NCDD SEACAP

វគ្គបណ្តុះបណ្តាលស្តីពី

ការគ្រោងប្លង់ និងសាងសង់ផ្លូវលំ

TRAINING COURSE ON DESIGN & CONSTRUCTION OF LOW VOLUME RURAL ROAD

ឧបត្ថម្ភដោយ — SUPPORTED BY

SEACAP & NCDD

រៀបចំដោយ៖ORGANIZED BY

ភ្នំពេញ, ថ្ងៃទី ៤-៧ ឧសភា ឆ្នាំ២០០៩

PHNOM PENH, MAY 4-7, 2009

Training Courses on Design and Construction of Low Volume Rural Road

Objective

The objective of the project is the effective transfer of appropriate knowledge on the selection, design, construction and management of Low Volume Rural Roads (LVRRs) to provincial and district engineers operating under the Cambodian National Decentralisation and De-concentration (NCDD) programme. The NCDD is investing in rural access and rural roads and is consequently interested acquiring knowledge relevant to improving the performance of these investments.

This project is also part of the wider South East Asia Community Access Programme (SEACAP), whose strategic theme is 'livelihoods of poor and vulnerable people in SE Asia improved sustainably'.

Courses Detail

The courses comprises of two training modules, as follows:

1. **Module 1 from 4th to 7th May 2009: LVRR paving and surfacing training.** This is a 4 day course based the materials developed for DF 55 in Vietnam, but amended and upgraded to suit Cambodian rural infrastructure needs and environments.
2. **Module 2 from 25th to 29th May: LVRR maintenance training.** This is a 5-day course based on the materials used for the SEACAP 11 project in Vietnam, also suitably amended and upgraded to suit Cambodian rural infrastructure needs and environments.

Training Venue

Training venue is **Meeting Room of the General Department Administration**, **Ministry of Interior** located at No. 275 Norodom Blvd., Phnom Penh.

វគ៌បណ្ដុះបណ្ដាល
ស្ដីអំពី
ឱការគ្រោងប្លង្ក ការសាងសង្ក និងការថែរទាំផ្លូវជនបទត

គោលបំណង

គោលបំណង្ខ នវគបណ្ឌុបណ្ឌាលន្ទេ គឺដើម្បីផ្ដល្កជូនវិស្វករថ្នាក្កខេត្ត និថ្នាក្កស្រុកដែលកំពុងប្រតិបតិ្តការ ងារនៅក្រោមកម៌វិធីវិមជឍការ និងវិសហាមជឍការជាតិកម្ពុជា ឧគ៕៕ ប្ត នូវចំណេ្ណដឹងសមស្រប អំពីការជ្រើស រើសការគ្រោងបង្ក ការសាងសង្ក និងការគ្រប្គគ្រងផ្លូវជនបទដែលមានចរាចរណ៍ទាប (LVRRs) ប្រកបដោយ ប្រសិទ្ធិភាព។ **គ៕៕** កំពុងផ្ដល្កមូលនិធិកសាននិងថែទាំផ្លូវជនបទ ហេតុដូចន្ទេ ហើយមានការចាប្កអារម៉ណ៍ ទៅលើការ ប្រមូលនូវចំណេ្ណដឹងដែលជាប្កពាក្កពន្ធចំពេ្ណ ការធ្វើអោយប្រតិបតិ្តការ្ខ នការវិនិយោគន្ទេ មានភាព ប្រសើរឡើង។

គំរោងន្ទេ កនាផ្នែកមួយ្ខ នកម៌វិធីតភ្ជាប្កសហាគមន៍អាស៊ីអាគ្នេយ៍ដន់មួយ ដែលមានយុទ្ធសាស្រ្ត ឱធ្វី អោយប្រសើរនូវការទ្រទ្រង្កជីភាពរស្កនៅរបស្កប្រជាជនក្រីក្រ និងងាយរងគ្រោះ នៅតំបន្កអាស៊ីអាគ្នេយ៍ ប្រកប ដោយចិរភាពត។

វគបណ្ឌុបណ្ឌាល

ការបណ្ឌុបណ្ឌាលន្ទេ ចែកចេញជាពីរវគ.គឺ៖

១៕ **វគទី ១_ ចាប្កពី្ខ ថ្ងទី៤ ដល្ក្ខ ថ្ងទី៧ ខែឧសភា ឆ្នាំ២០០៩៖ ការបណ្ឌុបណ្ឌាល អំពីកម្រាលផ្លូវជន បទដែលមានចរាចរណ៍ទាប។** វគបណ្ឌុបណ្ឌាលន្ទេ ផែកលើ្ខ កសារដែលរៀបចំឡើង សំរាប្កគំរោង DF 55 នៅ ប្រទេសវៀតណាម ហើយត្រូវ៉ានកែសម្រួលអោយសមស្របទៅនឹងតម្រូវការ និង បរិស្ថានហេដ្ឋារចនាសម្ពន្ធជនបទនៅប្រទេសកម្ពុជា។

២៕ **វគទី២_ ចាប្កពី្ខ ថ្ងទី២៥ ដល្ក្ខ ថ្ងទី២៩ ខែឧសភា ឆ្នាំ២០០៩៖ ការបណ្ឌុបណ្ឌាលអំពីការថែរទាំ ផ្លូវជនបទដែលមានចរាចរណ៍ទាប។** វគបណ្ឌុបណ្ឌាលន្ទេ ផែកលើ្ខ កសារដែលត្រូវ៉ានប្រើនៅក្នុង គំរោង SEACAP 11 នៅ ប្រទេសវៀតណាម ហើយកត្រូវ៉ានកែសម្រួលអោយសមស្របទៅនឹង តម្រូវការ និងបរិស្ថានហេដ្ឋារចនាសម្ពន្ធជនបទនៅ ប្រទេសកម្ពុជា។

ទីកន្លែង

ទីក្ខ នងបណ្ឌុបណ្ឌាល៖ **បន្ទប្កប្រជុំអគនាយកដ្ឋានរដ្ឋ៉ាល្ខ នក្រសួងមហា្ខ ផ្ទ,** អាគារលេខ ២៧៥ មហាវិថីព្រះ្ខ នរោត្តម ភ្នំពេញ។

វគ្គទី ០១ ការគ្រោងប្លង់ និងការសាងសង់ផ្លូវជនបទ

ពីថ្ងៃទី៤ ដល់ថ្ងៃទី៧ ខែឧសភា ឆ្នាំ២០០៩

កម្មវិធីបណ្តុះបណ្តាល

	ពេល	មាតិការ
ថ្ងៃទី៤ ខែឧសភា	ព្រឹក	**ការបើកវគ្គ** ការចុះឈ្មោះ ការប្រកាសបើកវគ្គបណ្តុះបណ្តាលជាផ្លូវការ ការណែនាំអំពីការវគ្គបណ្តុះបណ្តាល
		មេរៀនទី ១៖ គោលការណ៍ផ្លូវជនបទ • និយមន័យផ្លូវជនបទ • បរិស្ថានផ្លូវ
	ថ្ងៃ	**មេរៀនទី ២៖ ជម្រើសកម្រាលផ្លូវ** • ជម្រើសកម្រាលផ្លូវដីធម្មជាតិ • កម្រាលកៅស៊ូ • កម្រាលថ្ម • កម្រាលបេតុង
ថ្ងៃទី៥ ខែឧសភា	ព្រឹក	**មេរៀនទី ៣៖ ជម្រើសកម្រាលផ្លូវ និងការគ្រោងប្លង់** • វិធីសាស្ត្រទូទៅ • ការកំណត់តម្លៃ គម្រោងមួយអាយុកាលផ្លូវ • ការប្រមូលទិន្នន័យ និងការគ្រោងប្លង់ • ប្រពន្ធដោ្ហ ទឹក
	ថ្ងៃ	**មេរៀនទី ៤៖ ការសាងសង់ និងការគ្រប់គ្រង** • បទដ្ឋានបច្ចេកទេស • គ្រឿងចក្រ និងនីតិវិធីសាងសង់ • ការគ្រប់គ្រងគុណភាព • ការគ្រប់គ្រងផ្លូវ
ថ្ងៃទី៦ ខែឧសភា	ព្រឹក	**មេរៀនទី ៥៖ ការគ្រោងប្លង់ដែលសមស្របនឹងលក្ខខណ្ឌបរិស្ថាន** • សេចក្តីណែនាំ • ការណែនាំអំពីលំហាត់អនុវត្ត
	ថ្ងៃ	**មេរៀនទី ៦៖ ការធ្វើលំហាត់អនុវត្តជាក្រុម** • បែងចែកជាបីក្រុម
ថ្ងៃទី៧ ខែឧសភា	ព្រឹក	**មេរៀនទី ៧៖ ការវាយតម្លៃលទ្ធផលសិក្សា** • បទបង្ហាញអំពីលទ្ធផលលំហាត់អនុវត្ត • ការប្រលង
	ថ្ងៃ	**ការបិទវគ្គបណ្តុះបណ្តាល** • ការចែកជូនវិញ្ញាបនបត្រ • យោបល់ឆ្លើយតបអំពីវគ្គបណ្តុះបណ្តាល • ការប្រកាសបិទវគ្គបណ្តុះបណ្តាលជាផ្លូវការ

Module 1: Design and Construction of Low Volume Rural Road

(4th to 7th May 2009)

Training Programme

	Session	Session Content
May 4th	Morning	**Opening Activities** Registration Formal Opening Course Introduction
		Session 1: LVRR Principles • LVRR definition • The Road Environment
	Afternoon	**Session 2: Surfacing and Pavement Options** • Unsealed surfacing options • Flexible pavements and seals • Block pavements • Concrete pavements
May 5th	Morning	**Session 3: Pavement Option Selection and Design** • General approach • Whole life costing • Data collection and detailed design • Drainage
	Afternoon	**Session 4: Construction and Management** • Specifications • Construction plant and procedures • Quality control • Whole life management
May 6th	Morning	**Session 5: EOD** • Description • Introduction to exercise
	Afternoon	**Session 6: Desk Study Exercise** • 3 Groups
May 7th	Morning	**Session 7: Assessment** • Exercise presentations • Examination
	Afternoon	**Closing Activities** • Certificates • Course Assessment • Closure

1 LOW VOLUME RURAL ROAD PRINCIPLES

SUMMARY

Session 1 lays out the general principles that govern the appropriate design, construction and long term management of Low Volume Rural Roads (LVRRs) within the overall requirements of rural infrastructure development. This module describes the function that LVRRS have to perform and how this together with the road environment must have a direct impact on their design if they are to be part of a sustainable infrastructure.

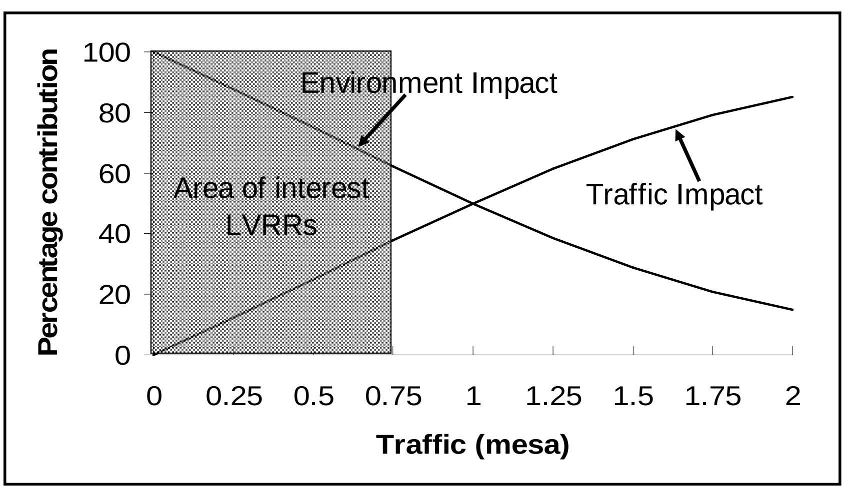
CONTENT

1.1 What is a Low Volume Rural Road?

General Definition of LVRRs

There clearly has to be an upper limit to the roads that may be included within the LVRR approach to rural road design and construction. In general terms this limit is indicated on the following Figure in terms of esa (equivalent standard axles) as being a road environment below which traffic is not the dominant factor influencing road deterioration. Very roughly this upper limit is about equivalent to a motorised ADT (average daily motorised traffic) of about 150-200 with 10-25medium to heavy trucks (<6-8t axle load)

This is a general conceptual figure which needs to be interpreted and adapted for specific regions bearing in mind their particular characteristics.



Relative Impacts of Traffic and other Road Environment Factors

A general LVRR Classification would normally encompasses roads that are suitable for up to medium sized commercial vehicles and with a maximum design loading carried by a single axle of around 6Tonnes. This limit has been identified as appropriate for a substantial portion of the rural road networks in consideration of current and likely future traffic demand, and the pragmatic management of the road network with the limited resources available.

It is important to note that the LVRR Classification does not imply that all Rural Roads must comply with a 6T limit; only that roads to be designed under the LVRR principles must do so. If some Rural Roads are deemed to require a higher axle load or higher traffic standard then logically they must be dealt with under other categories.

A Typical LVRR Definition

Design Parameter	**Description**	**Definition**	
Road system	Low volume rural roads	For all-year accessibility	
Classification	One-lane roads. Defined by maximum number of 4-wheeled motorized vehicles, maximum axle load and maximum vehicle body width	Traffic lane	One
		Maximum 4-wheeled motorized vehicles	150-200 per day
		Maximum axle load limit	6Tonnes for any vehicle
		Maximum vehicle body width	2.3m

1.2 The Road Environment and its Impact

What is the Road Environment?

The principal elements in the road design process are traditionally focussed on traffic and the choice of materials and their thickness within each pavement layer. It is now appreciated that additional road environment factors must be taken into account if the selected designs are to be cost-effective and sustainable.

In reality the performance of a LVRR depends on a whole range of factors that cumulatively can be described as the “road environment”.

Factors important to the road environment can be broadly grouped as illustrated in the following table

:

Road Environment Impact Factors

Impact Factor	**Description**
Construction Materials	The nature, engineering character and location of construction materials are key aspects of the road environment assessment.
Climate.	The prevailing climate will influence the supply (precipitation, water table), evaporation (temperature ranges and extremes) and movement (temperature gradients) of water. Climate impacts upon the road in terms of direct erosion through run-off, influence on the groundwater regime (hydrology), the moisture regime within the pavement, and accessibility for maintenance
Surface and sub-surface hydrology**.**	It is often the interaction of water, or more specifically its movement, within and adjacent to the road structure that has an over-arching impact on the road performance.
Terrain	The terrain, whether flat, rolling or mountainous reflects the geological and geomorphological history. Apart from its obvious influence on the long section geometry (grade) of the road, the characteristics of the terrain will also reflect and influence the occurrence and type of soil present, type of vegetation, availability of materials and resources.
Subgrade Conditions	The sub-grade is essentially the foundation layer for the pavement and as such the assessment of its condition is fundamental to an appreciation of the road environment.
Construction Regime	The construction regime governs whether or not the road design is applied in an appropriate manner. Key elements include: • Appropriate plant use • Selection and placement of materials • Quality assurance • Compliance with specification • Technical supervision
Maintenance Regime	All roads, however designed and constructed will require regular maintenance to ensure that the design life is reached. Indeed good maintenance can often extend the period that the road can function, well beyond the design life. Achieving this will depend on the maintenance strategies adopted, the timeliness of the interventions, the local capacity and available funding to carry out the necessary works
The “Green” Environment	Road construction and ongoing road use and maintenance have an impact on the natural environment, including flora, fauna, hydrology, slope stability, health and safety. These impacts have to be assessed and mitigated as much as possible by appropriate design and construction procedures.

Cambodian Road Environment Factors

The following paragraphs summarise some key issues about the road environment factors in Cambodia and indicate some potential influences on up-grade selection.

Construction Materials: There is a perceived lack of conventional road building materials in many areas of rural Cambodia. Key issues are,

1. Large areas of Cambodia are dominated by Quaternary alluvium and lacustrine deposits of sand silt and clay[1,2]. In general terms these Quaternary deposits

[1] 1: 1,000,000 geological map of S E Asia
[2] Atlas of Cambodia; National Poverty and Environment Maps, Danida, 2006

underlie a large swathe of Cambodia running NW-SE from Odder Mancheay and Banteay Mancheay through to Svay Rieng and Takaev. Within this area only isolated rock outcrops occur.

2. In the South East a band of hilly terrain running through the provinces of Battambang, Pursat, and Koh Kong to Kompot is underlain by sedimentary and igneous rock with the latter, in particular, having potential as construction aggregate.
3. In the North West the provinces Rattanakiri and Mandal Kiri have substantial outcrops of potentially useable igneous, sedimentary and occasional metamorphic rocks types rock, as have parts of the provinces of Krahcheh, Stung Teng and Siem Reap
4. The residual weathering of some rock types, as for example in Siem Reap, is associated with useable laterite gravel deposits.
5. The regional variation in materials resources implies that that an overall Cambodian upgrade option is not logical and that a flexible approach is necessary.

Climate: Cambodia's climate is tropical monsoonal and this leads to the following key points:

1. A distinct rainy season from mid-May to early October which is variable with very high rainfall adjacent to the South West coast (2,500-4,000mm/year) and a lower, but still significant, rainfall (1,400 - 2,000mm/yr) in central and North Eastern areas, Figure 4.
2. In practical terms this climatic regime has an impact in terms of the general unsuitability of unsealed gravel surfacing options in the South West and recommended limitations on its use elsewhere depending on gradient. It also impacts upon general sub-grade condition.

Hydrology: Significant areas of the Lower Mekong basin in Cambodia are subjected to serious flooding.

1. SEACAP 19 Technical Paper 6[3] notes that the hydrology effects in the Lower Mekong are…. "… *complex, and although floods occur every year, they vary greatly in height and intensity. Some of the lower lying parts of the flood plains are inundated every year, while others receive floods only occasionally. ……The problem is that these vulnerable but densely populated areas require a lot of infrastructure."*
2. Current regional evidence indicates that stone block and concrete pavement options are the most flood resistant options. Unsealed options are particular vulnerable to flood induced damage.

Terrain: There are distinct terrain divisions within Cambodia as follows;

[3] Howell, J, 2008. Study of Road Embankment Erosion and Protection, SEACAP 19 report to DFID

1. The Tonle Sap Lake and the lower basin of the Bassac and Mekong rivers form the basis of a large central lowlands region of Cambodia with an elevation of less that 100m.
2. South of the central region are the Northwest to Southeast running Cardomom Mountains (max elevation 1,800m) extending into the Elephant range in Kampot (500 -1000m)
3. Higher elevation (100 - 500m) terrain north of the central region ranges rises up to the Dangrak Mountains and Korat Plateau to the North and the Rattanakiri Plateau in the Northeast (500 - 1500m).

The variable terrain indicates that up-grade options must include those suited to moderately steep terrain and alignment grades. In some areas there will be a need for a combination of steep terrain and very high rainfall to be accommodated in pavement selection.

Subgrade: Key points are,

1. The climate data shows a high rainfall environment where sub-grade conditions can be expected to be at least seasonally wet.
2. Some drying out is to be expected during the dry season, but road sub-grades are likely to wet for at least 6-8 months of the year and probably longer. It follows that the measurements to assess the strength of the sub-grade should be in the soaked condition.
3. A comparison with similar regional environments indicates that sub-grade conditions are likely to be highly variable. Highland regions may produce generally good sub-grade conditions (CBR>10%), if allowance is made for local unpredictability and localised flat-lying areas. In contrast, rural roads on flat low-lying terrain on poor quality embankments or on saturated natural ground are unlikely to have general CBR sub-grades values in excess of 5%. .

Traffic: There is limited formally reported data on the traffic patterns in rural Cambodia, however from the limited and frequently anecdotal information the following key points may be surmised:

1. There are likely to be a majority of Cambodian rural roads falling within the LVRR envelope.
2. The types of traffic using the LVRRs are likely to be similar to those encountered in other countries in the region with a wide spectrum of road users from pedestrians to small trucks.
3. A National Workshop in 2005 highlighted the general problem of axle overloading in Cambodia and the risk of overloading on LVRRs needs to be recognised in any upgrade assessment.

Construction Regime: Although Cambodia allows International Contractors to bid for main road projects it is likely that most LVRR up-grade programmes will be undertaken by local contractors, many of them small provincially-based operations. Key points that follow from this are,

1. Contractors may have limited experience in construction techniques outside the standard unsealed gravel or concreting operations.
2. Regional and national experience indicates that small contractors have limited experience in working to detailed specifications.
3. There is a general lack of experience in road construction supervision and associated quality control.

Maintenance Regime: In 2006 the SEACAP 2 project reported that maintenance for rural roads was "… a major and complex issue that has not yet been solved in Cambodia." , and that it would ".. take a considerable period of time (in years) and a coordinated range of initiatives to do so according to World Bank knowledge and experience in other countries."

The inference from the above and recent experience is that effective maintenance programmes for the Cambodia rural road network are not yet in place. Consequently, when assessing upgrading options, no assumptions should be made that any effective maintenance will take place unless the upgrading programme specifically includes a guaranteed maintenance component.

Basic LVRR Principle

They should be:

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

Module 1 Session 1
Self Assessment

Read through Session 1 and answer the following:

1. A suitable upper axle limit for a LVRR would be

2 tonnes	
6 tonnes	
10 tonnes	
12 tonnes	

2. List 4 key road environment factors

3. Name 3 provinces where there is likely to be a shortage of good rock aggregate

4. Name 3 provinces where flooding is likely to influence road design

5. Name 3 provinces where likely to have annual rainfall > 2000mm/year

2 SURFACING AND PAVEMENT OPTIONS

SUMMARY
This module summarises the wide range of LVRR surfacing and road pavement options that have been trialled under the SEACAP programmes in the region. The advantages and disadvantages of the various options are outlined in the context of the various road environment conditions that occur in Cambodia

CONTENT
- Unsealed earth or gravel surfacing
- Sealed Flexible Pavements
- Block Pavements
- Concrete Pavements

2.1 Unsealed Surfacing

Unsealed Road Types

Regional research has indicated a wide range of materials used in the construction of engineered unsealed roads; from in situ sands, silty clays to the well graded strong cohesive gravels. It is also clear from this research that a significant percentage of unsealed "gravel" roads , probably the majority in many areas, are actually constructed with material outside the generally accepted specifications in terms of grading and plasticity. It is logical therefore to consider two major divisions of unsealed LVRRs:

- Those constructed with an as-specified a gravel wearing course (GWC)
- Engineered roads built local material that is outside the GWC specification – using the terminology from recent SEACAP research these have been Engineered Natural Surface Road (ENSRs).

General Guidance on ENSRs

In the majority of situations in Cambodia an ENS will be a "soil" road, that is, built with material of a finer grading than a GWC road (GWCR). Hence, even more so than with a GWCR an ENSR will always deteriorate with time as well as with traffic. Under even moderate climatic conditions and easy terrain, some soil types will deteriorate too quickly for an ENS to be a viable surface option. The properties of the local soil and the local environment are fundamental and, for example, it is anticipated that few soils will make a viable ENSR if the longitudinal gradient is too high..

The deterioration of ENSRs is governed by the combined actions of traffic and the environment and, most of the time, it is at the surface itself that deterioration occurs. However, although by definition a length of road comprises only one type of material, the surfacing may be relatively dry and strong for much of the time whereas the underlying material may be wetter, less compacted, and consequently weaker. If this weaker material is too close to the surface it may be at risk of failure. For example, this can occur if the embankment height in low lying areas is inadequate. Under these circumstances it may sometimes be necessary to consider the pavement as a layered structure in much the same way as is done for normal multilayered pavements and to consider likely failures at depth, but under most circumstances this will not be necessary.

The surface of an ENSR is usually permeable although, in some cases, the permeability may be very low; thus material properties, rainfall, and surface drainage influence the behaviour of the surfacing itself. On the other hand, surface water run-off and side drainage usually affect the moisture penetration into the underlying layer (roadbed) and thus its bearing capacity.

ENSR Advantages

- Low initial materials cost
- Can usually be constructed with local labour and plant
- Suitable for light basic access traffic
- Can be locally maintained

ENSR Disadvantages

- Unsuitable for medium to high traffic
- Susceptible to erosion by flooding or rainfall-terrain combinations
- Dust hazards
- High input of low-level maintenance

General Guidance on GWCRs

Recent SEACAP research taking into account international research on GWC roads indicated that they can only be considered as a serious viable pavement option for rural roads on engineering and economic grounds under the following conditions:

1. Where suitable material is locally available in sufficient quantities both for construction and maintenance (probably within 10km of the road). This should be verified with a detailed whole life costing of surfacing options if the materials hauls are longer than 10km. A realistic assessment of the likelihood of routine and periodic maintenance being carried out should be included in the whole life costing, including the risks and consequences of inadequate maintenance.
2. Where road **gradients are less than 4%** in medium rainfall areas (1,000 – 2,000 mm/year).
3. Where **adequate drainage** (crossfall, side and dispersion) can be guaranteed.
4. Where **adequate quality assurance** controls are in place for construction supervision to ensure contract and specification compliance.
5. Where an appropriate **maintenance regime** can be guaranteed as part of a whole-life construction and maintenance specification.
6. Where **flooding** is only a minor local occurrence.

7. Where **traffic** is below 200 motor vpd equivalent. This is recommended from international experience.

Specified Gravel Wearing Course (GWC)

One or more layers of compacted natural gravel placed directly on the existing sub-grade Before placing, the existing surface should be shaped and compacted with a camber (crossfall) of about 3 - 6% sloping down each side from the road centre line. The gravel layers should be laid to the same crossfall and a constant thickness. The overall gravel thickness is typically 15 - 30cm. Individual gravel layer thickness usually up to 15cm (compacted) maximum.

GWC Advantages

1. Proven performance in tropical and sub-tropical, gravel-rich environments.
2. Suitable for light to medium traffic.
3. Usually lower initial cost than most other surfacing options apart from ENSRs.
4. Can be used as an intermediate surface in a planned and resourced 'stage construction' strategy.

GWC Disadvantages

1. Material may occur in limited natural deposits of variable quality
2. Gravel is a **wearing surface.** Subject to unsustainable gravel loss when use in inappropriate environments
3. It is essential to have a sustained maintenance programme and regular re-gravelling to replace gravel loss, hence high maintenance costs;
4. Dust pollution in dry weather. Health & Environmental concerns.

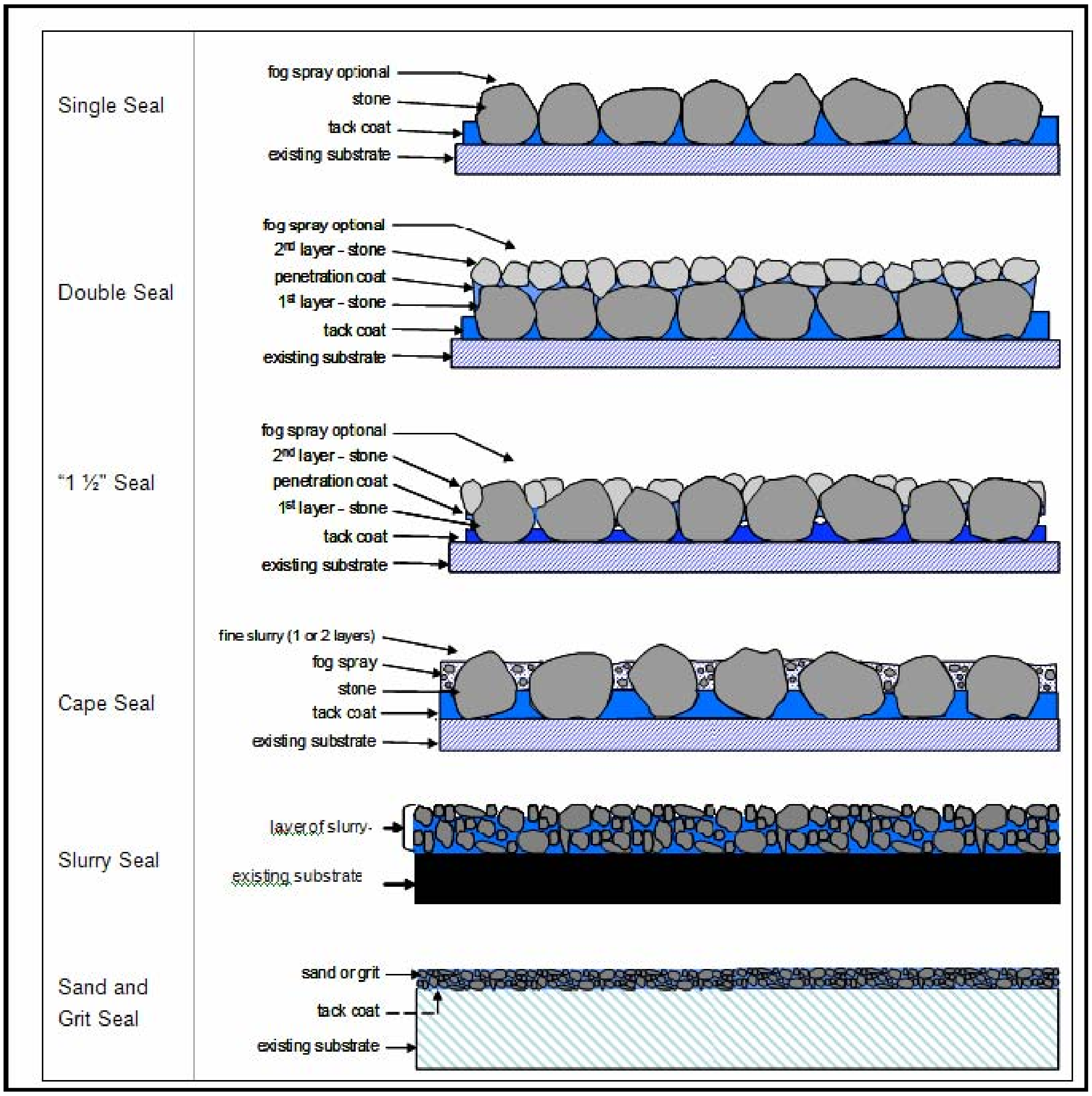
2.2 Flexible Sealed Pavements

General Description

Pavements described in this section generally comprise a **bituminous seal** overlying a **granular base and sub-base**. Seals are essentially the combination of a bitumen film with stone or sand embedded into it.

Seals are flexible and relatively easy to maintain surfaces but may require imported processed material (bitumen) and good quality screened and crushed stone or sand. However, sand seals and low grade natural aggregates have been successfully used in a number of regions in appropriate circumstances.

Some Typical Seal Options



Note. A fog spray is a thin spray of bitumen emulsion.

The principal seal options trialled under SEACAP regional programmes are:

- Bituminous emulsion stone chip seals, these can be either single bituminous surface treatment, SBST(E) or double bituminous surface treatment, DBST(E).
- Hot bitumen double or single chip seals (SBST, DBST)
- Bituminous emulsion sand seal, SS(E)
- Bitumen penetration macadam, (PenMac)
- OTTA seal

The principal focus of this course will be on the use of **bituminous emulsion seals**

Bituminous Emulsion Seals

Key Reference: RRST Construction Guideline Section 4

Bitumen emulsion contains penetration grade bitumen dispersed in water. When the emulsion is used and exposed to air, the water in the emulsion evaporates or separates from the bitumen during a process of 'breaking' (and changing from brown to black in colour). This leaves the residual bitumen in place to adhere to the road-base and aggregate. Emulsions are classified as:-

- Anionic, where the particles of bitumen are negatively charged, or
- Cationic, where the particles of bitumen are positively charged.

Use of emulsions should be compatible with the conditions and environment of the application.

Rapid setting emulsion (RS) grades are the best suited to surface dressing work to achieve rapid development of the bond between the bitumen and the other materials

Principal Advantages over Hot Bitumen

1. Provide safer handling by avoiding the need to heat the bitumen to a high temperature, and it is not flammable.
2. For application using labour-based methods, bitumen emulsion is the safer and easier to use option

Principal Disadvantages and Concerns in Relation to Hot Bitumen

1. Availability is still limited in some developing countries and access to emulsion is more expensive.
2. Shorter storing time. Emulsion must be used within 3 months of manufacture and regularly agitated (rolled if stored in drums) to prevent premature separation of the components.
3. It is not recommended for low ambient temperature due to longer breaking time
4. Local contractors may not be experienced with using emulsion.

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Regionally Trialled Bituminous Emulsion Seals

Bituminous Emulsion Sand seal: A sand seal consists of supply and application of a seal of bituminous binder material over the previously prepared road base. The seal is immediately covered with sand or fine aggregate chippings. The sand/fine aggregate completely covers the seal and is lightly rolled into the seal to form a weather proof matrix and running surface suitable for light vehicular traffic.

A sand seal may be used either to provide an additional layer of protection on a chip seal already laid, or as a single sealing to a block pavement. It may also be used as a maintenance activity on existing asphalt or surface dressed road to seal minor cracks and extend the life of the surface.

Bituminous Emulsion Stone Chip seal consists of supply and application of a seal of bituminous binder material over the previously prepared road base. The seal is immediately covered with single sized stone aggregate chippings. The chippings completely cover the seal and are lightly rolled into the seal to form an interlocking mosaic..

Summary of Advantages and Concerns for Emulsion Seal Types

Description	Principal Advantages	Principal Concerns
SS(E) Sand bitumen emulsion	Application suitable for labour based methods because of low health and safety risks. Reported as suitable for low volume traffic roads in areas deficient in stone aggregate but with plentiful supplies of suitable sand. Suitable for commune based maintenance operations.	A re-seal after 6 months recommended for a more durable surface. Vietnam trials (not re-sealed) indicate poor performance compared to chip seals Procedures not well known by local contractors; requires good site control. Sand seal on block options tend to strip and crack at joints. Not suitable for steep gradients. Potential difficulties in obtaining small quantities of emulsion for maintenance.
DBST(E) Double stone chip bitumen emulsion	Application suitable for labour based methods because of low health and safety risks. Suitable for commune based maintenance operations	Care required in matching emulsion application rates to available stone sizes and aggregate shape. Procedures not well known by local contractors; requires good site control. Potential difficulties in obtaining small quantities of emulsion for maintenance.

Note: Some regional trials used a combination of SS(E) and SBST(E). Indications are that they do not generally perform as well as the DBST options.

Advantages and Concerns for Standard Hot Bitumen Seal Types

Description	Principal Advantages	Principal Concerns
DBST (hot bitumen)	Well known and established procedure in Cambodia.	Generally very poor site control of bitumen application temperature which affects durability. Significant health and safety hazard.
Penetration macadam	Well known and established procedure. Robust performance if well constructed Low initial maintenance if well constructed. Load spreading layer.	Difficult to control quality. Costly use of bitumen at around 7 kg/m^2. Significant health and safety hazard. .
OTTA Seal See Note	Suitable for areas lacking in traditional single size aggregates. Reported favourable life-cycle cost-benefit ratios in comparison to chip seals Load spreading layer. Resistant to stone loss.	Not a procedure widely known in Cambodia, although construction trials were apparently successful. Requires a pneumatic tyred roller, which many small contractors may not possess. Requires a reasonable amount of traffic to work up the bitumen

Otta seal is a bituminous sprayed seal incorporating a graded aggregate instead of the generally used one sized crushed rock aggregate This type of surfacing allows the use of relatively inferior, naturally occurring, unscreened gravels in circumstances where the use of traditional bituminous sprayed surfacing using relatively expensive crushed rock would generally be unaffordable or simply not possible due to the unavailability of such materials.

OTTA seals rely on a combination of mechanical particle interlock and the binding effect of bitumen for their strength, similar to a bituminous premix. Early trafficking and/or heavy rolling is necessary to develop the relatively thick bitumen film around the particles. Within this bitumen/aggregate admixture, the likelihood of stone becoming dislodged and whipped off the road by vehicles is relatively small. Under trafficking, the seal acts as a stress - dispersing mat comprised of a bitumen/aggregate admixture - a mechanism of performance which is quite different to that of chip seal surfacings

Stabilised Bases and Sub-Bases

Key Reference: RRST Construction Guideline Section 5

General description

In cases when the only economically available natural materials contain a considerable quantity of high plasticity fine material and/or a relatively high proportion of weak particles, then available materials may be effectively improved in order to increase strength and bearing capacity by treatment with an additive such as cement, lime, bitumen or mechanical stabilisation (or blending).

These course notes concentrate on cement, lime and mechanical stabilisation

Stabiliser Selection

Selection of the appropriate stabiliser usually based on material grading and plasticity characteristics. The usual range of suitability for applying the various types of stabilisation is defined by the percentage of material passing the 0.075 mm sieve and the plasticity index (PI) of the soil.

In general terms it would be expected that clay soils would be more suitable for lime stabilisation and more sandy materials would be suited to cement stabilization.

Chemical Stabilisation Options

Type of Stabilisation	**Soil Properties**					
	More than 25% <0.075			Less than 25% < 0.075mm		
	PI <	10<PI<	PI >	PI < 6; PP <	PI <	PI >
Cement	S	S	M	S	S	S
Lime	M	S	S	X	M	S

Key PI: Plasticity Index PP: Plasticity Product (PI x % passing 0.075mm)

S: Suitable M: Marginally Effective X: Not Suitable

It is essential to check the grading and plasticity of the proposed sources of natural material, both prior to construction and during its progress

Testing of stabilised material should comprise the Strength and index testing of laboratory mixed stabilised material from the designated natural material source and on-site mixed materials during construction.

Whilst the CBR test is generally the norm for testing base and sub-base materials it is preferable in some case to use unconfined compression tests (UCS), particularly for cement stabilised materials wherever possible. This is because the nature and strength behaviour of the stabilised material is very different to the crushed rock material that defines the CBR test.

As the increase of strength of lime or cement stabilised materials occurs over relatively long periods of time, samples are generally cured for 7, 14 or 28 days prior to testing.

Lime Stabilised Base and Sub-base

When lime is added to a plastic material, it first flocculates the clay and substantially reduces the plasticity. The removal of water and the increase in Plastic Limit cause a substantial and rapid increase in the strength and traffickability of the material. Typically 3 to 8 percent stabiliser is necessary to gain a significant increase in the compressive and tensile strengths.

Lime to be used in the stabilisation should be in its powdered hydrated form [Ca(OH)2] complying with national specifications.

Adequate checks should be made on the chemical analysis reports for each source of lime indicating the amount of "available lime".

Cement Stabilised Base and Sub-base

Cement is commonly used worldwide to improve the engineering properties of certain appropriate in situ or imported soils materials. Although cement can be used to stabilise most soils it is most commonly employed in sandy materials and is generally not effective in soils with a high organic content or those with high clay content.

Typically 3 to 6 percent of cement has been used in the RRST project to effectively stabilise sandy soils. The choice of cement content will depend on the strength required and the nature of the material to be stabilised.

Portland or other kinds of cement used for stabilisation should be checked to ensure it meets the specified national requirements. Cement quality at source and on site should be checked. In general, cement grade 300 or better may be used for soil stabilisation.

Mechanical Stabilisation (Blending)

Blending of materials is carried out for two main reasons namely to improve the stability of

1. Cohesive soils of low strength by adding coarse material or
2. Granular materials by adding a fine material to provide binding

Care must be taken to ensure that the plasticity of the fines fraction is controlled. The strength of a blended material must always be determined by testing samples that are representative of the field-mixed product and not on well-mixed laboratory samples. Once mechanical stabilisation has been achieved it can be expected to remain unchanged for the life of the road.

Mechanical stabilisation is usually found to be the most cost-effective process for improving poorly graded materials, however, this cannot always be achieved. It is important to consider the practical limits of this type of processing. For example, production of a uniform mixture when one material has a high clay content is difficult.

Stabilisation Advantages and Concerns

Description	Principal Advantages	Principal Concerns
Cement stabilisation	Utilises locally available materials with little haulage. Can use locally available agricultural equipment for on-site mixing. Less curing time than needed for lime stabilisation (road closure benefit)	Very difficult to construct during the rainy seasons. Percentage to be added on site up to 1% greater that that indicated by laboratory testing if using agricultural mixing plant Specific care needs to be taken to ensure correct amount of cement, complete mixing, correct moisture addition and adequate curing. Limited time available for final compaction and shaping after mixing is completed.
Lime stabilisation	Utilises locally available materials with little haulage. Can use locally available agricultural equipment for on-site mixing. It is sometimes an advantage to use a small percentage of cement (1%) along with lime in a stabilisation programme.	Adequate testing is necessary to verify suitability and amount of additive. Percentage to be added on site is at least 1% greater that that indicated by laboratory testing if using agricultural mixing plant Difficult to undertake during the rainy seasons. Requires greater curing and road closure time than cement stabilisation. Potential health issue with lime dust during mixing. Workers require protection against lime-skin contact. Specific care needs to be taken to ensure correct amounts of lime, complete and intimate mixing, correct moisture addition and adequate curing..
Mechanical stabilisation	Utilises locally available materials with little haulage. Not effected as much by rain during construction as lime or cement stabilisation No significant health and safety issues	Testing programme required to identify mix proportions. Requires careful control on site operations to ensure adequate mixing.

Non-Stabilised Base and Sub-Base Options

Key Reference: RRST Construction Guideline Section 6

General Description

In areas where there is an adequate supply of good natural gravel or crushed stone, the use of non-stabilised, or unbound, granular base and sub-bases is appropriate. Unbound granular material employed either as a sub-base or a base pavement layer has to perform a number of functions:

- Provide a working platform for construction
- Provide a structural layer for load spreading and protection of underlying layers
- Provide a layer with resistance to rutting
- Sometimes to act as a pavement drainage, or impervious layer.

The internal factors governing the engineering performance of an unbound gravel aggregate are: the engineering behaviour and geometric properties of its constituent particles, its mass grading and the plasticity of its fines.

Natural Gravel Base or Sub-base

Natural gravel may be used for base or sub-base provides it meets the required criteria of strength, grading and plasticity. It is worth noting that these criteria may be different form those required by a GWC.

Regional experience indicates that whilst within Cambodian gravel deposits a material suitable for sub-base (eg CBR of 30%) can be recovered , a material suitable for base (eg CBR of 60-80%) is much scarcer. Experience indicates that natural clayey gravel may be well suited to strengthening by lime stabilisation.

Armoured Gravel Road-Base

This option can be used in the circumstances where an existing gravel/laterite surface is to be upgraded to a sealed surface, or for a completely new pavement construction. The intention is the cost-effective use of suitable locally available natural gravels, and to improve them sufficiently to accept a thin bituminous surfacing.

This activity has two components: an initial component of natural gravel laid to camber, watered and compacted in two layers, followed by a topping or armouring (usually 50-75mm thick) of crushed/broken stone aggregate laid to camber, watered and compacted.

The stone armouring materials source should be sampled and tested to ensure it is capable of providing a consistent supply of rock materials that comply with the specified grading, strength, and shape criteria.

Additional 5mm down screenings or natural sand may be required as a blinding material where the crushed rock grading is deficient in fines. These should be sampled, tested and quality monitored at the same time as principal crushed rock material.

Natural gravel must satisfy the requirements for natural gravel used for sub-base.

Sand Sub-Base

Locally available sand is a potential sub-base alternative, providing that laboratory test on grading and initial site compaction testing indicate adequate compaction is possible.

Sand for sub-base should be tested and inspected to ensure that it complies with any target grading and that compaction and strength testing (CBR) confirm its compactability.

If the sand is hydraulically pumped to its point of placement, as could be the case in Delta regions, ensure that appropriate measures are in place to drain off excess water prior to compaction.

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Quarry Run Sub-base

The term “Quarry Run” is used as a general term to cover naturally occurring rock and weathered rock materials excavated from a quarry or borrow area and delivered to site without processing, apart from any required selection or screening for the removal of oversize boulders or cobbles.

It is a low cost sub-base option, provides a use for materials that may otherwise be considers as waste for dumping. Provided they are acceptable, this use of these materials, therefore, brings with it an environmental advantage.

Material likely to be highly variable in terms of grading and plasticity hence would require adequate control testing and site monitoring of delivered material.

In general, the materials must comply with specified grading and plasticity criteria as well as compacted strength and particular care must be taken in ensuring the removal of oversize material.

For the purposes of the construction of rural road sub-base the target for acceptable quarry run material will be to meet the established requirements for naturally occurring gravel.

Graded Crushed Stone for Base or Sub-base

This is not generally used as an option for rural roads due to the requirement for graded aggregate size processing and the consequent cost. It is however a potential sub-base and base alternative to stone macadam in areas where adequate supplies of quarried and processed rock are readily and cheaply available.

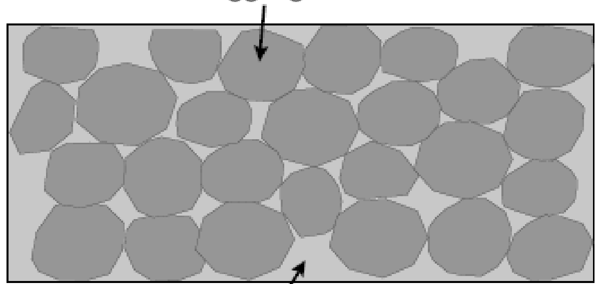
The materials source should be sampled and tested to ensure it is capable of providing a consistent supply of crushed aggregate materials that complies with the specified grading, strength, and shape criteria.

Dry Bound or Water Bound Macadam Base-Sub-base

A Macadam layer essentially consists of a stone skeleton of single size stone (usually 35-50mm nominal size) in which the voids are filled with another material. The stone skeleton, because of its single size, has large amounts of voids but has a high shear strength. If confined properly, a crucial requirement for macadam basecourses, the stone skeleton forms the "backbone" of the macadam and is largely responsible for the strength of the constructed layer. The material used to fill the voids provides lateral stability to the stone skeleton but adds little bearing capacity.

In **Dry-bound Macadam (DBM)** the voids in a layer of almost single-sized stone are filled with a dry, cohesionless fine aggregate filler. The voids are filled with filler through the use of vibratory compaction equipment only, and little or no water is used.

The term **Waterbound Macadam (WBM)** is generally used to describe a material similar to DBM except that the fines are “slushed” into the voids.. The slushing process consists of saturating the macadam layer (coarse and fine aggregate) by spraying it with water, after which a number of passes are made with a steel drum roller, forcing the excess fines to the surface of the layer, from which they are then swept away.



There are number of variations on **Penetration Macadam (PenMac)** but as used in Vietnam for example, the penetration macadam process involves first laying and compacting single-sized crushed/broken stone layer followed by a first application bitumen. This is then followed by a second stone application onto the grouted aggregate, using 10–20mm chippings. A second application of bitumen is then followed by a surface application of fine chippings. The Penentration Macadam layer is normally constructed on top of a DBM or WBM roadbase

Non-Stabilised Materials: Advantages and Concerns

Description	Principal Advantages	Principal Concerns
Dry-bound macadam (DBM)	Straightforward well-proven construction techniques. Recommended for weak moisture-susceptible sub-grades. An appropriate base for bitumen or emulsion sealing.	Requires the use of both static and vibrating compaction machinery; the latter may not be readily available from small contractors. New construction techniques for local contractors; requires initial guidance. Requires quality control of materials and site procedures.
Water-bound macadam	Standard procedure understood by most contractors. An appropriate base for bitumen or emulsion sealing	Not appropriate over moisture-susceptible sub-grades There may be local variations from internationally accepted forms of water bound macadam.
Graded crushed stone (fine and coarse)	Potential sub-base and base alternative to stone macadam in areas where adequate supplies of quarried and processed rock are readily and cheaply available	Not generally used as an option for rural roads due to requirement for aggregate processing and the need for heavier compaction plant than normally available to small contractors.
Sand	Potential sub-base alternative, providing that laboratory test on grading and initial site compaction testing indicate adequate compaction is possible.	Requires consistently well graded fine to coarse sand. May require compaction trials. The light compaction plant available to small contractors may require compaction in thin 8-10cm layers.
Quarry-run	Low cost use of locally available materials for sub-base if suitable quality material meeting specification is available.	Material likely to be highly variable in terms of grading and plasticity hence would require adequate control testing and site monitoring of delivered material. Satisfactory removal of oversize material is a potential problem.

Penetration Macadam		
Natural gravel	Low cost use of locally available materials if suitable quality material meeting specification is available. Local contractors well experienced in using this option. .	Requires adequate testing control on variable natural materials to meet base or sub-base specifications, which may be greater than for normal GWC use. Some natural gravels may not achieve technical requirements unless stabilised.

Block Pavements

Key Reference: RRST Construction Guideline Section 7

General description

Block paving is a well-established technique used in many countries and its success is based on the proven ability of individual blocks to effectively disperse load. Concrete or clay brick and stone block options have been adapted successfully as a viable alternative to gravel or unsealed macadam on low volume rural roads, especially for high rainfall or steep terrain road environments. Blocks are re-usable so that if road base failure occurs they can be merely taken up, cleaned and reused after the road-base/foundation has been repaired.

The SEACAP programmes have trialled a number of block-based options for potential use in Cambodia, namely;

- Fired clay bricks
- Concrete blocks
- Dressed stone
- Cobble stones

Blocks should be placed to a regular pattern (to maximise interlock/load spreading) within a road edge restraint or kerb constructed (for example) of mortared stone or concrete to resist the side thrust forces caused by traffic wheel loading. Blocks/bricks are tapped into position and to the level of the surrounding stones and vibrated into final position with a plate compactor. Jointing of larger stones may be with coarse sand; however to avoid excessive moisture penetration the block/brick joints are usually cement mortared full depth or cement mortar sealed in the high regional rainfall environments. Concrete blocks or bricks may be surfaced with a thin bituminous or bituminous emulsion seal, although has not been a successful trial option in low-maintenance environments.

Unconfined or un-axial strength and block shape are the principal considerations when selecting or approving block materials, whilst water absorption and bulk density form part of the Vietnamese standard for construction bricks

Fired Clay Brick pavement

Description

This surfacing consists of placing a layer of bricks usually laid on their longer edge, within mortar bedded and jointed edge restraints or kerbs on each side of the pavement.

The kerbs are usually also of brick, although other materials such as concrete or dressed stone units are sometimes used. The bricks are normally laid in a herring bone pattern to assist load transfer between individual bricks, or other approved pattern indicated on the Engineering Drawings.

There are social and economic benefits to the communities through local brick manufacture and in labour based construction and in ongoing maintenance.

The characteristics and quality of the bricks produced is determined by the suitability of the raw material for brick making and the quality of the manufacturing process.

Although SEACAP specifications define brick dimensions as 200mm x 100mm x 70mm these may be varied at the Engineer's discretion, depending on local practice in brick production, provided a brick layer thickness of 100mm is retained.

It is essential that "Engineering Quality" bricks are use in the construction of road pavements and a Vietnamese Standard crushing strength of 20MPa is recommended.

Concrete Brick Pavement

As for fired clay brick pavement this surfacing consists of placing a layer of bricks usually laid on their longer edge, within mortar bedded and jointed edge restraints or kerbs on each side of the pavement. The kerbs are usually also of brick, although other materials such as concrete or dressed stone units are sometimes used. The bricks are normally laid in a herring bone pattern to assist load transfer between individual bricks, or other approved pattern indicated on the Engineering Drawings

Cobble Stone pavement

Description

This pavement comprises roughly cubic selected cobble stones of 100-150mm size being laid to camber between edge restraints and compacted into a sand bedding layer. Economic benefits exist to the communities through labour-based stone excavation and preparation and in construction and in ongoing maintenance. This surface has good durability, load bearing and load spreading characteristics. It is suitable for staged construction options and has low maintenance requirements and is easy to repair.

Rock for cobble stone should be tested to ensure it meets the specified requirements of compressive strength, Abrasion value and Sodium Sulphate Soundness

Cobble stones should be roughly cubic in shape with a thickness in the range 100-150mm. The individual cobble stones should have at least one face that is reasonably flat and suitable to be the upper surface.

The material infilling the spaces between the cobble stones should be a loose, dry natural or crushed stone material with a particle size distribution equivalent to a well graded coarse sand to fine gravel. It must be clean and free from clay coating, organic debris and other deleterious materials.

Mortared Dressed Stone Pavement

Description

This activity comprises 200mm thick stone setts being laid to camber between edge restraints and compacted into a sand bedding layer (Specification RRST 209), followed by cement mortaring of the joints.

The SEACAP specification defines the dressed stones as being 300mm x 200mm x 100mm in size, however other similar dimensions may approved by the Engineer depending on local availability and practice.

Block Options: Advantages and Concerns

Description	Principal Advantages	Principal Concerns
Fired clay brick	Social and economic benefits to the communities through local brick manufacture. Local labour employment both in labour based construction and in ongoing maintenance. Good durability, load bearing and load spreading characteristics provided specification-compliant bricks are used. Low maintenance procedures.	Appropriate only when local brick manufacturing can supply bricks of consistently suitable quality. Needs careful control of construction using string lines within pre-constructed edge constraints (kerbs).
Concrete brick	Economic benefits to the communities through local brick manufacture. Local labour employment both in construction and in ongoing maintenance. Good durability, load bearing and load spreading characteristics. Appropriate in areas where concrete brick/block manufacturing is established. Low cost maintenance procedures.	The mortared joint option may be more suitable than the sand sealed, sand joint, option. Adhesion between bricks and bitumen requires investigation prior to construction if a seal option is planned. Needs careful control of construction using string lines within pre-constructed edge constraints (kerbs).
Dressed stone and Cobble stone	Economic benefits to the communities through labour-based stone excavation and preparation. Local labour employment both in construction and in ongoing maintenance. Good durability, load bearing and load spreading characteristics. Suitable for staged construction options. Low cost maintenance procedures.	High cost. Appropriate in areas only where suitable un-weathered stone (e.g. granite) is readily available. High roughness makes it unpopular with some local stakeholders. Not suitable for use with stone that polishes or is slippery when wet. Needs careful control of construction using string lines within pre-constructed edge constraints (kerbs).

Cement Concrete Pavements

Key Reference: RRST Construction Guideline Section 8

General description

Cement concrete slab pavements are widely used to provide a high strength, durable road surface with very low maintenance requirements. However, they require a good quality non-erodible sub-base to support them. They are suitable for any traffic loading from bicycles to high flows of heavy trucks. Cement concrete slab pavements are the most initially expensive of the options, however, in Whole Life Cost terms they can be cheaper than other surfaces due to long life, savings in maintenance organisation and works costs, and Vehicle Operating Costs. These factors can outweigh the high initial construction costs in some circumstances.

Three types of cement concrete slab pavement have been trialled under the SEACAP programme:-

1. Bamboo reinforced concrete pavement
2. Steel reinforced concrete pavement
3. Non-reinforced concrete pavement.

Recent SEACAP research taking into account international research as well as results from the RRST monitoring programme, has indicated that there is no significant benefit to be gained by the use of bamboo reinforcing over the use of well constructed non-reinforced concrete.

Principal General Advantages

- They have good load spreading properties and are suitable for weak subgrades
- Can be cost-effective when considering whole life costs
- Low maintenance costs for slabs
- They are robust and able to cope with high vehicle loading,,
- They are resistant to flood erosion,

Principal General Disadvantages and Concerns

- High initial investment cost
- Occasional replacement of bituminous joints as periodic maintenance.

General Issues on Materials

The concrete materials are required to comply with current Cambodian Standards applicable to crushed stone aggregate and cement. Particular note should be taken of the age of any proposed cement

Prior to construction concrete cubes for approval testing should be made using the actually proposed materials, including the water sources.

Steel for dowel bars and the reinforcement mesh or grids must be accompanied by suitable certification as to their source and suitability.

Concrete Pavements: Advantages and Concerns

Description	Principal Advantages	Principal Concerns
Steel reinforced concrete	Suitable for high rainfall and flood prone regions. A preferred option where there is high risk of axle overloading. Minimal maintenance if properly constructed and cured.	Requires expansion and contraction joints often with steel load transfer dowels. Wider pavements may be constructed in two side-by-side panels, however steel ties will be required across the centreline joints. Requires significant curing time following initial construction. This has traffic implications where traffic cannot be easily diverted during work. Potentially the most costly of the options. Susceptible to fluctuation in the price of steel and cement. Requires good sub-base.
Non reinforced concrete	Suitable for high rainfall and flood prone regions. Commonly used option at commune level. Well understood by local small contractors. Minimal maintenance if properly constructed and cured.	Requires expansion and contraction joints often with steel load transfer dowels. Wider pavements may be constructed in two side-by-side panels, however ties will be required across the centreline joints.. May be susceptible to shrinkage cracking unless well constructed and cured. Often requires steel load transfer dowels to be installed at transverse joints, otherwise high risk of problems at joints and slab cracking caused by commercial vehicles. Requires significant curing time following initial construction; traffic implications where traffic cannot be easily diverted during work High cost. Susceptible to price fluctuation of cost of cement. Requires good sub-base
Bamboo reinforced concrete	Theoretically having the same advantages as the above with a lower cost than steel reinforcement. However a recent review of the properties of bamboo reinforcement has concluded that there is no overall benefit in its use over well-constructed non-reinforced concrete[1].	

[1] Rolt, J., Bamboo Reinforced Concrete Pavements. SEACAP 19 Technical Paper 1, 2008

Module 1 Session 2
Self Assessment SA1-2

SA1-2.1 On basis of information given list **one advantage** and **one disadvantage** of each of the following pavement and surfacing options

Option	Advantage -Disadvantage
Unsealed GWC Surfacing	Advantage
	Disadvantage
ENS Surfacing	Advantage
	Disadvantage
Double Bituminous Emulsion Stone Chip seal DBST(E)	Advantage
	Disadvantage
Non-reinforced concrete pavement	Advantage
	Disadvantage
Dressed Stone or Cobble Stone	Advantage
	Disadvantage
Lime Stabilised Base	Advantage
	Disadvantage

Water-Bound Macadam	Advantage	
	Disadvantage	
Mortared Brick	Advantage	
	Disadvantage	
Armoured Gravel	Advantage	
	Disadvantage	

3 PAVEMENT OPTION SELECTION AND DESIGN

◆**SUMMARY**

This module outlines a general approach to the selection and design of LVRRs that is based upon the task the roads have to perform; the environments in which they have to operate; and their anticipated whole life costs. The pavement design process has to be compatible with existing Cambodian Standards and based upon the collection and analysis of appropriate data. The selection of pavement options should take into account not only the immediate construction cost but also their likely maintenance costs – together making up what is termed the Whole Life Asset Costs

◆**CONTENT**

- General approach
- Whole life costing
- Data collection and detailed design
- Drainage

3.1 General Approach

Selection Procedure

The procedures developed for the selection of low volume rural road paving are based on two key principles:

1. The pavements must be fit for purpose in terms of traffic volume and axle loads,
2. The pavements should be compatible with the previously discussed road environment factors.

The above two principles are an extension of the traditional approach to pavement design based on traffic and sub-grade strength. The key issues that need to be addressed in seeking appropriate selection procedures are in particular:

1. The availability and engineering character of construction materials.
2. Erosive climate-terrain environments in some regions,
3. Lack of natural construction materials in some areas,
4. Traffic and axle loading data and constraints on traffic,
5. The construction and maintenance regimes,
6. High water tables and flooding,

7. Impact of earthworks on pavement design in hill/mountain areas,
8. Localised steep gradients,

.

A two phase selection approach has been developed, as follows:

1. Phase I: Identification of appropriate **pavement types** compatible with the road environment.
2. Phase II: **Detailed design** of the selected pavement components (e.g. layer thicknesses) compatible with engineering standards and requirements – i.e. traffic, axle load and sub-grade strength.

Phase I - Key activities

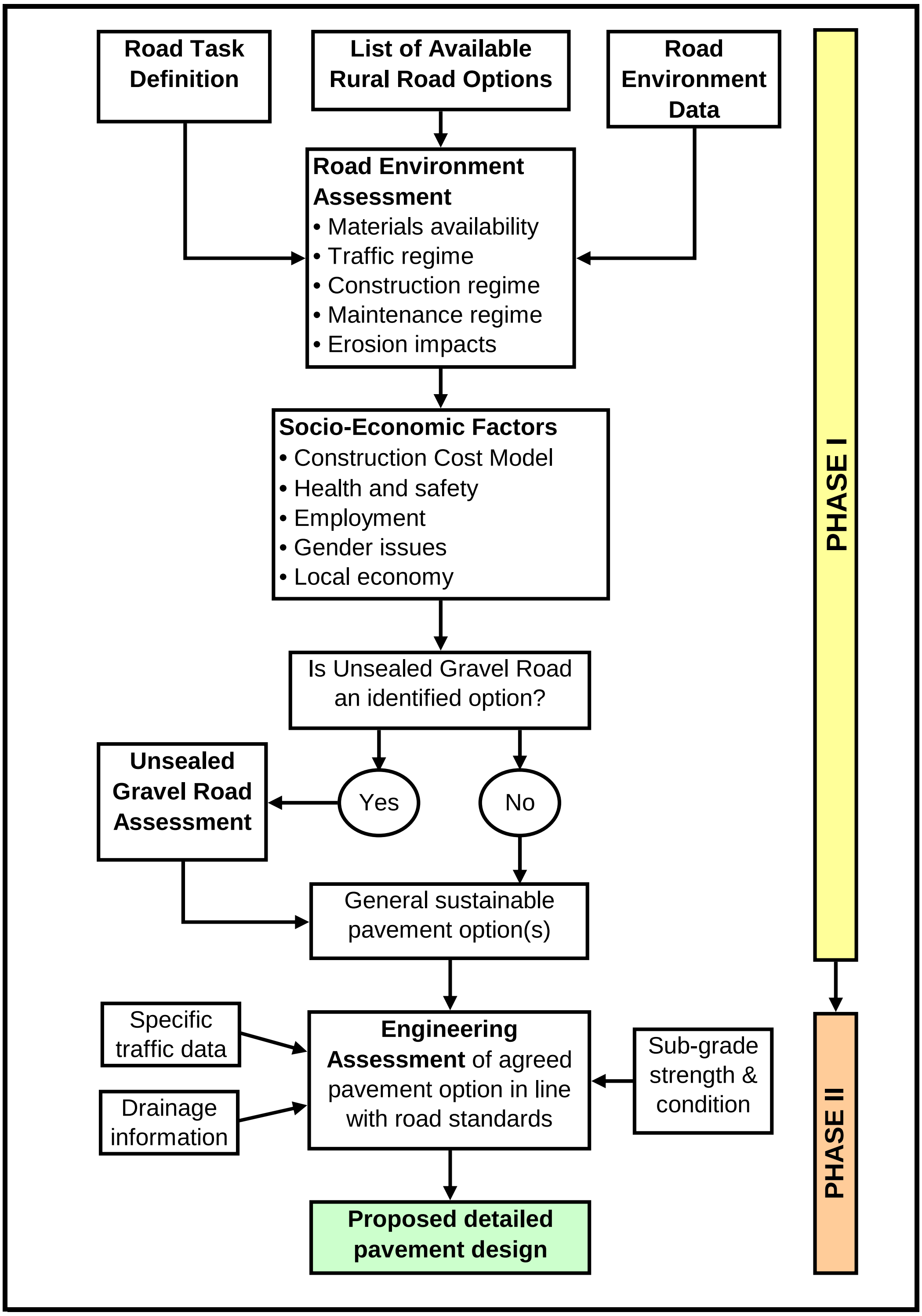
1. Collect all road environment information.
2. Assess all data using relevant matrices and tables and carry forward a shortened list for Social, Economic and Stakeholder Review.
3. If unsealed gravel surfacing is an identified option, refer to the Guidance Gravel Surfacing Selection Flow Chart.
4. Undertake a Social, Economic and Stakeholder Review to produce a final short list of suitable design options and carry this forward to Phase II.
5. The use of a Cost Model is recommended as part of a ranking process in terms of Whole-Life Costs.

.

Phase II - Key activities

1. Where relevant, use appropriate established local Road Standards to define pavement layer thicknesses.
2. Where this is not possible refer to specialist publications (for example SEACAP 1 Reports) on special case options (e.g. bricks, cobble stones, stone setts).
3. Design pavement drainage in accordance with relevant local Road Standards and the assessed drainage requirements..

For special cases, e.g. expected high axle loading, refer to international guidance documentation



Outline of Proposed Rural Road Selection and Design Procedure

Relative Advantages of Pavement Layer Options on Key Issues

	Key Issues												
	Local material use *	**Labour based**	**Ease of construction**	**Maintenance reduction**	**Sustainability**	**Resistance to rain/flooding**	**Load spreading**	**Suitable for small contractors**	**Advantages to local economy**	**Resistance to heavy axles**	**Local employment**	**Whole life cost advantages ****	**Roughness**
Emulsion sand seals	2	1	2	0	x	x	0	1	2	0	1	0	1
S and DBST with emulsion	0	1	2	2	2	2	0	1	2	0	1	2	2
Penetration Macadam	x	x	0	2	2	2	2	0	0	2	0	0	2
S and DBST with hot bitumen	0	2	0	2	2	2	0	2	0	0	x	2	2
Lime stabilised base and subbase	1	0	2	0	1	0	x	1	0	0	x	2	0
Cement stabilised base and subbase	1	0	2	0	1	0	x	1	0	0	x	2	0
Sealed Dry Bound Macadam	0	0	2	2	2	2	0	2	0	2	0	2	2
Sealed Water Bound Macadam	0	0	2	2	2	2	0	2	0	2	0	2	2
Dressed Stone/Cobbles	1	1	2	1	1	2	1	1	1	1	2	0	x
Bricks, Concrete and Clay	1	1	2	2	1	2	1	1	1	2	1	2	2
Sealed Armoured Gravel	2	0	2	2	2	2	0	2	0	x	0	2	2
Un-reinforced concrete	2	1	2	1	1	1	2	1	2	1	0	2	1
Unsealed Natural Gravel	1	0	1	x	x	x	0	1	2	0	0	x	x

Notes 1 = positive advantage; 0 = no advantage or disadvantage; x = definite disadvantage

2 = probable advantage;

* = assuming material available locally ** = Interim performance

3.2 Data Collection

Road Environments Key Data and Collection method

General road environment information must be collected prior to pavement selection and design phases. SEACAP has introduced processing and calculating methods for some original key road environment data as well as recommending standard data summary forms (attached). Following are some notes key data for selection and design:

Climate The total annual rainfall in the area of the road should be established from provincial records or from the department of meteorology can be classed as follows

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

Terrain: Terrain refers to the nature of the land that the road passes through Flat, Rolling Mountainous). It does not refer to each specific curve and hill. Road design in a high rainfall environment requires much attention to this important aspect

Hydrology: Information on apparent water levels and liability flooding can be collected by observation, measurement and investigation as part of the geotechnical surveys.

Sub-grade: Subgrade strength can be measured in two ways, by laboratory or in situ DCP testing. It is recommended that both are carried out when possible and that the results are compared.

Laboratory testing 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 geotechnical 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 for sub-grade is usually assessed at 95% of the maximum dry density obtained under AASHTO modified compaction.

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 existing condition and indicates the strength on the day of the test. It is subject to variation in moisture content and so some allowance for this has to be made. DCP tests take 10-20 minutes and can be carried out at a much closer spacing than soaked laboratory tests, typically 50-100 metres.

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.

Construction materials: The availability of construction materials has a fundamental impact on selection of pavement type and their nature, engineering character and location are essential aspects of any LVRR road assessment.

A fundamental principle, is that appropriate road construction materials need to be selected on a “fitness for purpose” basis; that this is related to their actual service performance. There is need to ensure that materials used are neither sub-standard nor wastefully above the standards demanded by their engineering task.

Materials testing programmes vary greatly in size and scope depending on the type of the road project and associated works. However, even for limited scope LVRR projects, materials testing should not be commissioned on an arbitrary basis, but should be rationally programmed and at the very least aimed at defining service performance in terms of:

- The load bearing capacity of the compacted material,
- Its volume stability in response to soaking-drying,
- Its component particle strength and durability (granular materials).

Where genuine material problems or shortages exist, it is the responsibility of the road designers to overcome the issue by a combination of:

- Adapting the specification and road design to suit local materials (e.g. thickening pavement layers, raising compaction levels, sealing shoulders),
- Adapting or modifying the materials to suit a realistic specification (e.g. mechanical or chemical stabilisation).

Traffic regime: Consideration needs to be given to the influence of traffic on the performance of the structure, including vehicle types, size, loading and user behaviour In order to collect these data, it requires to undertake traffic counts on all originally designated base on 12 hours – 3 days by manual traffic counts method using the standard traffic count form. A 12 hours – 7 days count is usually recommended when there is a significant variability of traffic.

3.3 Data Analysis and Summary

After collection, the original key road environment data need to be calculated and summarized to allow easy access for design input.

Sub-grade Strength Calculations

The Sub-grade strength can be assessed based on relationship formula between DCP reading and CBR. Relationships between CBR and MR (Modulus of Resilience) are also available .

Traffic Volume Calculation

From completed forms in site, these the daily average flow counts for each vehicle type should be calculated and then converted into an equivalent daily traffic using the factors in the following table to determine the Average Daily Traffic (ADT).

If traffic is known to pass at night, then a multiplication by 1.2 should be applied to estimate the 24 hour count; if no traffic passes at night, the 24 hour count equals the day count.

Traffic Counted	ADT Factor
Truck>5t	5
Large Bus	5
Truck <5t	2.5
Small Bus	2
Motor cycle trailer	1
Car	0.8
Animal	0.2
Motorcycle	0.1
Bicycle	0.05
Pedestrian	0.02

Correction factors for Traffic Conversion to ADT: (Based on ORN 20, TRL, 2000)

3.3 Data Analysis

After collecting, processing and sumarising, the key original environment data form the base to facilitate design engineers to analyse and present optimum design..

Material Characteristics Analysis

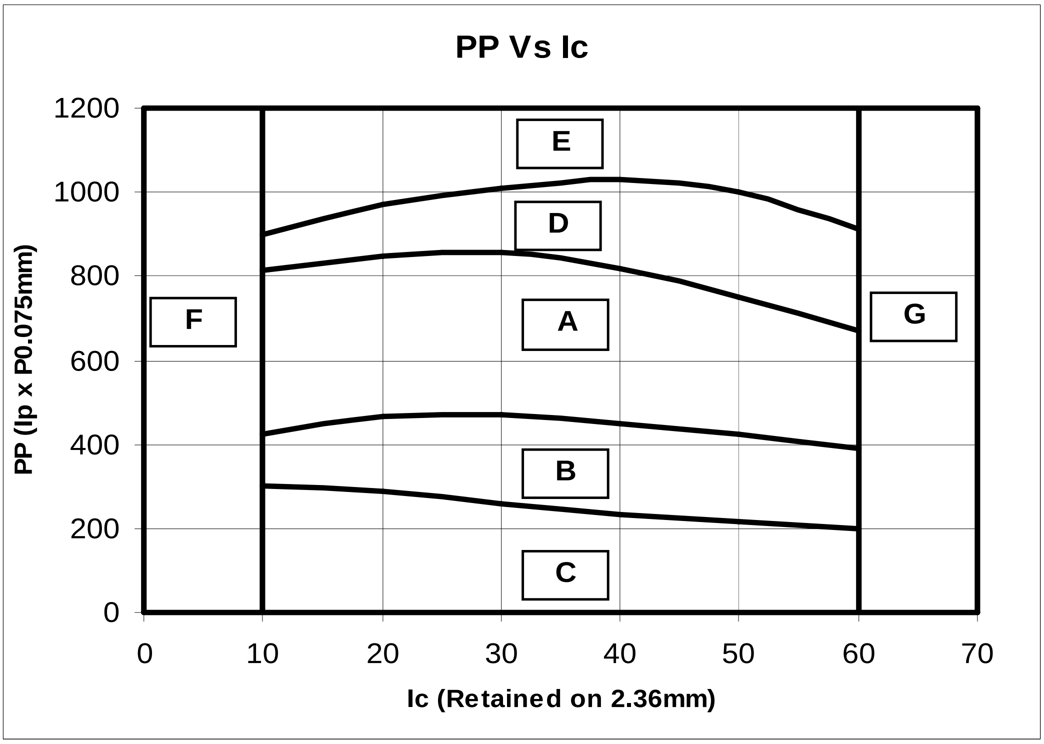
Design solutions and quality of the structures greatly depends on material characteristics and so it requires accurate analysis and assessment. As for lime/cement/ emulsion stabilised or gravel options, the material characteristics very much depends on their grading and plasticity characteristics. The following presents the general guidance on the selection of appropriate methods of treatment for natural materials based on their grading and plasticity characteristics. The usual range of suitability for applying the various types of stabilisation is defined by the percentage of material passing the 0.075mm sieve and the Plasticity Index (PI) of the soil.

For gravel material suitability, the assessment of test results bases on plasticity index and grading such as:

Plasticity Product (PP) Plasticity Index **X** % material passing 0.075mm sieve
Plasticity Modulus (PM) Plasticity Index **X** % material passing 0.425mm sieve

Grading Modulus (GM) (% passing 26.5mm – % passing 2.00mm) **X** (% passing 4.74mm)/100

Experience has indicated that value of these indices as material assessment criteria and the following Figure, which utilises the Plasticity Product value has proved useful in other regions

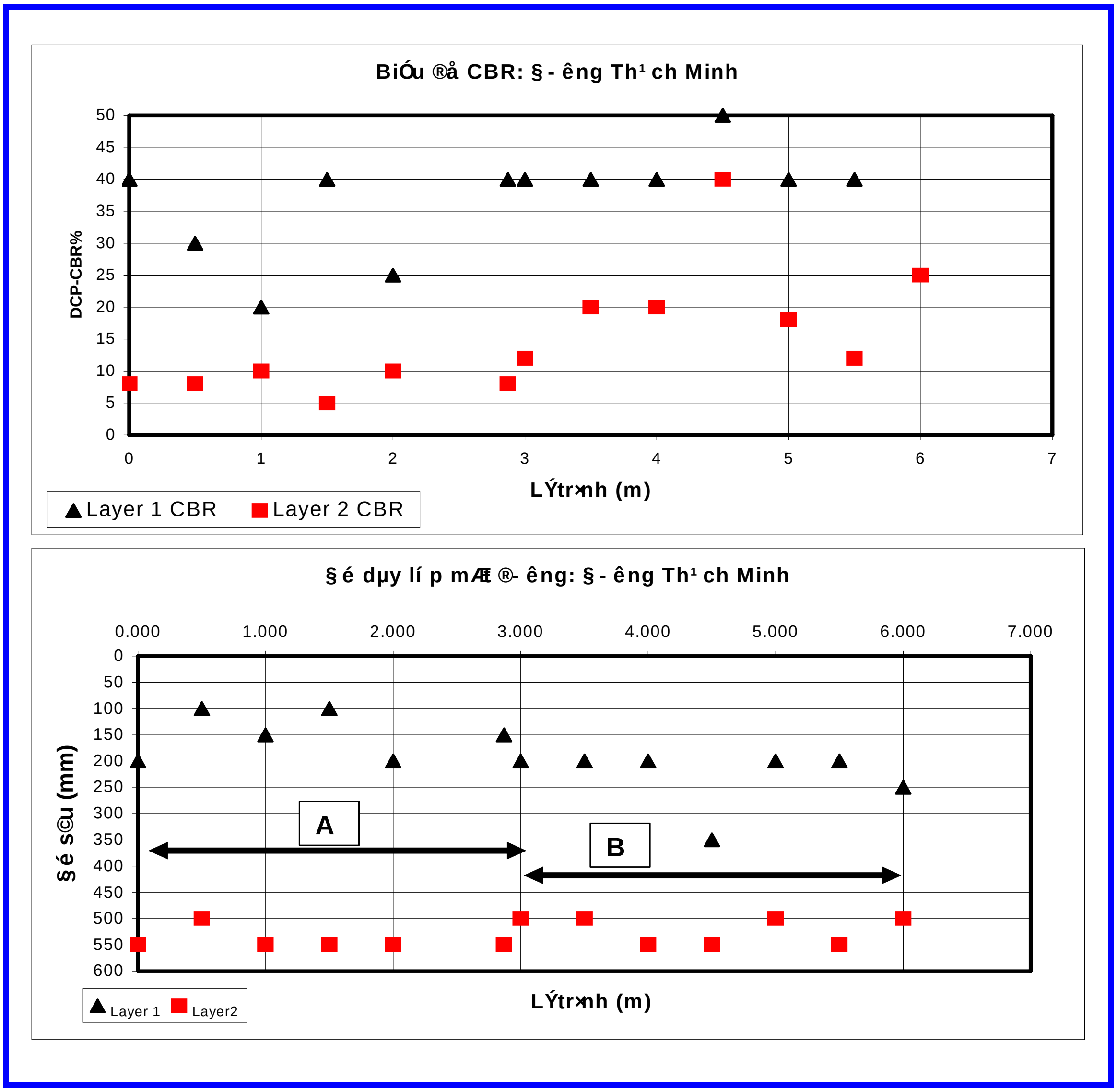


A:	Good performance under wet and dry conditions
B	Good performance under wet conditions; corrugates in dry conditions
C	Lacks cohesion: rapid deterioration with trafiic
D	Good in dry conditions; slippery in wet; potholes/erosion
E	Poor in both wet and dry conditions
F	Too coarse: erodes badly; difficult to maintain
G	Too fine; trafficability problems in wet and very dusty when dry

Plasticity Product and Particle Size Assessment

Sub-grade Data Analysis.

Design solutions also very much depend on subgrade data such as current pavement/base condition and strength. In the RRST programme, the analysis of in situ DCP test based on the setting up of relationship charts between CBR and depth allows the assessment of strength and thickness of the existing pavement layers on individual road as shown below



: Analysis of insitu pavement strength test result using DCP apparatus

Notes:

Section A Variable residual gravel surface (minimum in situ CBR 20%); existing sub-grade in situ CBR 7%.

Section B: Consistent residual gravel surface allow for minimum in situ CBR 35%; existing sub-grade allow for minimum in situ CBR 12-15%.

Traffic Data Analysis

Analysis of traffic count data is not only the assessment of average daily traffic (ADT) but also type of key traffic vehicles operating on the road from which it is possible to present design solutions suitable to geometric dimension of the route; for e.g. the shoulder should be made wider if traffic counts show significant number of pedestrians on that road.

Rainfalls and Terrain Data Analysis

The rainfall and gradient data can be analysed with aspects in relation to drainage capacity, erosion and material loss condition of unsealed gravel/crushed stone pavements. Erosion potential can be defined taking into account the gradient and rainfall as below.

	Annual Rainfall (mm)			
	<1000	1000-2500	2500-4000	>4000
Gradient				
Flat <1%	A	A	B	C
Moderate 1-3%	A	B	B	C
High 3-6%	B	C	C	D
Very High >6%	C	C	D	D

Erosion Potential		
	A	Low
	B	Moderate
	C	High
	D	Very High

Definition of Erosion Potential

Collection and Summary data Sheets for Design Input

A1: Road condition Survey Sheets

A2: Road data Summary Sheets

A3: Laboratory Test Summary Sheets

A4: Traffic Count Sheets

Initial Road Survey — **Sheet number /**

Chain	General	E'Work	Shoulder L	WTL	WTR	Shoulder R	E'Work	General	Condition	Material	Gradient	Curve

Road Name

GPS Start	N
	E
GPS End	N
	E

Surveyor		Date	

LEGEND

- Houses
- Bridge
- Culvert
- Road
- **W** Surface water
- **R** Rice field
- Ditch

E'Work
E - Embankment
C - Cutting
N - None

D DCP
S Sample
M Material source

Material
E - Earth
S - Sand
Cl - Clay
Gr - Gravel-cobble
BS - Bitumen

Access Condition
1 - Excellent 2WD
2 - 2WD in dry season
3 - Fair 4WD all weather
4 - Poor 4WD in Dry
5 - Failed - Not passable

Gradient
a - <0%
b - 0-2%
c - 2-4%
d - 4-6%
e - 6-8%
f - >8%

Comments

Road condition survey form

Province:
Road Name:

Rainfall: 1600-1800
Traffic: ADT 434

Section	From	To	L (m)	Ch	L1 CBR	L2 CBR	L1 Thick (mm)	Depth L2 (mm)	Min Thick L2 (mm)	Flooding	Gradient	Sub-Grade	Pavement Widths L/CW/R	Pavement Condition	Existing Pavement	Comment
1		0.000	0.000	0												
2	0.000	0.100	0.100	100	50	5	150	450	300	No	0	Soft grey clay	2/3.5/2	1	Gravel	
3	0.100	0.350	0.250	350						No	0	Soft grey clay	1.5/3.5/2	1	Gravel	
4	0.350	0.450	0.100	450						No	0	Soft grey clay	1.5/3.0/1	1	Gravel	
5	0.450	0.500	0.050	500	20	4	150	600	450	No	0	Soft grey clay	2/3.5/2	2	Gravel	
6	0.500	0.570	0.070	570						No	0	Soft grey clay	2/3.5/1.5	2	Gravel	
7	0.570	1.350	0.780	1350	40	4	200	500	300	No	0	Soft grey clay	1.5/3.5/1	2	Gravel	
8	1.350	1.500	0.150	1500						No	0	Soft grey clay	1/3.0/1	3	Earth	
9	1.500	1.600	0.100	1600	12	2	150	550	400	No	0	Soft grey clay	1/2.5/1	3	Earth	Eworks
10	1.600	2.000	0.400	2000	12	4	150	500	350	No	0	Soft grey clay	0.75/2.5/0.75	3	Earth	Eworks

Road Data Summary Sheet

Laboratory Summary

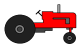
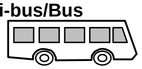
	Sieves Size - D (mm) / Passing percentage - P (%)									MDD	OMC	W	WL	Wp	Ip
Chain	**50.0**	**37.5**	**19.0**	**9.50**	**4.75**	**2.00**	**0.425**	**0.075**	**0.002**	g/cm3					
0.000												8.8	23	17	6
0.250												23	33	21	12
0.500	100.0	100.0	100.0	99.8	97.6	95.7	93.2	88.9	20	1.55	15	24	35	21	14
1.000												37	23	17	6
1.500												31	52	36	16
2.000	100.0	100.0	100.0	77.7	66.5	58.0	50.2	43.9	5	1.87	9.6	8.8	46	27	19
2.245												15	46	27	19

Laboratory test summary form

FORM : Manual Classified Traffic Count

Province		**SURVEYOR**	
District		**LOCATION**	

Daily 12 hour counts ***DATE***

Traffic Class						**Daily Average**
MOTORCYCLE 						
CAR, 4WD, PICKUP 						
Tractor 						
LIGHT TRUCK =< 5 TONS GVW 						
TRUCK > 5 T (2 axle) GVW 						
TRUCK > 5 T (3 axle +) GVW 						
Mini-bus/Bus 						
PEDESTRIAN, WALKER						
ANIMAL/HAND CART 						
BICYCLE 						
TOTALS						
Rain This Period?						

Daily Survey Period: 6.00 hours to 18.00 hours

GVW = Gross Vehicle Weight

Classified Traffic Count

E3.4 Costing and Whole Life Costs

Objective

Cost calculation is a very important that in project development. It helps the funding agency (Ministry, Local Authority or Donor) to have the construction cost estimation as a basis to prioritise infrastructure options, select the appropriate design and assess competitive bids.

The basic steps of cost calculation include:

- Set up Bill of Quantity using available cost data or Cost Norms
- Cost unit analysis
- Detail of cost estimate
- Summary of construction cost estimate
- Calculating other costs

Cost Norms and the RRST Pavement Options

The outcome of the SEACAP research in Vietnam will be used to illustrate the potential use of cost norms in Cambodia.

Construction Norms are the legal basis for construction cost estimation in Vietnam. Most of the SEACAP pavement options did not have official Cost Norms, therefore, they had to be developed as a basis for the cost estimation of the trial roads on the following principles:

- New cost norms were created for the new options (eg Block Pavements)
- Some related available cost norms were used without any adjustment (eg Unsealed Gravel)
- Some related available cost norms have been adjusted to fit the new construction techniques and trial characteristics (Dry-Bound Macadam)

Whole Life Costs

Introduction

In order to select the most appropriate surfacing option for a rural road, beside the consideration of its performance in a limited road environment, much importance should be paid to the cost estimation of that option. A universally accepted method for defining the costs is used the concept of “Whole Life Costing” which considers costs such as construction, maintenance and vehicle operation over the ‘life’ of the road.

There are two approaches to the assessment of whole life costs for rural roads, which each reflect discrete objectives, and may result in different conclusions depending on the local circumstances. These can be characterized as:-

a) **Whole Life Costs** for the Road Asset

b) **Whole Life** Transport **Costs**

Whole Life Road Asset Costs assessment would aim to minimize the costs of **Construction** and **Maintenance** of a particular road and pavement over a selected assessment period. This assessment would be of interest to an asset manager such as a PDoT, particularly in a severely constrained resource environment.

A Whole Life Transport Cost assessment would bring in the component of user **Vehicle Operating Costs (VOCs)**, and may include other economic or socio-economic factors (e.g. user time savings, socio-economic or environmental impact). This assessment would be of more interest to, for example, national policy makers, planners and development agencies.

Any assessment will only be as good as the data and knowledge used in the relationships incorporated in the evaluation. The confidence in the construction cost data, for example, may be high. However, the knowledge and confidence are poor for both maintenance cost components of various road surface options and user Vehicle Operating Costs (VOCs). The latter aspect is particularly likely to be uncertain regarding the effects of different road conditions within Cambodia.

Whole Life Cost of Road Asset

Whole life Asset Costing is a process of assessing all cost associated with an investment over its intended (initial) or design lifetime. The aim is to minimize the sum of these values to obtain the minimum overall expenditure on the asset, yet achieving an acceptable level of service of the asset. The principal cost components are the initial investment or construction cost and the future cost of maintaining (or rehabilitating) the asset period selected (for exsample 12 years from construction)

Any rehabilitation cost will need to be included in total cost. Usually an assessment of the residual value of the asset at the end of the assessment period is included to incorporate the possible different consequences of construction and maintenance strategies for the pavement and surface options investigated.

From an economic evaluation viewpoint, an important decision is the reduction in value that is assigned to future costs. A discount rate is usually used to reflect future cost and benifits. In this way a dollar spent after one year is only value at 90 cents at a discount rate 10%. Similarly, a dollar expected to be spent after two years is value at only 81 cents in current terms. The decision on discount rate selection is usually base on a combination of policy and economic considerations. In some industrialized countries the discount rate for public investment is 7%. Several international funding agencies use a rate of 12%. In the absence of specification by the responsible authority, figures of around 10% are often used.

Construction costs

Construction costs are available from previous contracts throughout the country. For whole life costing purposes it would be very useful to regularly compile these costs on a regional basis, and Brocken down for each surface and paving option. In view of the high variability of energy/transport and materials costs the data should also be compiled by year so that any inflation cost adjustment can be made. Refinement could later be incorporated for such factors as size of contract, remoteness from main administrative center. etc, as these aspects usually influence the overall cost of work.

Maintenance costs

The maintenance required on a LVRR is a function of the rate and the nature of road deterioration, and is best predicted based upon empirical knowledge.

Before coming to a final decision on the selection of a pavement or surface type, **it is advisable to assess the future maintenance requirements** of the option being considered and to decide whether or not there is a likelihood of this level of maintenance being resourced (financially and physically) and being arranged in a timely manner.

It is the analysis of the trade off between initial and recurrent coststhat is crucial. Both of which must fit within the resource and capacity anvelopes of the road authority.

Maintenance for LVRRs can be categorised principally as Routine and Periodic

A pragmatic assessment of the costs of the maintenance operations and the excepted maintenance resources and capacity are needed to achieve a realistic WLC assessment.

Residual value

WLC assessment requires valuation of asset in monetary terms. Each road investment still has an economic value to transport network beyond the analysis period. Realistic estimation of residual value of the asset is essential for the evaluation of WLC. Over-estimation this residual value will lead to lower WLC and may result in selecting less effective option.

Whole Life Transport Costs

The Whole Life Costs of rural roads in terms of national and community interests should include an assessment of “whole Life Transport Costs” vehicle whole life costs savings for road interventions or maintenance strategies, i.e. with the aim to minimize the sum of Road Asset Construction costs, Road Asset Maintenance costs, Vehicle Operating Costs (VOC) over the selected assessment period.

The RRST Cost Model

Introduction

A decision support cost model has been designed based on MS-EXCEL spreadsheets in order to provide rural road authorities and design consultants with a supportive tool for their road surface and pavement selection process. The Cost Model is an output of the RRST-1 programme. The model introduces a menu of appropriate rural road pavements with the whole life cost details (construction and maintenance costs for road managers)[1] of each option, suggesting the most appropriate options for each defined local road environment. The initial menu is based on the research findings of the RRGAP, and RRST-1 and RRST-II trials. It is expected that further options will be added in later model versions based on other investigations.

1 The cost model has been designed with the intention that a later edition will be able to accommodate an optional Vehicle Operating Cost sub-model.

The cost calculation method within the model is pursuant to the current decrees and documents issued by the Government. Thus the model is also very helpful in preparing cost estimates.

The essential input for the model

Natural factors – which are to an extent uncontrollable:

- Sub-grade geological and hydrological conditions:
  - Types of soil,
  - Strength
  - Flood regime
- Road alignment longitudinal gradient,
- Terrain (mountainous, midland, plain etc.), related to region,
- Annual rainfall (impact to deterioration rates of some types of pavement), related to region,
- Material sources and haulage distances to the site.

Man-made factors - controllable:

- Traffic volume
- Axle load

Expected outputs

- Construction cost of the selected option per km (with defined surface width),
- Maintenance cost per km in terms of present cost,
- Maintenance cost per km in terms of NPV.
-

Types of Pavement

There are currently 27 pavement options that may be selected within the model. From the RRST investigations and trials, they are some of the most appropriate options for the rural road sector in the region; they have been successfully proven and used in many countries

.

The Model Function

Input and Output

The model is set up on the sheet “Data input and output screen”. This page provides the necessary tools to input the data or select the road environment parameters. Various road environment parameters can be selected at some **yellow** fields which appear on a scroll arrow when clicking at the right hand side. Other **yellow** fields will be used for inputting data such as material prices, haulage distances etc. Other fields will be kept untouched [2].

[2] To avoid any change of formulas at the key fields by accident, these fields will be locked.

After selecting the equivalent road environment parameters and inputting the required data, select the yellow fields within the **"Type of Pavement"** column, then click the scroll arrow to choose one of the pavement options in the list. The related information of the selected pavement option such as construction cost, maintenance cost and whole life costing chart etc. will be displayed at the same page.

The page will also provide the notices and recommendations of using different pavement options for the certain road environments at the **Red** fields**.** The recommendations are pointed out based on the “codes” of flood regimes, annual rainfall, gradients and soil types used for sub-grade (refer to the index).

Road Maintenance in the model consists of two principal calculated cost components:-

Routine Maintenance, and

Periodic Maintenance

These are added together to calculate Total Maintenance Costs. Emergency maintenance is considered to be accommodated in the adjustment for routine maintenance discussed below.

Routine Maintenance is calculated in two sub-components:-

Routine Maintenance based on the cost Norms, plus

Routine Maintenance grading for earth or gravel roads only

The first sub-component is based on the current MoT **Routine Maintenance Norms.**

This page accommodates the current norms for routine maintenance and management issued by the MoT which can be used to calculate routine maintenance costs. These Norms are considered to require updating and extending to reflect actual maintenance needs and costs for a wide range of conditions. However, for the purposes of the Initial model version, they will be used as the basis for calculating Routine Maintenance costs. However, a **20%** increase in the costs calculated according to the Norms will be made to allow for the costs of planning and supervising the maintenance works including quality control, and any emergency maintenance works required. It is also necessary to add a cost sub-component for routine maintenance grading.

The MoT Routine Maintenance Cost Norms do not include an item for the activity of camber reshaping or grading. This is an essential component of earth and gravel road maintenance (recognized by PIARC[3] and many national road agencies). One of the problems of gravel roads in Vietnam is that this need is not recognized at design stage, nor in maintenance funding and implementation arrangements. The cost of this grading is calculated and added to the Maintenance costs discussed above

The periodic maintenance costs will be difficult to determine for the new pavement types until the results of the long term monitoring of the RRST are available. However the RRGAP investigations allow the Periodic Maintenance costs of **gravel/laterite** to be assessed in the initial version of the model.

From the RRGAP data the following rates of annual gravel loss have been assessed to be appropriate for various conditions in Vietnam, Table 2. Figure 1 and figure 2 are example of applying Gravel Loss Matrix for gravel loss analysis.

3 PIARC (World Road Association) International Road Maintenance Handbook.

Gravel Loss Matrix for Use in Rural Roads Cost Model

Annual expected Gravel Loss to be computed from Basic Gravel Loss (1.) adjusted for Regional (2.) and General (3.) Factors.

Terrain Region		**Low delta/coastal Subject to flood**	**Low delta/coastal Minimal flood**	**Inland Flat**	**Rolling small hills**	**Hilly and mountainous**
1. Basic Gravel Loss (mm/year)		40	25	30	20	35
Key Regional Factor		Poor quality material	Poor quality material	Poor quality material	Gradient	Sheet erosion (See Note I)
2. Adjustment to Basic Loss for Regional Factor		+15mm/year	+5 mm/year	+10 mm/year	2-4%: +5 mm/year 4-6%: +10 mm/year	A: +5mm/year B: +15 mm/year C: +30 mm/year
3. Further General Adjustments	3.1 Maintenance guaranteed	-30%	-30%	-30%	-30%	-30%
	3.2 Traffic Level					
	B1	+10%	+10%	+10%	+10%	+10%
	A3	+15%	+15%	+15%	+15%	+15%
	A2	+20%	+20%	+20%	+20%	+20%
	A1	+25%	+25%	+25%	+25%	+25%

Gravel loss figures based on 90% confidence level assessment of RRGAP gravel loss data

Gravel Loss Table Notes

Note I:

Sheet erosion definition; A = Gradient <2% subject to minor sheet flooding
B = Gradient 2-4% subject to regular sheet flooding
C = Gradient >4% subject to regular sheet flooding

Sheet flooding means that water covers the road surface due to flooding from surrounding ground and not just the rainwater that falls directly on the road surface.

Note 2: Data figures were recovered from provinces with annual rainfall below 3000 mm/year.

Note 3: The Table figures assume a general compliance with construction specifications.

Note 4: "Maintenance guaranteed" assumes that all drainage system and camber maintenance are arranged regularly to keep the road surface crossfall between 3 and 7%.

Note 5: Does not apply to coarse grained crushed stone macadam.

The annual gravel loss using the above matrix will be calculated by the model for each year and accumulated to subsequent years. When the reducing residual gravel thickness is predicted to decrease to less than 80mm in any year, the model will calculate the cost of providing additional gravel to bring the layer thickness back to the Design thickness AT THE BEGINNING OF THAT YEAR, and calculate and record it as a periodic maintenance cost for that year. The model will reset the thickness to the design thickness at the beginning of that year and start loss calculations again for that and subsequent years.

An option for **no maintenance** will be available in the model to show the affects of routine and periodic maintenance not being funded or provided in an effective way. It will also show the effects of inadequate drainage (either in respect to original provision or drainage maintenance). In this case the residual gravel thickness will be calculated each year, however when the residual gravel thickness reaches zero (0), the road will be shown to be re-constructed at the appropriate cost by the model in the following year.

Pending the results of the RRST long term monitoring, for **paved road** types incorporating bitumen, concrete or brick, the periodic maintenance costs will be entered as 5% of the initial costs of construction of the pavement layers only, and applied at a timing of 10 years after the construction of the pavement.

For the **unsealed pavement types** (other than gravel/laterite), this includes cobble stone paving, hand packed stone, water bound macadam, etc., the periodic maintenance costs will be entered as 7% of the initial costs of construction of the pavement layers only, and applied at a timing of 6 years and again at 12 years after the construction of the pavement.

Residual value of the pavement

The residual value of the pavement at the end of the analysis period is an important factor in the asset Whole Life Costing. This will be calculated as follows:

For gravel/laterite road surfaces the residual value will be the residual gravel thickness divided by the initial constructed thickness. This figure is then multiplied by the value (cost) of the initial constructed thickness of gravel surfacing for the analysis section of road.

For other paving types the residual values will be calculated as the following percentage of the initial constructed value of the **full** pavement layer. That is everything constructed above the subgrade level, but excluding shoulders.

Code	Type of road surfaces	Recommended Residual Value after 15 years (percentage)
C1	Steel reinforced concrete on Natural gravel sub-base	70
C2	Steel reinforced concrete on Lime stabilised sub-base	70
C3	Steel reinforced concrete on Cement stabilised sub-base	70
C4	Steel reinforced concrete on sand sub-base	70
C5	Bamboo reinforced concrete on sand sub-base	70
C6	Bamboo reinforced concrete on Lime stabilised	70
C7	Bamboo reinforced concrete on Cement stabilised	70
C8	Non-reinforced concrete on Natural gravel	70
C9	Non-reinforced concrete on Lime stabilised sub-base	70
C10	Non-reinforced concrete on Cement stabilised sub-base	70
C11	Emulsion seal on Lime stabilised	40
C12	Emulsion seal on Cement stabilised	40
C13	Emulsion seal on Emulsion stabilised	40
C14	Emulsion seal on Dry bound macadam sub-base	50
C15	Emulsion seal on Natural gravel with Amoured	50
C16	Two layers bitumen seal on Water bound macadam	60
C17	Sand seal on Concrete brick on Dry bound macadam	70
C18	Sand seal on Concrete brick on Natural gravel	70
C19	Burnt clay brick on Lime stabilised	60
C20	Burnt clay brick on Cement stabilised	60
C21	Emulsion sand seal on Burnt clay brick on Lime stabilised	60
C22	Emulsion sand seal on Burnt clay brick on Cement stabilised	60
C23	Mortar Dressed stone on Natural gravel sub-base	60
C24	Bitumen penetration macadam 6cm	60
C25	Water bound macadam	50
C26	Natural gravel surface/laterite	Calculate from Table 2

Road Enviroment Codes

3.5.1 Traffic and Axle load

Ref	Equivalent standard axle	Classification of estimated traffic volume	Class of loading	Code	Number of vehicle passes during design period
1	6T	High traffic volume	A1	I	> $15x10^5$
2	6T	Medium traffic volume	A2	II	5 – $15x10^5$
3	6T	Low traffic volume	A3	III	< $5x10^5$
4	2.5T	High traffic volume	B1	I	> $15x10^5$
5	2.5T	Medium traffic volume	B2	II	5 – $15x10^5$
6	2.5T	Low traffic volume	B3	III	< $5x10^5$

Note: If vehicle passes during the design period will exceed $5x10^5$, or heavy truck traffic is expected on the road (axle loads >10t), then:-

i) gravel will probably not be a viable surfacing option, and

ii) road pavements will require specific engineering design.

Flooding regime defined as follows:

I: No flooding
II: Sometimes (gravel may not be suitable)
III: Annual but small (gravel not suitable)
IV: Annual and big (gravel not suitable)

Local Soil

SS: Sandy soil
CS: Clayey soil
Gr: Gravel

Road Environment Codes

Codes in fact are the parameters which help the model bring about recommendations for using the selected pavement options.

1: Most suitable
2: Possible but may not be ideal
3: Not recommended

3.5 Pavement Drainage

Importance

Pavement drainage is frequently emphasised in design manuals as being of the utmost importance, however, recent research has confirmed that although this importance is widely recognised by rural road practitioners there is a significant problem in applying drainage principles in construction and maintenance practice. Commonly observed problems include:

- Inappropriate “boxed-in” pavement design
- Missing and poorly maintained side drainage
- Insufficient or badly sited cross drainage (culverts)
- Lack of maintained road shape (cross-fall) on unsealed roads
- Build–up of vegetation and debris on shoulders preventing adequate run-off.

Any one of the above factors will adversely impact upon perhaps the most important single aspect in road design; the protection of the road from surface or ground water.

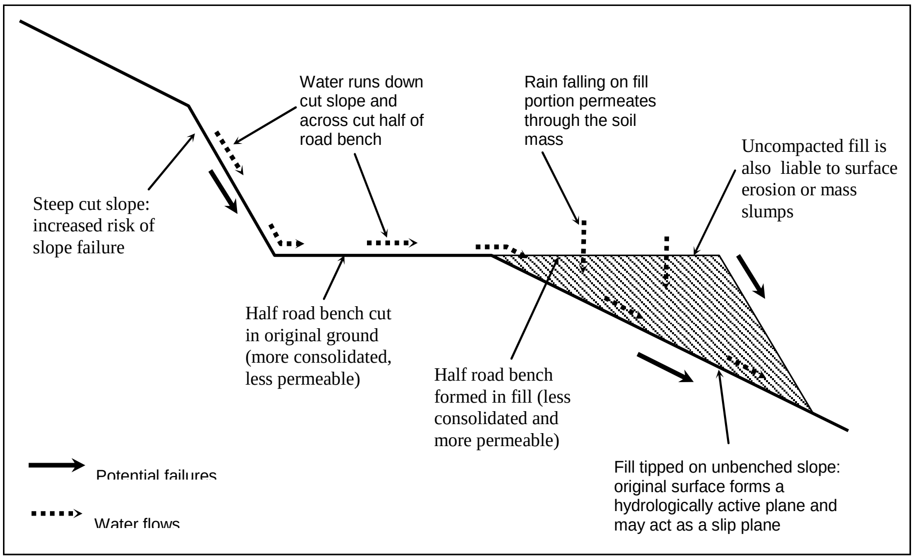
A good road drainage system, which is properly maintained, is vital to the successful operation of a road. It has four main functions:

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

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

There are also significant drainage issues related to the maintenance of earthwork stability. This is of particular importance in hilly or mountainous terrain where poor drainage can have severe consequences on the provision of all-year access, with significant consequences for the rural communities for which the LVRRs are designed to serve.

Typical Water Impacts on Mountainous Road Section



Carriageway Drainage

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

Provided the crossfalls are adhered to and the bituminous surfacing and the shoulders are properly maintained, rainwater falling on the road will be shed steadily over the shoulders. When permeable roadbase materials are used, particular attention must be given to the drainage of this layer. Ideally, the roadbase and sub-base should extend right across the shoulders to the drainage ditches, this has however significant cost implications.

If it is too costly to extend the roadbase across the shoulder, the sub-base should be extended to the shoulder and consist of a material that is able to carry water away to the side ditches by providing a continuous drainage layer of pervious material.

The 'trench' type (or boxed-in) cross-sections in which the pavement layers are confined between continuous impervious shoulders should not be used. If this type of design is unavoidable, drainage grips of graded granular free draining material, 300mm wide and extending from under the base and for the full depth of the sub-base layer under the shoulder are recommended every 5 metres.

In circumstances where the subgrade itself is permeable and can drain freely it is preferable that vertical drainage is not impeded. This is achieved by ensuring that each layer of the pavement is more permeable than the layer above. In these circumstances, the additional drainage layer through the shoulders is not required.

External Drainage

Both in the design and in 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 re-alignment (often resulting in sharp changes in direction) should be avoided. The surface flows in drains and culverts should also be kept to a minimum by the use of frequent turnouts where side drains cannot be discharged to existing watercourses. In sidelong ground, where discharge from the side drain on the high side passes to the low side, it is best to use frequent small culverts rather than occasional large ones.

Suitable guidance for LVRR side ditches and cut of drains is given in 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.

Module 1 Session 3
Self Assessment SA1-3

1. List 3 key activities to be undertaken as part of the Phase 1 of the Pavement Option and Design procedures

1
2
3

2. What is the likely gravel loss in mm/year to be designed for in unsealed gravel roads in the following physical environments.

1 Low lying flood area	mm/yr
2 Flat inland	mm/yr
13. Rolling hills	mm/yr

3 List 5 key inputs required to assess Whole Life Asset Cost for LVRRs

1
2
3
4
5

.4 – Complete the following table based on your own local conditions.

	Key Issues												
	Local material use *	**Labour based**	**Ease of construction**	**Maintenance reduction**	**Sustainability**	**Resistance to rain/flooding**	**Load spreading**	**Suitable for small contractors**	**Advantages to local economy**	**Resistance to heavy axles**	**Local employment**	**Whole life cost advantages ****	**Roughness**
Emulsion sand seals	2		2	0	x		0	1	2		1	0	1
S and DBST with emulsion	0		2	2	2		0	1	2		1	2	2
Penetration Macadam	x		0	2	2		2	0	0		0	0	2
S and DBST with hot bitumen	0		0	2	2		0	2	0		x	2	2
Lime stabilised base and subbase	1		2	0	1		x	1	0		x	2	0
Cement stabilised base and subbase	1		2	0	1		x	1	0		x	2	0
Sealed Dry Bound Macadam	0		2	2	2		0	2	0		0	2	2
Sealed Water Bound Macadam	0		2	2	2		0	2	0		0	2	2
Dressed Stone/Cobbles	1		2	1	1		1	1	1		2	0	x
Bricks, Concrete and Clay	1		2	2	1		1	1	1		1	2	2
Sealed Armoured Gravel	2		2	2	2		0	2	0		0	2	2
Un-reinforced concrete	2		2	1	1		2	1	2		0	2	1
Unsealed Natural Gravel	1		1	x	x		0	1	2		0	x	x

4 PAVEMENT CONSTRUCTION

◆**SUMMARY**

This module presents key issues relating to the construction of LVRR pavements and associated drainage. The need to comply with the design specifications is of a paramount importance not only in regard construction materials abut also in respect of construction plant and construction procedures. There is clear need to improve the quality control on rural road construction and this module highlights important issues to be considered.

◆**CONTENT**

- Specifications
- Construction plant and procedures
- Quality control
- Whole life management

4.1 Specification Compliance

Pavement Specifications

The construction of road pavements should be governed by adherence to the relevant contract specifications. These specifications should be:

1. Clear and understandable
2. Appropriate to the local road environment
3. Capable of being applied by local contractors
4. Aimed at producing a technically sustainable road
5. Cover all relevant technical and cost issues
6. Compatible with overall Cambodian regulation

Contract specifications normally cover the complete range of activities required to complete the construction of a required road in a satisfactory manner. Key activities include:

- Site preparation
- Setting out and surveying
- Pavement construction plant and procedures
- Construction materials
- Drainage
- Structures

In this discussion we are concerned primarily with construction materials and construction plant and procedures.

The SEACAP programmes have produced a series of pavement specifications for use with the trialled options – see RRST Construction Guidelines Section 3.

Typical Pavement Specifications

Reference	**Specification**
RRST 1-01	Bituminous Emulsion – Surface Dressing Chip seal
RRST 1-02	Bituminous Emulsion – Sand Seal
RRST 2-01	Gravel Sub-Base/Base
RRST 2-02	Lime Stabilised Sub-Base/Base
RRST 2-03	Cement Stabilised Sub-Base/Base
RRST 2-04	Emulsion Stabilised Sub-Base/Base
RRST 2-05	Armoured Gravel Roadbase
RRST 2-06	Sand Sub-Base
RRST 2-07	Quarry-Run Sub-Base
RRST 2-08	Graded Crushed Stone Sub-Base/Base
RRST 2-09	Sand Bedding Layer
RRST 2-10	Dry Bound Macadam Sub-Base/Base
RRST 3-01	Fired Clay Brick Pavement – Unmortared Joints
RRST 3-02	Fired Clay Brick Pavement – Mortared Joints
RRST 3-03	Cement Brick Pavement – Mortared Joints
RRST 3-04	Cobble Stone Paved Surface
RRST 3-05	Mortared Dressed Stone
RRST 4-01	Bamboo Reinforced Concrete
RRST 4-02	Steel Reinforced Concrete
RRST 4-03	Non-Reinforced Concrete

Construction Materials Specifications

A key objective in sustainable road construction is to best match the available construction material to its function in the road within its local environment. The effective use of natural resources enables a better and more sustainable rehabilitation of rural infrastructure within limited budgets.

The ability of the material to perform its function in the road is normally assessed by its compliance, or non-compliance, with construction material specifications. These specifications are applied to control the impacts of excavation, transportation, processing, compaction and placing, and the in-service impacts of both the traffic and environment depending on the nature and position of the materials in the pavement structure.

The direct application of traditional evaluation criteria and standards when selecting pavement materials for LVRRs is questionable. By necessity, general specifications must cover a very wide range of material types and cater for extreme climatic environments. As a consequence they are likely to contain significant in-built factors-of-safety. By implication, this means that proven specifications drawn-up for specific materials for particular environments need not be so conservative in approach and hence may allow the use of previously non-conforming or marginal materials.

It is not realistic to attempt to force contractors to meet inappropriate or unobtainable standards, and for overall cost-effectiveness and minimization of environmental impact, LVRR specifications should where possible take into account the nature of locally available materials. Hence the use of flexible material specifications that acknowledge local material variations is recommended.

It must be recognised that the consequence of using more focussed specifications may be a greater need to ensure that the materials actually comply the requirements and that the material approval for use needs to be accompanied by clear guidelines laying out the limits within which the approval is valid.

4.2 Construction Plant and Procedures

Introduction to the Construction Guidelines

The RRST Construction Guidelines synthesize the knowledge and experience developed under the Rural Road Surfacing Research (RRSR); including the Rural Road Surfacing Trials (RRST) and Rural Road Gravel Assessment Programme (RRGAP), as well as from other sources.

The RRST construction trials have confirmed the need for clear and informative guidelines to aid both the contractors and supervisors of construction of the range of rural pavement options. A wide range of technical pavement-layer specifications have been developed, applied and refined in both RRST programmes. These supervision and construction guidelines include the accumulated substantial experience and knowledge and provide guidance on the range of trialled paving techniques

The main body of the document then comprises a series of technical chapters relating directly to specific RRST pavement options and their specifications, grouped as follows:

- Surface seals
- Stabilised bases and sub-bases
- Non stabilised bases and sub-bases
- Block pavement options
- Cement Concrete pavements

Following these main chapters the document contains three important appendices. The first contains a series of illustrated guides to key construction issues for the RRDST pavement options. The second highlights some fundamental issues relating to site supervision and construction quality control, whilst the third contains a series of standard site forms developed and used during the RRST construction phases.

Key Issues

This section of Module E4 summarises some of the key issues with respect to the plant and procedures to be used in the construction of the RRST Pavement options. The relevant references in the RRTS Guidelines are as follows:

Bituminous Emulsion Seals:	Section 4 and Appendix A1
Stabilised Bases and Sub-bases	Section 5 and Appendix A2
Non Stabilised Bases and Sub-bases	Section 6 and Appendix A3
Block Pavements	Section 7 and Appendix A4
Concrete Pavements	Section 8 and Appendix A5

Presentations on this part of Session are based on the above references.

4.3 Quality Control

Introduction

Quality control in construction has a significant affect on the performance and life of any LVRR pavement surface and a greater awareness of this is required to be imparted to political, administrative and engineering personnel through improved awareness creation, training and project management. Essentially, poor quality control results in poor return on road asset investment. This issue is of substantial importance even for gravel road investments, and will be increasingly significant as the rate of investment per km increases with the adoption of the more expensive more durable surfaces.

Quality Control should not be an onerous administrative burden within the rural road sector, but rather it should comprise a few simple straightforward procedures

Construction quality supervision procedures are illustrated in the RRST Construction Guideline Appendix B and relevant standard forms are included as Appendix C

Components

Quality control is undertaken in order to achieve the following specific purposes:

- Quality Control needed to ensure design compliance
- Establish the as-built road condition
- Identifying potential problems

Quality control components include:

- Construction materials quality control
- Construction equipments control
- Construction procedures control
- Design compliance control

Construction Materials Quality Control

Quality of construction material is crucial, determining the quality of structure. Poor quality material will lead to early deterioration and damage of the structures. Material quality control should be normally undertaken in two distinct phases: General quality control of source materials and control of materials as delivered to site.

- Materials quality control at source to ensure that the source is capable of producing acceptable materials
- Materials quality control on the road to ensure the as-placed material comply reasonably with the specification

Controlling materials at sources include visually checking material at source for general approval and take sample for approval testing. Note that the likely variability of the source should be assessed. This is of particular importance with respect to hill gravel or laterite sources where no processing is involved. Sampling must be realistically representative of the material being won. Samples should be large enough to meet the required testing standards. Take samples from stockpiles or already excavated material rather from borrow pit faces. If the material is being processed then assess the capability of the plant to consistently produce satisfactory material in sufficient quantities.

Controlling materials on site includes visual checks materials as delivered to site, sample and test as required. As-delivered material must be as per agreed specification. Visual checks of as–delivered material can a give good indication of whether or not it meets sized and shape specifications

As delivered materials that do not meet agreed specifications should not be approved even if the original source has been approved.

Construction Plant Approval

Many of the RRST specifications require specific plant to use in the construction procedures. For example: rotavator for lime/cement stabilization base options or vibrating roller for dry bound macadam bases. Use of inappropriate plant, or plant in poor condition, should not be approved.

Construction Procedures Control

It is essential that the correct procedures are followed in constructing RRST options; otherwise this can lead to early pavement deterioration and even road failure. Most of the RRST specifications are based around the requirement to comply with a set of defined procedures

- Surface preparation: Treatment of deformation, rutting, soft spots and other defects on road bed. Do pegging and lining to provide road formation.
- Material placement or mixing: Follow the thickness requirement of laid material (uncompacted) as well as mixing rate for concrete aggregates or lime/cement stabilised material. The slump of concrete at site should be strictly monitored.
- Moisture control: Moisture content of gravel and lime/cement stabilised material should follow the Technical Guidelines.
- Compaction Technical Guidelines of type, weight and capacity of compacting equipment as well as compacting procedures for different types of pavement should be followed.
- Layer finishing or protection: Technical Guidelines also provide requirements for completion or protection of base/surface costs of some pavement options, particularly for some options of lime/cement stabilised or cement concrete, gravel, bituminous or emulsion sealing surfaces. These requirements should be strictly followed.

Design Compliance Control

Design compliance control is very important in determining to project quality. This work includes:

- Compliance of pavement layer dimensions
- Compliance of pavement layers strength or condition
- Compliance of surface shape

Quality control techniques

General quality control techniques are as follows:

- Observation – Visual Inspection
- Site testing
- Site measurement

Visual inspection is a common procedure and will help the supervision engineer to quickly assess the material and construction process. When using in combination with other techniques such as measuring and sampling, this will help to provide quick and effective supervision of quality. Visual inspection requires that the engineer should have experience and good knowledge of the Technical Guidelines.

Within the RRST, visual inspection was used to provide general approval of material quality at source, analysis of changeable characteristics of material and checking of particle size and shape of material at site. Visual inspection is also used to check some works during construction process such as laying material, watering, mixing lime stabilised material, compaction etc.

Specific requirements for laboratory testing are provided in the Technical Guidelines depending on selection of surfacing options. Results of laboratory testing will form the basis for accepting construction material quality. Some laboratory material testing required for assuring material quality are as follows:

- Standard compaction
- California bearing ratio (CBR)
- Atterberg limits
- Shape of aggregate, block or brick
- Strength of aggregate, block or brick
- Chemical nature of lime/cement

It is necessary to carry out field tests in some cases to check construction quality of subgrade and road bases. Field testing includes the followings:

- Subgrade strength testing using Dynamic Cone Penetrator (DCP)
- Sand replacement density
- Slump test - concrete

Site measurements are carried out to accept pavement structure layers and to accept the overall pavement when completed. Items needing to be measured are:

- Camber

- Pavement layers thickness.
- Carriageway/shoulder widths

Quality Assurance Partnership

Because of its high importance, the quality assurance should not be done by supervision consultant only but should be done in conjunction with all stakeholders. In RRTS Program the quality assurance is carried out with the involvement of all stakeholders, inlcuding Contractors, PDOTs/PPMUs, Local Consultants, RRST Consultant (Intech – TRL – ITST).

4.2 Road Management

The Challenges

The management of Low Volume Rural Roads (LVRRs) in developing countries presents a range of challenges to road designers and managers. A substantial proportion of the rural road network is developed only to gravel standard and individual routes are often in poor condition and sometimes severed during the rains; causing high transport costs and unreliable access. In particular, the challenges are due to factors including high rainfall, in some cases flooding or seasonal high water tables, material quality, traffic and haulage issues such as variable traffic loading, and the inability to provide timely maintenance through financial, operational and other constraints.

At the same time there are substantial demands for improved access and mobility for the rural communities, to support the achievement of the National Development Goals, improve socio-economic conditions and to reduce poverty.

The issues

Rural roads are valuable assets that require effective management in terms of ensuring that they are not subjected to tasks beyond their design capacity. Light or Low Volume Rural roads are designed and constructed at reduced cost to undertake specific tasks in terms of vehicle type, axle load and traffic capacity and hence a 6T rural road cannot be expected to undertake the functions of a district or provincial road.

Module 1 Session 4
Self Assessment SA1-4

1. Based on the SEACAP Construction Guideline list 5 key activities in the construction of a double chip seal (DBST)
.

2 Based on the SEACAP Construction Guideline list 5 key activities in the construction of a Lime stabilised base
.

3. Based on the SEACAP Construction Guideline list 5 key activities in the construction of a mortared brick surface

4. Give yes or no answers to whether the following activities can be assessed by inspector visual inspection, site measurement/testing or by laboratory testin

	Activities	Assessed by the following – Yes (Y) or No (N)		
No.		Site Visual Procedures	Site Measurement or Testing	Laboratory Testing
1	Sub-grade strength			
2	Aggregate shape			
3	Aggregate strength			
4	Age of cement or lime			
5	Residual (Bitumen) Content in Emulsion			
6	Thickness of concrete pavement			
7	Strength of aggregate			
8	Strength of compacted base			
9	Use of correct compaction plant			
10	Cleanness of chip stone for sealing			
11	Cross fall just before sealing			
12	Check the emulsion rate			
13	Check the chip stone rate			
14	Final road shape			

5 ENVIRONMENTALLY OPTIMISED DESIGN

◆**SUMMARY**

Environmentally Optimized Design (EOD) can be considered as the over-arching framework for the application of appropriate LVRR designs. It covers a spectrum of solutions for improving or creating low volume rural access – from dealing with individual critical areas on a road link (Spot Improvements) to providing a total whole rural link rehabilitation (Whole Length Improvement).

◆**CONTENT**

5.1 Environmentally Optimised Design

Introduction

During the past 20 years or so, DFID and other development agencies have supported research on various aspects of LVRRs with the aim of improving their affordability and sustainability. Some of this research has led to innovative and unconventional LVRR solutions and approaches that are highly beneficial and cost effective, for example, the use of alternative pavements and surfaces.

Key to successful solutions is recognition that conventional assumptions regarding road design criteria need to be challenged. One emerging design concept is for the Environmentally Optimised Design (EOD) approach. LVRR standards and designs need to support the function that the road is providing as well as recognising the important influences of the deterioration mechanisms.

They key principle of the EOD approach is that LVRR link design must be compatible with the governing road environment factors and that in consequence it is possible to modify this design along the road length if appropriate. This principle implies a spectrum of practical and affordable actions for improving or creating rural access – from dealing with individual critical areas on a road link (Spot Improvements) to providing a whole length design, which, in the latter case, could comprise different design and surfacing/paving options along its length.

Application

Most roads are designed using standard national designs along their entire length. However, this can be expensive and sometimes does not meet the needs of the users. The EOD approach is cost effective and appropriate for the users of low volume rural roads. Under the EOD approach, each road or road section is designed to meet their specific environment conditions.

EOD provides a framework for the effective application of the RRST trial outcomes, particularly for the common situation where aspirations of local communities have to be balanced with fixed budgets. The EOD approach allows budget resources to be concentrated on areas that may, for example:

- Be at high engineering risk
- Have significant safety issues
- Have high socio-economic priority

The most significant issues relate to the service that the road must perform (traffic, people, safety, health and affordability) and the conditions which the road must suit (terrain, climate, construction and maintenance capability, materials, subgrade, green environment).

Some conditions are constant along a road (climate) but some vary (eg gradients). Therefore the design may also vary from gravel on gentle slopes to sealed surface up a steep hill. This is referred to as ‘variable longitudinal design’.

When funds are limited and it is not possible to improve an entire road, it may be necessary to prioritise the improvement works along the road. The improvements can be prioritised according to certain criteria, typically the importance of safe and reliable access or a dust-free road through a village. Therefore in some cases a section of unformed road which provides access and is not dangerous may be left while other sites are improved. A road may vary from unformed track to gravel to a sealed pavement up a hill. Improvement works which are not connected to each other are referred to as ‘spot improvements’. It is perfectly feasible, therefore, to balance low cost surfacing solutions such as gravel or even engineered natural surfaces for low risk areas with higher cost solutions for the at-risk areas.

Environmentally Optimised Design (EOD) can be considered as a spectrum of solutions for improving or creating low volume rural access – from dealing with individual critical areas on a road link (Spot Improvements) to providing a total whole rural link design (Variable Longitudinal Design). The two end-members of this spectrum may be described as follows:

> **Variable Longitudinal Design:** Applies the principle of adapting roads designs to suit environments at a regional scale to the individual road alignment scale and allows differing pavement options to be selected in response to different impacting factors along an alignment and hence a more focussed use of limited construction resources.
>
> **Spot Improvements**: Involves the appropriate improvement of specifically identified road sections either in actual need of upgrade or deemed to be at high risk of failure, and allows the appropriate application of limited resources to be targeted at key areas on existing earth or gravel road links to improve access throughout the year.

Within the context of LVRR Standards and Specifications it is important to distinguish Spot Improvement applications from routine, periodic or emergency maintenance. Spot Improvement is engineering based and involves pavement options and other solutions compatible with the design life of the road.

The RRST pavement and surfacing option and their associated selection procedure are applicable both to Spot Improvement and Variable Longitudinal Design solutions.

5.2 The Desk Exercise

Introduction

The object of this exercise is gain some experience in the assessment of LVRR pavement options based on the previous 2 days of lectures and discussions and in particular in the use of EOD principles.

The exercise will involve dividing the trainees into a number of groups, each of which will compile a report and presentation on the selection of possible pavement options for rehabilitating a LVRR under EOD principles within a fixed budget and based on a package of information

6 EOD EXCERCISE

◆**SUMMARY**
This module is a demonstration of the principles for EOD and a desk exercise that allows these principles to be clearly demonstrated

◆**CONTENT**

- Data
- Analysis and Presentation

6.1 Desk Exercise Data

Road Reference K1877

Runs from Junction at KmO to Village V2 at KM 6.5

A walkover survey is summarised in the following Tables

From	To	Gradient%	Existing Road Condition	Existing Pavement	Sub-Grade CBR %
0	0.5	1	Very poor	Gr	2
0.5	1.0	2	Good	Gr	4
1.0	1.5	3	Good	Gr	4
1.5	2.0	3	Rough	E	3
2.0	2.5	4	Rough	E	7
2.5	3.0	6	Rough	Gr	10
3.0	3.5	6	Very poor	Gr	10
3.5	4.0	9	Impassable in rain	Gr	4
4.0	4.5	0	Very poor	Gr	5
4.5	5.0	0	Very poor	Gr	5
5.0	5.5	3	Difficult in rain	E	5
5.5	6.0	2	Good	E	5
6.0	6.5	2	Good	E	5

Other data

1. Hill gravel-laterite sources at A: Good grading and plasticity: soaked CBR 40-50%
2. Alluvial gavel and cobble at G
3. Village VI – small school and medical centre; local market (market day Fridays)
4. Village V2 – small school
5. Rainfall: 1800mm/yr
6. Small streams at Kms 0.4, 1.2 and 5.7 (single row pipe culverts)

Traffic

3 day traffic count at Km 1.0 (each day 0600 to 1800)

Vehicle	Thursday	Friday (market day)	Saturday
Small Bus	1	2	1
Truck >5t	0	1	1
Truck<5t	5	10	3
Pick-up	10	25	12
Car	1	3	1
Motor bike-trailer	33	78	21
Motor bike	120	356	134
Cyclist	340	300	56
Walker	233	567	300

Roads to be designed on 8 year design life with traffic assumed to increase at 50% per over that time

There is an available local budget of US70,000 and further US$40,000 available from Provincial Funds. This budget has to cover pavement and drainage.

Local contractors have given the following pavement prices

DBST:	US$3.25/m2
Good natural gravel (for wearing course or sub-base)	US$7.50/m3
Water bound macadam	US$15.00/m3
Crushed stone	US$18.00/m3
Concrete pavement	US$90.00/m3
Culverts	US$3,500 per culvert
Side drainage – allow for lump sum	US$10,000

DfID have supplied local design guidance tables for this province as shown below
(NOTE THESE ARE FOR USE IN THIS EXERCISE ONLY)

Gravel Wearing Course

Sustainable use of gravel wearing course

Annual rainfall	Maximum longitudinal gradient
Medium (1000 to 2000mm/year)	Up to 4%
Low (<1000mm)	Up to 6%

Appropriates thickness of gravel wearing course

Traffic A: < 50 ADT (Motor Vehicles)			**Traffic B 50-150 ADT (Motor Vehicles)**		
Subgrade Soaked CBR%	**Pavement Layer**	**Layer Thickness D (mm)**	**Subgrade Soaked CBR%**	**Pavement Layer**	**Layer Thickness D (mm)**
2-3.9	Wearing Course	250	2-3.9	Wearing Course	300
4-6.9	Wearing Course	220	4-5.9	Wearing Course	250
>7	Wearing Course	200	6-7.9	Wearing Course	220
			>8	Wearing Course	200

Pavement Thicknesses Required: Sealed Pavements

Subgrade Soaked CBR%	**Pavement Layer**	**Traffic Group A Layer Thickness (mm)**	**Traffic Group B Layer Thickness (mm)**
2-3.9	Surface	Seal	Seal
	Base	100	120
	Sub-Base	175	200
4-6.9	Surface	Seal	Seal
	Base	100	120
	Sub-Base	150	175
7-10.9	Surface	Seal	Seal
	Base	100	100
	Sub-Base	100	175
>11	Surface	Seal	Seal
	Base	100	100
	Sub-Base	100	150

Thicknesses Required: Concrete Pavements

Subgrade Soaked CBR%	**Pavement Layer**	**Traffic Group A** **Layer Thickness(mm)**	**Traffic Group B** **Layer Thickness(mm)**
2-6.9	Surface (concrete)	150	150
	Sub-Base	150	150
>7	Surface(concrete)	150	150
	Sub-Base	100	100

6.2 Analysis and Presentation

On the basis of the previous data put forward proposals for the rehabilitation of road K1877 pavement using a minimum standard of carriageway width 3.5m and shoulders 1.0m