections on the Specifications for LVRR external drainage have been adopted from the current Lao Road Design Manual (LRDM). Appropriate Figures are cross-referenced to that document for use in LVRR construction.

The recommended types of side ditches and cut-off drains are shown in Figure A1 and listed in Table A15 which gives guidelines regarding the choice of each particular type. These guidelines are based upon general economic and aesthetic considerations. However, the type of side ditch selected must be checked to ensure that it will carry the expected flow without running deep and wetting the pavement or running fast and causing scour.

Due to their location, cut-off drains are usually difficult to maintain and should therefore, whenever possible, be constructed as "natural permanent depressions" with as gentle side slopes as possible.

2 Expected flow in side ditches

The Road Design Manual Part IV, Hydraulic Design, covers the discharge capacity of side ditches as well as the determination of culvert sizes for discharging water crossing the road.

The side ditches must be designed to carry the storm-water run-off originating from the carriageway, shoulders, drains and cut slopes. Where cut-off drains are not provided, any run-off from beyond the cut slope must also be included. The expected flow, or run-off, should be estimated using the formula:

$$Q = 0.278\ C.I.A.$$

where:

Q	is the expected flow (m^3/s)
C	is the run-off coefficient (suggested value 0.9 for pavement, shoulder, drain and cut slope)
I	is the intensity of rainfall (mm/h) for a 5 minute storm with a return period of 2 years (determined in accordance with an approved method)
A	is the area drained (km^2)

3 Capacity of side ditches

The capacity of a side ditch should be estimated using the Manning Strickler formula (metric):

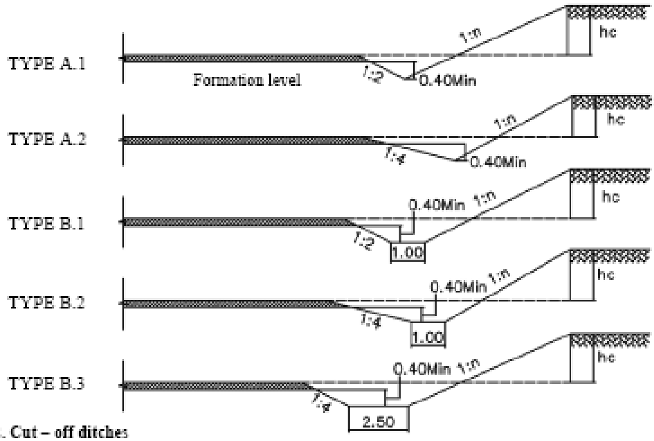
$$Q = K.A.R^{2/3}.S^{1/2}\ A.V$$

$$\text{or } V = K.R^{2/3}.S^{½}$$

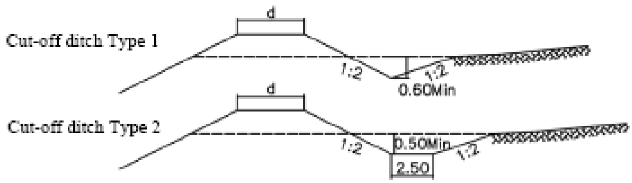
where:

Q	is the capacity (m^3/s)
A	is the cross-sectional area of water (m^2)
V	is the velocity of flow (m/s)
K	is the Roughness Coefficient
R	is the hydraulic radius, A/P where P is the wetted perimeter
S	is the longitudinal slope of flow in metres per metre (H/L)

1. Side ditches



2. Cut – off ditches



- Table relating to design of side ditches and cut - off ditches

Height of Cut hc	Slope (1:n) of cutting in Earth [1]	Distance ,d, between edge of cutting and cut-off ditch
hc < 1.00	1 : 3	d = 1.0
1.00 < hc ≤ 3.00	1 : 2	d = 4.0
hc > 3.00	1 : 1.5[2]	d ≥ 5.0

(1) In rock the slope 1:n will vary from 1 : 0.33 to 1 : 0.10
(2) If earth not stable at 1:1.5 the slope maybe decreased to 1 : 2
If natural slope steeper than 1:1.5 then the natural slope may be used as the cut slope
(3) The slopes in to the ditch should be as indicated or flatter

Figure A1 Side ditches and cut-off drains

Table A15 Guidelines for the selection of side ditch and cut-off drain types

Side ditch type	To be used under the following condition	Remarks
Al	Hilly to mountainous terrain with heavy earthwork.	Back slope to be varied according to stability of cut material. Slope should be stable and enable vegetation to establish.
A2	Rolling terrain with moderate earth work. Hilly to mountainous terrain where flatter ditch than Al is required due to capacity and/or velocity limitations.	As for Al
B1	Hilly to mountainous terrain where flatter ditch than Al is required due to capacity and/or velocity limitations.	As for Al, width may be increased if fill material is required
B2	Rolling terrain with mode-rate earthwork where a flatter ditch than A2 is required due to capacity and/or velocity limitation.	As for B1
B3	Flat terrain with little earthwork. Rolling terrain with moderate earthwork where a flatter ditch than B2 is required to capacity and/or velocity limitation.	As for B2
Cut-off drain type	**To be used under the following conditions**	**Remarks**
1	Moderate catchment area and little chance of siltation.	
2	Large catchment area and in areas liable to silting and/or damage to the drain profile by pedestrians, cattle etc.	

Limiting values for the velocity of flow (v) to prevent scour, together with the corresponding Roughness Coefficients, are given in Table A16 for the different types of drain material which will normally be encountered.

Table A16 Allowable velocity in ditch and corresponding roughness coefficients

Ditch material	Maximum allowable velocity (m/s)	Roughness Coefficient
Sand, loam, fine gravel, volcanic ash	0.6*	45
Stiff clay	1.1*	50
Coarse gravel	1.5	40
Conglomerate, hard shale, soft rock.	2.0	25
Hard rock	3.0	25
Masonry	3.0	40
Concrete	3.0	60

* In areas where good grass cover is guaranteed, these values may be increased up to a maximum of 1.5 m/s; in such cases a Roughness Coefficient of 30 should be used. Where grass cover is expected but not guaranteed a maximum velocity of 1.1 m/s should be used with a Roughness Coefficient of 30.

4 Scour protection

It is important to note that a side ditch will only perform as designed if the design cross-section is maintained, i.e. excessive scour must be prevented. In practice, due to local inconsistencies in roughness and surface level, side ditches in all but the hardest of materials will suffer from scour. Thus, for long lengths of side ditch at gradients in excess of 4-5%, scour checks should be considered.

A7. Realignment

This Appendix provides guidance on short realignments around difficult sites. Additional guidance should be used when establishing the alignment of a new road and taking into account aspects such as development objectives, national policies and detailed terrain evaluation.

One way of providing safe and reliable access past a site which is unsafe or in poor condition may be to realign a short length of the road past the site. The cost of the new road construction may be less than large improvement works and the resulting access may be safer, more reliable and easier to maintain than the access through the improved site.

In many cases a road was originally a footpath when its alignment was established, often with sections which were suitable for pedestrians but which are no longer suitable for a wider cross section and motor vehicles. In such cases, realignment past a problem site is reasonable.

Typical sites where short realignment should be considered include:

- Unsuitable water crossing sites which are eroding or unstable
- Steep hills
- Areas which flood
- Crossing steep or unstable slopes
- Sites where the road affects natural land drainage
- Swampy areas with weak soil

Typical sites to which the road could be realigned include:

- Areas of good soil with good natural drainage
- Routes along or just below a ridge line

In all cases, the whole life asset costs of the site improvement and the realignment should be compared, as described in 2.9. The final decision between the alternatives should balance the whole life cost comparison with a consideration of the safety and reliability of the access provided by each.

A8. Safety measures

An important aspect of providing access is to ensure that it is as safe as possible. The situation is particularly important when low volume rural roads are being improved for four reasons:

1. Improved road conditions can encourage drivers to drive at speeds that they may not be used to and that may be too quick for the width and the curvature of the road
2. The road may have been improved from an unformed track which was established without consideration of the safety issues affecting motorised vehicles
3. Many people live close to the roads and use them as part of their daily lives
4. Pedestrians and users of bicycles and animal carts are vulnerable to injury from motorised vehicles

Whenever low volume rural roads are being improved, the safety concerns relating to the current condition and the likely condition after improvement should be considered and all appropriate measures should be taken.

Safety concerns may be given a priority criteria of 1, where road users or others are at high risk of injury or the injury is likely to be severe, or 7, where road users or others are at medium risk of injury or the injury is likely to be slight.

Table A17 includes the various safety concerns which may occur on low volume roads and gives likely improvement measures.

Table A17 Safety concerns and safety measures

Safety concern	Risk	Safety measure
Unprotected steep or high drop alongside the road	Vehicles fall down the drop, particularly when passing on a narrow road	Edge barriers to prevent vehicles leaving the road Edge marker posts to indicate the edge of the road
Unstable slope above a village	Soil and rock, often dumped during construction, slide down onto the village	Better site management and spoil disposal Slope protection
Motorised traffic near a village, school or place of work	Pedestrians, cyclists and other vulnerable road users are hit by motorised traffic, often travelling fast	Traffic calming: speed bumps, narrowed village entrances, Separate path for vulnerable road users
Tight curve	Vehicles are unable to turn the tight curve under control and leave the road	Realignment to a larger radius
Slippery surface	Vehicles slide off the road, especially on a hill	Improved surface
Poor visibility around curve	Vehicles collide because of inadequate sight distance	Removal of visual obstructions inside the curve
Poor visibility over a crest	Vehicles collide because of inadequate sight distance	Removal of crest in the road
Narrow road	Vehicles are unable to pass safely	Wider road
Dust	Vehicles collide because of poor visibility due to the dust Dust harms the health of road users	Improved surface
Dangerous sites without warning	Drivers are at risk because they are not aware of dangers ahead	Warning signs of curves, steep drops, villages, etc
Area next to the road used as a bus stop	Bus users are hit by motorised traffic	Off carriageway bus stops
Area next to the road used by market traders	Market users are hit by motorised traffic	Off carriageway markets

A9. Slope stabilisation

Cut and embankment slope stabilisation is currently outside the specific scope of this edition of the EOD Manual. However, a separate research programme (SEACAP 21) has produced guidance on this issue. Two separate volumes are now available for use: A Slope Maintenance Manual and a Slope Maintenance Site Manual.

The *Slope Maintenance Manual* has drawn extensively on road construction and maintenance experience in south-east and south Asia over the past twenty years. The emphasis is on practical guidelines for the prioritisation and maintenance of existing slopes and retaining walls, particularly those that are undergoing or have undergone severe distress or failure.

The manual is intended mainly for use in the Provincial Departments of the Ministry of Public Works and Transport (MPWT) by field engineers. The accompanying *Slope Maintenance Site Handbook* has been written to provide guidance to field supervisors and is available in both English and Lao.

A10. Exercises and examples

The following exercises and examples are provided in this Appendix.

Exercises and examples	**Appendix**
Traffic analysis exercise	A10.1
Subgrade design strength and pavement design example	A10.2
Road and pavement design exercise	A10.3
Whole life asset cost exercise	A10.4

A10.1 Traffic analysis exercise

Question

Two-way traffic was counted from 6 am to 6 pm over 3 days and averaged to give the figures in Table A18 below. The Seasonal factor is 1.1, it is assumed that diverted and generated traffic will add 30% to the count as soon as the road is opened, annual growth rate of all vehicle types is 5% and the design life is 12 years.

Table A18 Example traffic count

Pedestrian	23	4WD	2
Bicycle	11	Minibus	5
Animal	5	Kolao	24
Motorcycle	25	Isuzu	3
Tuk-tuk/Jambo	3	Gaz 66	1
Farm tractor	31	Medium bus	1
Car	2	Large truck	1
Pick-up	7	Large bus	0

Refer to the Traffic Analysis Form.

What is the carriageway and shoulder width of the road? Is the traffic in Group A or B?

If the use of the road is restricted so that large trucks and large buses cannot travel, what is the carriageway and shoulder width and is the traffic in Group A or B?

Answer

The traffic counts by Traffic Category are as follows:

Category 1:	39
Category 2:	59
Category 3:	40
Category 4:	5
Category 5:	1

With Category 5 vehicles using the road, the LVRR standards do not apply.

We now assume that the traffic count of Category 5 is reduced to 0.

- With a count from 6 am to 6 pm, the Daily factor is 1.2
- The seasonal factor is 1.1
- The diverted and generated traffic equates to a factor of 1.3
- With annual growth of 5% and a 12 year design life, the Traffic growth factor is 1.8

Therefore the traffic counts should be multiplied by:

1.2 x 1.1 x 1.3 x 1.8 = 3.1

The final year counts by Traffic Category are as follows:

Category 1:	121
Category 2:	183
Category 3:	124
Category 4:	16
Category 5:	0

Refer to Table 3: LVRR standards apply
Refer to Table 4: The traffic is in Traffic Group B
Refer to Table 9: Carriageway width = 3.5 metres
Shoulder width = 1 metre

A10.2 Subgrade design strength and pavement design example

This example shows how results from DCP tests and laboratory soaked tests are used to determine the subgrade design strength and then to design improved pavements and surfaces.

The results come from an early trial of this manual in northern Lao on a road whose subgrade had been prepared but not yet compacted.

During earlier assessments and surveys, the following had been decided:

- The entire road would be improved.
- Most of the road passes through farmland and has gradients of 0-3%. A gravel surface was appropriate for these lengths of road.
- Four sections were prioritised for further pavement and surface improvement, due to being either on a gradient steeper than 6% or in a village.
- Two of these sections were divided into sub-sections. Pavement types were selected for all prioritised sections and sub-sections on the basis of available materials and skills and in order to trial a variety of pavements.
- Traffic was estimated as being Traffic Group B.

Table A19 collates the results from the DCP and laboratory soaked tests for the prioritised sections. The DCP results are for the weakest layer within the top 500 mm that is thicker than 50 mm. The laboratory soaked test was carried out at 95% of maximum dry density under modified compaction. Grey cells indicate that a test was not carried out at that chainage.

DCP results are affected by the density of the subgrade. It is acknowledged that the lack of compaction of the subgrade and the lack of density measurements may make the correlation between the in situ and laboratory strengths more difficult.

Section	Chainage	DCP test		Laboratory soaked test
		Left wheeltrack	Right wheeltrack	
	0+000	12	26	No test
1	0+100	10	14	8
	0+200	8	13	6
	0+300	15	15	9
	1+250	10	21	7
2	1+350	11	10	10
	1+400	25	19	No test
	1+500	16	13	13
	1+600	21	19	No test
	1+650	No test	15	12
	1+700	9	No test	No test
	1+750	16	14	9
	1+800	22	29	No test
	1+950	No test	4	No test
3	2+000	7	No test	5
	2+050	21	No test	No test
	2+100	No test	No test	18
	2+400	12	15	7
4	2+450	5	7	No test
	2+500	12	20	23

Sections 1 to 4 were then analysed and designed using the pavement design charts. The analysis and design of each section is presented in the following paragraphs. For each section a graph shows the results from the DCP tests in the left and right wheel tracks (LWT & RWT) and from the soaked tests. A table then gives the selected pavement type, the subgrade design strength (in terms of the appropriate range on the relevant pavement design table) and the resulting pavement design. The subgrade design strength is determined by comparing the three sets of data on the graph and referring to Appendix A1.

The road was due to receive a 150 mm wearing course of gravel with a soaked strength of 25%. It was assumed that for logistical reasons this layer would be provided along the entire road, including the four sections prioritised for further improvement. This gravel layer is therefore substituted into the pavement designs of the four sections. The final column in the table gives the layers that are required on top of the gravel wearing course in order to match the pavement design. In most cases, the gravel substitutes for 100-150 mm of either capping or sub-base, but in two cases it is allowed to substitute for 175 mm of capping because the percentage strength increase is much greater than the percentage thickness decrease, as described in 2.8.2.

Since design tables are available for pavements with and without a capping layer, the designs are repeated for each alternative, although this is not done for Section 1 because capping is not specified for use under a concrete pavement.

After the analysis and design of Section 4, Table A27 summarises the required pavement layers for the four sections. Other design details to add include shoulders and transitions at either end of each sub-section.

Section 1

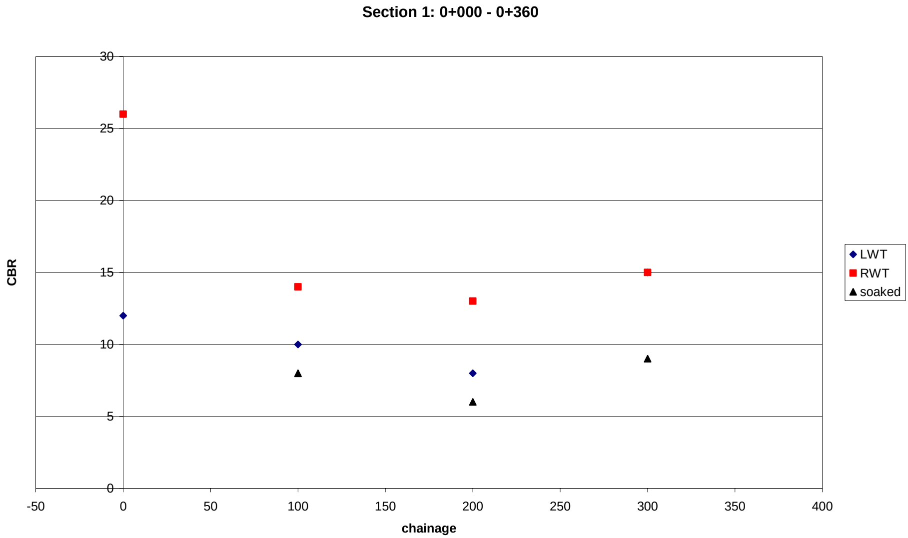


Table A20 Section 1 Pavement design

Chainage	Pavement type	Subgrade design strength	Design	Required pavement layers
0+000 – 0+360	Concrete	> 7	150 mm of concrete 100 mm of sub-base (25%)	150 mm of concrete

Section 2

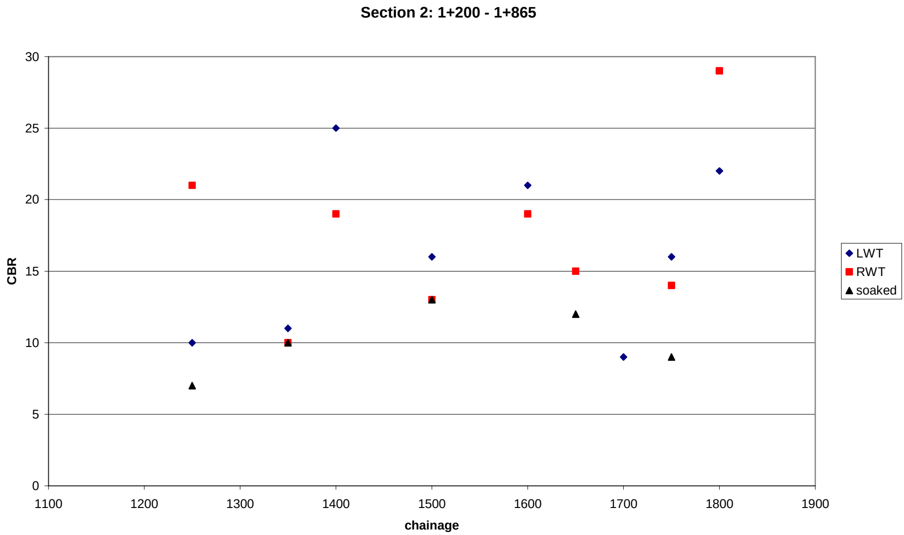


Table A21 Section 2 Pavement design with capping

Chainage	Pavement type	Subgrade design strength	Design	Required pavement layers
1+200 – 1+400	Sealed gravel	7 – 10.9	Seal 100 mm of base (80%) 150 mm of sub-base (25%) 100 mm of capping (10%)	Seal 100 mm of base (80%) 100 mm of sub-base (25%)
1+400 – 1+700	Sealed gravel	> 11	Seal 100 mm of base (80%) 150 mm of sub-base (25%)	Seal 100 mm of base (80%)
1+700 – 1+865	Sealed armoured gravel	7 – 10.9	Seal 70 mm of armouring 100 mm of base (50%) 150 mm of sub-base (25%) 100 mm of capping (10%)	Seal 70 mm of armouring 100 mm of base (50%) 100 mm of sub-base (25%)

Table A22 Section 2 Pavement design without capping

Chainage	Pavement type	Subgrade design strength	Design	Required pavement layers
1+200 – 1+400	Sealed gravel	7 – 10.9	Seal 100 mm of base (80%) 225 mm of sub-base (25%)	Seal 100 mm of base (80%) 75 mm of sub-base (25%)
1+400 – 1+700	Sealed gravel	> 11	Seal 100 mm of base (80%) 150 mm of sub-base (25%)	Seal 100 mm of base (80%)
1+700 – 1+865	Sealed armoured gravel	7 – 10.9	Seal 70 mm of armouring 100 mm of base (50%) 225 mm of sub-base (25%)	Seal 70 mm of armouring 100 mm of base (50%) 75 mm of sub-base (25%)

Section 3

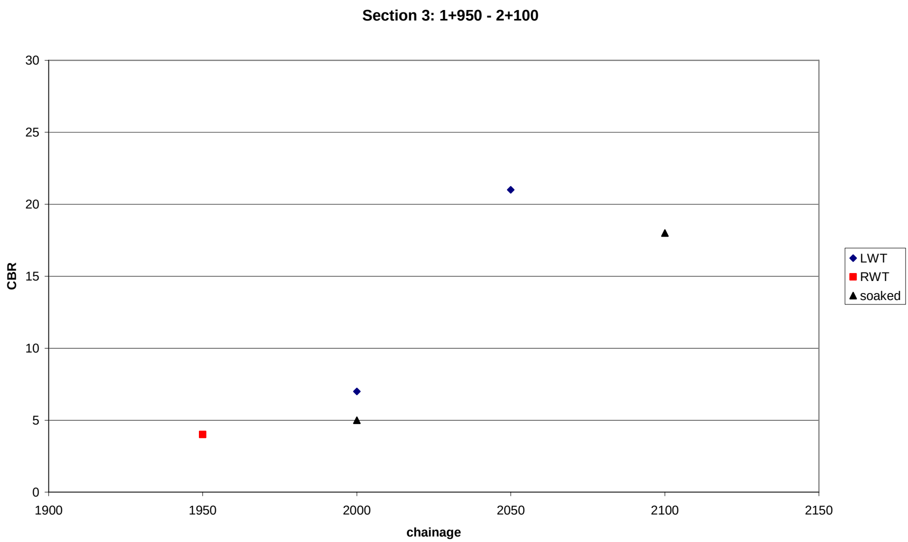


Table A23 Section 3 Pavement design with capping

Chainage	Pavement type	Subgrade design strength	Design	Required pavement layers
1+950 – 2+025	Sealed gravel	4 – 6.9	Seal 100 mm of base (80%) 150 mm of sub-base (25%) 175 mm of capping (10%)	Seal 100 mm of base (80%) 150 mm of sub-base (25%)
2+025 – 2+100	Sealed gravel	> 11	Seal 100 mm of base (80%) 150 mm of sub-base (25%)	Seal 100 mm of base (80%)

Table A24 Section 3 Pavement design without capping

Chainage	Pavement type	Subgrade design strength	Design	Required pavement layers
1+950 – 2+025	Sealed gravel	4 – 6.9	Seal 100 mm of base (80%) 275 mm of sub-base (25%)	Seal 100 mm of base (80%) 125 mm of sub-base (25%)
2+025 – 2+100	Sealed gravel	> 11	Seal 100 mm of base (80%) 150 mm of sub-base (25%)	Seal 100 mm of base (80%)

Section 4

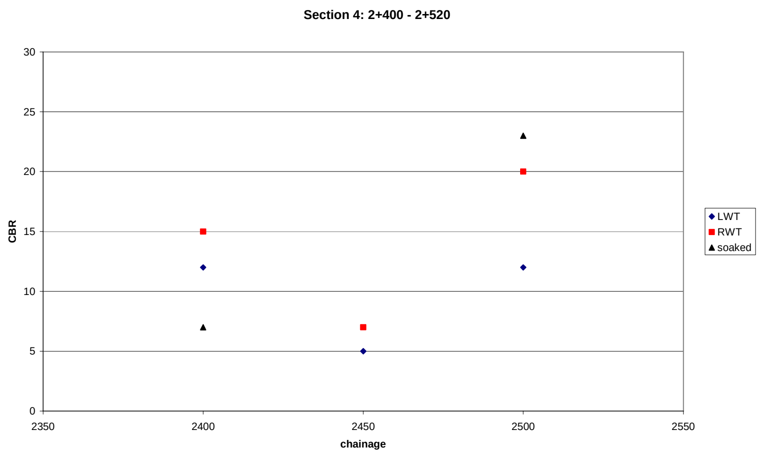


Table A25 Section 4 Pavement design with capping

Chainage	Pavement type	Subgrade design strength	Design	Required pavement layers
2+400 – 2+520	Sealed armoured gravel	4 – 6.9	Seal 70 mm of armouring 100 mm of base (50%) 150 mm of sub-base (25%) 175 mm of capping (10%)	Seal 70 mm of armouring 100 mm of base (50%) 150 mm of sub-base (25%)

Table A26 Section 4 Pavement design without capping

Chainage	Pavement type	Subgrade design strength	Design	Required pavement layers
2+400 – 2+520	Sealed armoured gravel	4 – 6.9	Seal 70 mm of armouring 100 mm of base (50%) 275 mm of sub-base (25%)	Seal 70 mm of armouring 100 mm of base (50%) 125 mm of sub-base (25%)

Table A27 Summary of required pavement layers

Section	Chainage	Required pavement layers
1	0+000 – 0+360	150 mm of concrete Shoulders (est.)
2	1+200 – 1+400	Seal (DBST) 100 mm of base (80%) 75 mm of sub-base (25%) Shoulders (est.)
	1+400 – 1+700	Seal (DBST) 100 mm of base (80%) Shoulders (est.)
	1+700 – 1+865	Seal (DBST) 70 mm of armouring 100 mm of base (50%) 75 mm of sub-base (25%) Shoulder (est.)
3	1+950 – 2+025	Seal (DBST) 100 mm of base (80%) 125 mm of sub-base (25%) Shoulders (est.)
	2+025 – 2+100	Seal (DBST) 100 mm of base (80%) Shoulders (est.)
4	2+400 – 2+520	Seal (DBST) 70 mm of armouring 100 mm of base (50%) 125 mm of sub-base (25%) Shoulders (est.)

A10.3 Road and pavement design exercise

Question

Design the geometric cross section, geometry and pavement of a road for the following situation. Assume that there is no financial restriction.

- The road is in poor condition and the improved road will follow the same alignment
- The road is 7 km long
- The total rise and fall of the road is 685 metres
- The traffic for most the road is as given in the traffic analysis exercise above, with no vehicles in Traffic Category 5
- In two villages along the road, the traffic in Traffic Category 1 is assumed to be three times that on the rest of the road, the traffic in Traffic Category 2 is assumed to be two times that on the rest of the road and the traffic in Traffic Categories 3 and 4 is assumed to be the same as that on the rest of the road
- The rainfall is 1700 mm per year
- Most of the road has a gradient of less than 4%, but there are occasional hills up to 50 metres long with gradients of 10%
- Realignment around these hills would be expensive
- Flooding is not a problem along the road
- Ground water is always more than 0.5 metres below ground level
- The subgrade, when soaked, has a CBR of 5.5% along the entire road
- Gravel which can achieve a soaked CBR of 65% is available
- A local soil which can achieve a soaked CBR of 13% is also available
- Strong aggregate, suitable for chippings and armouring, is available
- Contractors are capable of constructing gravel layers and bituminous seals
- The VMC is able to successfully maintain a gravel road and is expected to be able to maintain a bituminous seal

Answer

The design process for the improvement of an existing road will be used. The relevant steps are described below.

1. Screening
- The project is acceptable from a budget, traffic and maintenance perspective.

2. Site visit and rapid survey
3. Assess traffic
- LVRR standards apply for the entire road
- The traffic is in Traffic Group B for the entire road

4. Assess terrain
- Total rise and fall per kilometre = 98 metres
- Therefore the road crosses approximately 20 5-metre contours per kilometre
- The terrain is therefore classed as Rolling

5. Assess annual rainfall
- The annual rainfall comes in the range 1500-2000 mm per year

6. Assess local materials
- With medium gravel, chippings, armouring and a soil which could act as a capping layer available, a gravel and a sealed armoured gravel pavement may be appropriate

7. Assess construction and maintenance capacity
- Local capacity appears capable of constructing and maintaining a gravel road and a bituminous seal

8. Initial design work
- For most of the road, carriageway width = 3.5 metres and shoulder width = 1 metre
- For the road in the two villages, although the traffic in Traffic Categories 1 and 2 is higher, the carriageway and shoulder widths remain at 3.5 metres and 1 metre
- Sections that have a gravel surface must have, unless there are good reasons for exception:
    - a carriageway camber of 6%
    - a shoulder camber of 6%

  - a minimum horizontal radius of 70 metres
  - a minimum vertical crest radius of 900 metres
  - a minimum vertical sag radius of 250 metres
  - a minimum sight distance of 100 metres
  - a maximum gradient of 6%
- Sections that have a bituminous or concrete surface must have, unless there are good reasons for exception:
  - a carriageway camber of 4% (bituminous) or 1-2% (concrete)
  - a shoulder camber of 6%
  - a minimum horizontal radius of 60 metres
  - a minimum vertical crest radius of 500 metres
  - a minimum vertical sag radius of 250 metres
  - a minimum sight distance of 70 metres
  - a maximum gradient of 8% for hills longer than 300 metres
  - a maximum gradient of 15% for hills shorter than 300 metres
- Adverse camber removed on curves with a horizontal radius of less than 500 metres.

9. Main survey
10. Data collection
11. Selection of improvements
12. Pavement and surface design

- It is assumed that the road has been surveyed and that a pavement will be constructed along the entire length of the road with the geometric cross section and geometry as above
- An unsealed gravel pavement is suitable for most of the road with gradient less than 4% and rainfall of 1500-2000 mm per year, although the traffic level of Traffic Categories 3 and 4 is higher than ideal for a gravel road
- An improved pavement is required on the short hills and through the villages
- A sealed gravel pavement is not suitable because gravel with the required soaked CBR of 80% is not available
- A sealed armoured gravel pavement will be used on the short hills and through the villages
- DBST will be used as the contractors are familiar with it and have no experience of an Otta seal
- Additional slope protection, safety and environmental measures will be constructed as required

13. Estimate costs
14. Prioritisation

15. Prepare contract documents

- These steps are not relevant for the question – it is assumed that the selected pavements are the most appropriate and have the lowest whole life costs

The pavement designs are summarised below. All materials must meet the relevant specifications. Note that both pavements meet the requirements for the height above ground water given in Table 11.

Gravel pavement – refer to Tables Ax and Ax

- Gravel layer, 200 mm thick with a minimum soaked CBR of 25%
- Capping layer, 150 mm thick with a minimum soaked CBR of 10%
- Regravel before the gravel thickness is less than 100 mm

Sealed armoured gravel pavement – refer to Tables Ax and Ax

- DBST
- Armouring, 70 mm thick
- Gravel base, 100 mm thick with a minimum soaked CBR of 25%
- Gravel sub-base, 150 mm thick, with a minimum soaked CBR of 25%
- Capping layer, 175 mm thick with a minimum soaked CBR of 10%

A10.4 Whole life asset cost exercise

Question

Which of the two pavement types below has the lowest whole life asset costs over a design life of 12 years and with a discount rate of 10%?

All costs are given per kilometre and are for this example only. The currency is not stated.

Gravelled pavement

Construction cost:	11,000
Annual routine maintenance cost:	700
Regravelling cost in years 4, 7 and 10:	6,500
Residual value after 12 years:	8,000

Sealed gravel pavement

Construction cost:	18,500
Annual routine maintenance cost:	900
Resealing cost in year 8:	4,000
Residual value after 12 years:	16,000

Answer

The construction cost, maintenance costs, residual value and whole life asset costs are given in Table A28.

Although the costs are examples only, this example calculation shows how whole life asset costs are calculated and also shows how whole life asset cost comparisons can give a different result to construction costs alone.

Table A28 Whole life asset costs

Gravelled pavement (km)					Sealed gravel pavement (km)				
Yr	**Activity**	**Discount factor**	**Current cost**	**Discounted cost**	**Yr**	**Activity**	**Discount factor**	**Current cost**	**Discounted cost**
0	Constr	1.00	11,000	11,000	0	Constr	1.00	18,500	18,500
1	RM	0.91	700	637	1	RM	0.91	900	819
2	RM	0.83	700	581	2	RM	0.83	900	747
3	RM	0.75	700	525	3	RM	0.75	900	675
4	RM	0.68	700	476	4	RM	0.68	900	612
5	RM	0.62	700	434	5	RM	0.62	900	558
6	RM	0.56	700	392	6	RM	0.56	900	504
7	RM	0.51	700	357	7	RM	0.51	900	459
8	RM	0.47	700	329	8	RM	0.47	900	423
9	RM	0.42	700	294	9	RM	0.42	900	378
10	RM	0.39	700	273	10	RM	0.39	900	351
11	RM	0.35	700	245	11	RM	0.35	900	315
12	RM	0.32	700	224	12	RM	0.32	900	288
4	RG	0.68	6,500	4,420					
7	RG	0.51	6,500	3,315	8	RS	0.47	4,000	1,880
10	RG	0.39	6,500	2,535					
12	RV	0.32	-8,000	-2,560	12	RV	0.32	-16,000	-5,120
			Total	**23,477**				**Total**	**21,389**

Constr: Construction
RM: Routine maintenance
RG: Regravelling
RS: Resealing
RV: Residual value