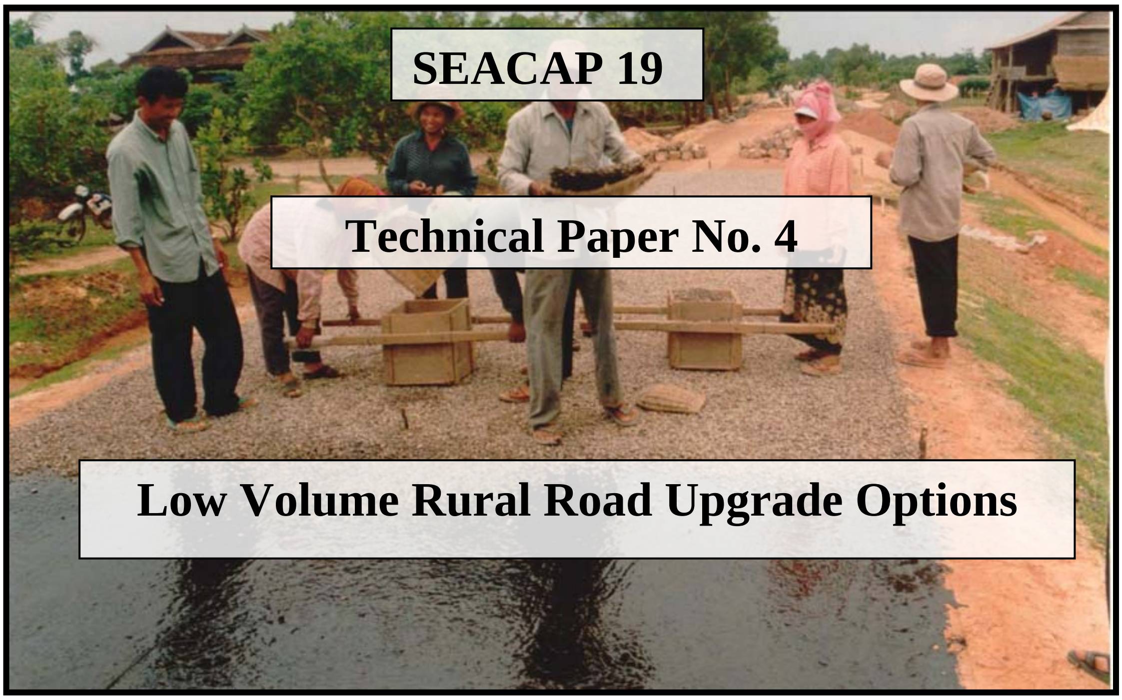
ROYAL GOVERNMENT OF CAMBODIA

SOUTH EAST ASIA COMMUNITY ACCESS PROGRAMME

DEVELOPMENT OF LOCAL RESOURCE BASED STANDARDS



December 2008

UNPUBLISHED PROJECT REPORT

UNPUBLISHED PROJECT REPORT

DEVELOPMENT OF LOCAL RESOURCE BASED STANDARDS

Low Volume Rural Road Upgrade Options

By

Dr J R Cook (OtB Engineering)

Heng Kackada (KACE)

Prepared for: Project Record:	**SEACAP 019. Development of Local Resource Based Standards.**
Client:	**DfID; South East Asian Community Access Programme (SEACAP) for the Royal Government of Cambodia**

Approvals

Task Manager

Dr J R Cook

Quality Reviewed
Dr J Rolt,

CONTENTS

ABBREVIATIONS AND ACRONYMS

ADB	Asian Development Bank
ADT	Average Daily Traffic
ASEAN	Association of Southeast Asian Nations
AusAID	Australian Agency for International Aid
BRC	Bamboo Reinforced Concrete
CBR	California Bearing Ratio
CNCTP	Cambodia National Community of Transport Practitioners
CSA	Crushed Stone Aggregate
CSIR	Council for Scientific and Industrial Research
DBM	Dry Bound Macadam
DBST	Double Bitumen Surface Treatment (two layers of SBST)
DFID	Department for International Development
DTW	A Mechanical Engineering NGO
E	Bitumen Emulsion
EOD	Environmentally Optimised Design
FFW	Food For Work
GMSARN	Greater Mekong Sub-region Academic & Research Network
GTZ	German Agency for Technical Co-operation
IFRTD	International Forum for Rural Transport Development
ILO	International Labour Organisation
IRAP	Integrated Rural Accessibility Planning
IRD	Integrated Rural Development
IRI	International Roughness Index
ITC	Institute of Technology Cambodia
KaR	Knowledge and Research
km	kilometre
kW	kilowatt
LBAT	Labour-Based Appropriate Technology
LCS	Low Cost Surfacing
LVRR	Low Volume Rural Road
m	metre
MPW&T	Ministry of Public Works and Transport (Cambodia)
MRD	Ministry of Rural Development (Cambodia)
NGOs	Non-Governmental Organisations
NPA	Norwegian People’s Aid

NRDP	North-western Rural Development Project
ORN	Overseas Road Note
PDRD	Provincial Department of Rural Development
PIARC	World Road Association
PRDC	Provincial Rural Development Committee
PRIP	Provincial and Rural Infrastructure Programme
RGC	Royal Government of Cambodia
RIIP	Rural Infrastructure Improvement Project
RRGAP	The Rural Road Gravel Assessment Programme
RRSR	The Rural Road Surfacing Research
RRST	Rural Roads Surfacing Trials
SBST	Single Bitumen Surface Treatment (bitumen sprayed coat with stone chippings)
SEACAP	South East Asia Community Access Programme
SEILA	Multilateral donors - Government Rural Infrastructure Development Programme
SIDA	Swedish International Development Agency
SS	Sand Seal
gTKP	Transport Knowledge Partnership
TRIP	Tertiary Roads Improvement Project
TRL	Transport Research Laboratory
UK	United Kingdom
UN	United Nations
UNDP	United Nations Development Programme
WB	World Bank
WBM	Water Bound Macadam
WFP	World Food Programme

EXECUTIVE SUMMARY

There is a clear message from recent research that Cambodia requires a cost-effective and sustainable approach to rural infrastructure improvement and that the identification of appropriate pavement and surfacing options must be central to this approach.

There is an increasing recognition that it is a major challenge for engineers and road managers to provide and maintain all weather rural access on a sustainable basis with the limited available resources. For many programmes unsealed gravel roads are still seen by donors and road engineers as the optimum solution. However, this view has been coming under increasing criticism both from rural road practitioners, particularly in regions such as S E Asia that have high and intense rainfall patterns. There has in consequence in the last 10-15 years been an increased research emphasis on establishing viable upgrade alternatives to the use of unsealed gravel surfaces.

A number of LVRR pavement trials programmes have been undertaken in the last few years in the Cambodia, Lao and Vietnam. Only one trial programme so far in Cambodia has involved performance monitoring and hence there has been limited input to determining appropriate pavement upgrade options for Cambodia. This paper therefore relies heavily on the extensive SEACAP trials of over 140 km of roads in Vietnam for regional input to the review of Cambodian upgrade options

Upgrade options are reviewed under the following groupings:

- Bitumen emulsion surfacing
- Hot bitumen surfacing
- Stabilised pavement layers
- Non-stabilised pavement layers
- Block paving
- Concrete pavements

It has become increasingly recognised that the life-time performance of Low Volume Rural Roads (LVRRs) is influenced to a relatively greater extent than higher volume roads by the impacts of what is termed the Road Environment. It follows that any summary of the of LVRR upgrade options should include an assessment of these road environment factors.

Upgrade options are assessed in relation to key construction, performance and sustainability criteria and to some typical Cambodian road environments.

Proposals for addressing the identified knowledge and application gaps are contained in a concise Concept Note attached as Appendix A to this Technical paper. This Concept Note summarises a possible way forward through a number of Modules that could be adopted singly or in combinations. These Modules are:

I Performance Monitoring

II Additional Trial Design and Construction

III Data Analysis and Interpretation

IV Dissemination and Mainstreaming

V Training of Upgrading Procedures

SEACAP 19: TECHNICAL PAPER 4
LVRR Pavement Upgrade Options

1 Introduction

1.1 Task Objectives

There are two fundamental issues related to the upgrading of rural road pavements; firstly the justification for so doing in term economics and road-task performance and secondly, choosing the appropriate upgrade solution or range of solutions. This Technical Paper 4 is primarily concerned with assessing knowledge on the latter as regards Cambodia whilst the associated Technical Paper 5 is concerned with up-grade justification

A number of rural pavement options have recently been trialled regionally and this Task is responding to a clear need to review these options, identify those most likely to be appropriate to Cambodia and define the further work required to mainstream them into the Cambodian Rural Road Standards.

Initial work undertaken on this Task highlighted the fact that although the ToR specifically mentions WBM, TRL-KACE proposed that the Task should include a wider range of options. This Technical Paper therefore summarises the engineering issues for a range of pavement options that should be considered for the upgrading of Cambodian Low Volume Rural Roads (LVRRs).

1.2 Task Framework

Within the framework of SEACAP, and SC19 in particular, this Technical Paper contributes to the overall development of resource-based rural road standards for Cambodia, both by reviewing currently available information and by presenting a clear way forward for relevant research, development and mainstreaming.

This document is the formal output from Task 4 and comprises one of a suite of technical papers from the SEACAP 19 project of which the following have particular relevance to this document.

TP 1: Bamboo reinforced concrete pavements
TP 2.1 Behaviour of engineered natural surfaced roads; review
TP 2.2 Behaviour of engineered natural surfaced roads: Experimental evidence
TP 3 Stabilised Pavement options
TP 5 Justification issues for LVRR upgrading
TP 7 Pilot road materials database

1.3 Document Structure

The main elements of the document are a Main Text which reviews and summarises current research information on LVRR paving options and a Concept Note outlining the way forward to expand and apply current knowledge.

Following the Introduction, Chapter 2 presents the background on the need to consider options for pavement upgrading while Chapter 3 summarises the relevant regional research. Chapter 4 summarise the outcomes from this research and Chapter 5 introduces some important issues relating to the appropriate selection of pavement and surface options. Chapter 6 identifies knowledge and dissemination gaps that are likely to hinder effective mainstreaming of LVRR pavement research in Cambodia as an introduction to the Concept Note which is include as an Appendix.

2 Background

2.1 The Upgrade Requirement

Poverty in Cambodia is overwhelmingly rural, with poverty headcounts ranging from a low of 10-15 percent in Phnom Penh to 40-45 percent in the rural areas, reaching 70-80 percent in some areas around the Tonle Sap Basin and a current World Bank review paper[1] has identified a key issue in alleviating this poverty as … "*The strategic development of the rural road network to facilitate integration of rural areas with the national and regional economy*".

It is currently assessed that there are around 2300kms of tertiary rural roads in Cambodia over 99% of which are unsealed earth or surfaced with gravel. Since the early 1990s a wide variety if rural road programmes have delivered over 10,000km of predominantly unsealed roads, however, without adequate maintenance provisions it is likely that the total asset value of the rural network has not been increased and may have in fact diminished with valuable resources essentially being wasted on inappropriate infrastructure development.

A case study undertaken in Battambang Province[2] well illustrates this point by summarising: "*The important point to be made here is that while $4.5M worth of resources were invested in rural roads and rural transport infrastructure, the total value of the maintainable stock of assets declined and that the local economy suffered heavy increases in vehicle operating costs and lost employment opportunities. The situation in Battambang is not unique. If one were to project the implications of these findings to the national level, the waste of resources would have significant implications for national development*".

There is therefore a clear message from recent research that Cambodia requires a cost-effective and sustainable approach to rural infrastructure improvement and that the identification of appropriate pavement and surfacing options must be central to this approach.

Previous SEACAP reporting[3] presented factors relevant to the identification of suitable options for the sustainable upgrading of the rural road network in Cambodia. These included:

- The particular physical, climatic, poverty and operational environment of Cambodia is extremely demanding on the road sector compared to most other countries.
- An underdeveloped road network, much of which currently has an unsupportable maintenance burden.
- Gravel/laterite is used often in unsustainable situations. Knowledge of alternatives and benefits are not widely known or available for application.
- Road management and maintenance systems are not developed and assets are not efficiently preserved.
- Established policy is not yet widely mainstreamed or supported by a pragmatic strategy for implementation.
- A lack of appropriate established specifications and standards for rural roads,
- Severe overloading of road vehicles with associated safety risks and accelerated deterioration of roads.

[1] World Bank, 2007. Country Review Paper: Cambodia

[2] Johnston & Salter D, 2001. Rural Road Investment, Maintenance and Sustainability A case study on the experience in the Cambodian of Province of Battambang. The ILO, Upstream Project, ILO CMB/97/M02/SID,

[3] SEACAP 2, Final Report, Intech-TRL, 2006

In a general summary SEACAP 2 noted that further work was required on "*…appropriate designs for improved pavement performance for the particular conditions experienced in Cambodia, in order to lower the construction and whole life costs, contributing towards lower transport costs and sustainable development.*"

The principal objective of upgrading rural roads in Cambodian is to provide sustainable and affordable all-weather access for rural communities. Rural road pavement upgrades in this context are likely to comprise ENS upgraded to either unsealed gravel or "sealed" pavement and unsealed gravel upgraded to "sealed" pavement.

The extent of this upgrade within an overall Environmentally Optimised Design (EOD) framework may vary from a Spot Improvement to Whole Length Improvement (Box 1).

Box 1: Environmentally Optimised Design

EOD 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 design (Whole Length Improvement).

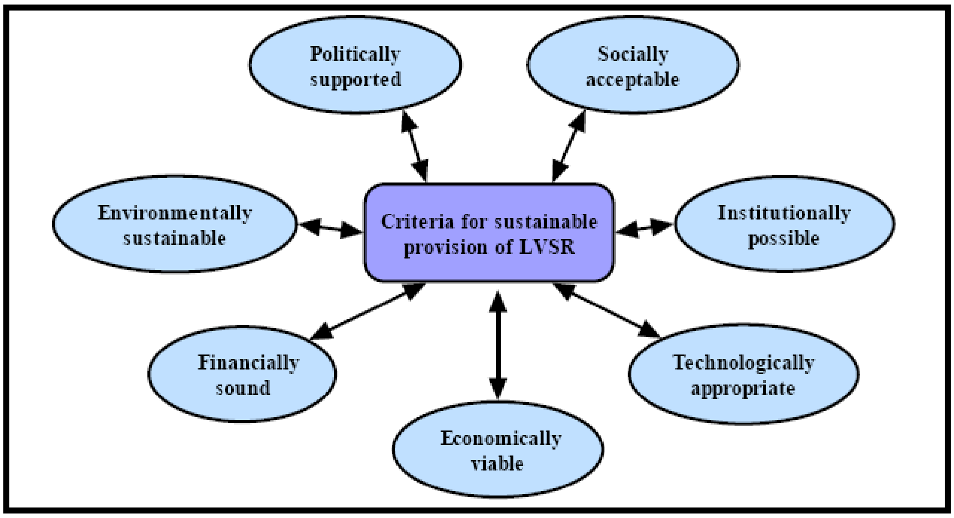
Whole Length Improvement applies the principle of adapting roads designs to suit environments at a regional scale to the individual road alignment scale and allows differing pavement options to be selected in response to different impacting factors along an alignment.

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.

2.2 Sustainable Development

The term 'sustainability' in the context of rural infrastructure is often used purely in terms of technical or engineering solutions. This is misleading as there are in fact many different components that contribute to the "sustainability" of a particular road project[4] (Figure 1).

Figure 1 Components of Sustainability



[4] SADC, 2003. Guidelines on Low-Volume Sealed roads – Chap 4

1. Politically supported – the road project must be clearly supported at the relevant local authority level as well as at Ministerial level.
2. Socially acceptable – the local people (stakeholders) must benefit in the long term from the road upgrade.
3. Economically viable – the economic benefits from using the upgraded road (for example, the development opportunities) must be greater than the economic costs.
4. Financially sound – there must be adequate funding in place for construction and long-term maintenance of the improved road.
5. Institutionally possible – the organisations and bodies responsible for constructing and maintaining the road must have the necessary resources and knowledge.
6. Technically appropriate – the proposed road design must be compatible with its intended function and its physical environment.
7. Environmentally sustainable – the road construction as well as its subsequent use and maintenance should not cause significant environmental damage.

Unless all the components of sustainability are satisfied, it is unlikely that a road upgrade project will bring long-term benefit to a rural community.

As Engineers, we should be fully aware of all the sustainability components but are principally concerned with two components namely,

- Institutional Sustainability
- Technical Sustainability

This document is particularly concerned with "Technical Sustainability" although it fully acknowledges the need to take into account other "Sustainabilities" within an overall process of LVRR upgrade.

2.3 Regional and International Research

There is an increasing recognition that there it is a major challenge for engineers and road managers to provide and maintain all-weather rural access on a sustainable basis with the limited available resources. However, for many programmes unsealed gravel roads are still seen by donors and road engineers as the optimum solution. This view has been coming under increasing criticism from rural road practitioners, particularly in regions such as South East Asia that have high and intense rainfall patterns. There has in consequence in the last 10-15 years been an increased research emphasis on establishing viable upgrade alternatives to the use of unsealed gravel surfaces.

A recent World Bank paper[5] provides a comprehensive review of near-current knowledge. It includes a compilation table of rural road pavement options, summarises international experience and lists the benefits of upgrading to sealed pavements as,

- Provides access at all times;
- Sealing protects the base and subgrade;
- A larger variety of vehicles can use the road;
- Increased transport efficiency as the travel time is reduced;
- Maintenance cost may be reduced for some surfacing options.

The point is also made that there are some issues in favour of retaining unsealed pavements:

- Initial higher construction costs of sealed options;

[5] The World Bank, 2005. Surfacing Alternatives for Unsealed Rural roads

- Some sealed roads can be less tolerant to overloading from heavy vehicles
- Once damaged, repair may be more costly and requires skills and equipment not always available;
- A neglected gravel road can be reinstated at relatively low cost, a deteriorated sealed road may require full reconstruction;
- Accident rate and severity may increase, generally as speed increases.

The SADC guidelines for the pavement design of low volume rural roads have been produced after extensive research and performance analysis of trial roads and existing pavements and consider sealed roads with unbound pavement layers with traffic levels ranging from 0.5 million esas down to 0.05 million esas. The guidelines provide a useful manual on all the considerations faced by the challenges of LVRR development.

In the SE Asian region the relevant research in the last 5 years has been spearheaded by the SEACAP road trials and performance data gathering programme in Vietnam, Lao and Cambodia, Box 2.

Box 2: Relevant SEACAP Projects

Vietnam.
SEACAP 1 - design, construction and monitoring of trial roads in a wide variety of physical environments.

SEACAP 4 - collection and analysis of condition data on over 200 unsealed road links

Cambodia.
SEACAP 8 - assessment of low cost surfacing trials and associated costs, together with related issues of maintenance and axle overloading.

Lao.
SEACAP 3 - drafting of LVRR standards and specifications.

SEACAP 17 - design, construction and initial monitoring of trial roads in hill terrain.

3 Regional LVRR Pavement Trials

3.1 General

A number of LVRR pavement trials programmes have been undertaken in the last few years in Cambodia, Vietnam and Lao. Not all these programmes have involved performance monitoring and hence have limited usefulness as input to determining appropriate pavement upgrade options for Cambodia. The following sections summarises these programmes and highlight key issues.

3.2 Cambodia

3.2.1 Puok Trials

The construction of Pouk Low Cost Surfacing Trials in Siem Reap Province was completed in September 2002 under the ILO Upstream Project utilising DFID funding provided under the Engineering Knowledge and Research programme. The objective was to trial rural road surfacing alternatives that were likely to be more sustainable than unsealed natural gravel.

An initial monitoring of the surfacing trials undertaken in April-May 2003 indicated that all trial road sections were in good condition. However, by July-August of 2003 the trial sections were being subjected to loading by a significant numbers of sand haulage trucks. It was apparent that these trucks hauling wet sand were heavily overloaded and used the road on a regular daily basis. The result was that two sections of the trials became severely damaged and some other sections also showed signs of distress.

Subsequent investigations[6] indicated the extent of the damage and recommendations were made for the rehabilitation of some of the trial sections which were carried out under the SEACAP 8 project. Details of the original trial sections and their subsequent repair are summarised in Table 1. It can be seen that the damage was primarily structural.

One of the key tasks of the SEACAP 19 project was an assessment of Bamboo Reinforced Concrete (BRC) and the Puok trial section was sampled and tested as part of this activity, Plates 1 and 2. The research[7] has concluded that bamboo reinforcement is not contributing to the overall strength of such pavements and that BRC pavements offers no significant benefit over well-constructed non-reinforced concrete pavement.

A summary of the overall conclusions arising out of the Puok trials in relation to the selection of pavement is presented in Table 2

Plate 1: Bamboo within Sample Block

Plate 2: Disintegrated Bamboo from Sample

[6] Cook, J R, LCS Working Paper No 18, Puok Market Trial Road Investigation: October 2003.
[7] Rolt, J., Bamboo Reinforced Concrete Pavements. SEACAP 19 Technical Paper 1, 2008

Table 1 The Puok Low Cost Surfacing Trials

Section No	Original Trial Design	Condition Summary after Overloading	Pavement Rehabilitation – Final Trial Option
Transition gap	10.1 metres long gap of Laterite surfacing between ILO-built BRC pavement and the start of the LCS trials		150mm thick non-reinforced concrete pavement.
No 1	BRC pavement	No deterioration apart from minor cracking of bitumen seal joints	
No 2	Sand-Aggregate Roadbase with SBST. Poor grade hand-broken aggregate were mixed with local sand to produce roadbase material	Edge broken at access points to people's houses	Overlain with bitumen emulsion sand seal.
No 3	Dressed Stone with Bitumen-Sand Sealed Joint	No significant deterioration. Localised shallow depressions	Overlain with thin layer of well graded crushed aggregate blinding then DBST sealed (14mm and 8mm stone chips).
No 4	Armoured Laterite Road with SBST	Severe rutting. 80% of the Section had failed	150mm of hand packed stone blinded with sand/fine aggregate and sealed with sand seal on SBST (14mm stone chips)
No 5	Dressed Stone Pavement and Bitumen-Sand Seal Joint	No significant deterioration. Some shallow localised rutting	Overlain with thin layer of well graded crushed aggregate blinding then sealed with sand seal on SBST.
No 6	Sand-Aggregate Roadbase with SBST	Potholes, minor pavement edge erosion, shallow rutting but not affecting the integrity of the seal.	Maintenance repairs – design remains as original
No 7	Water Bound Macadam and SBST	Minor pavement edge erosion, shallow rutting not impacting on the integrity of the seal.	Maintenance repairs – design remains as original
No 8	Water Bound Macadam and DBST	Minor pavement edge erosion, shallow rutting not affecting the integrity of the seal.	Maintenance repairs – design remains as original
No 9	Armoured Laterite Roadbase and Sand Seal	Severe rutting and break-up of surface affecting 20% of this section. Significant rutting in one wheel track.	150mm of hand packed stone blinded with sand/fine aggregate, and sealed with sand seal on SBST (14mm stone chips).
No 10	Hand-Packed Stone with Laterite Gravel Wearing Course	Severe loss of laterite wearing course	Replacement of wearing course with 100mm of specification compliant laterite gravel.

Table 2 Principal Conclusions from the Puok Trials

Pavement Description	Conclusions			
	A	B	C	D
BRC pavement	3	3	4	4
SBST on sand-aggregate roadbase	2	2	2	3
Dressed stone	2	2	2	2
Dressed stone with DBST.	2	2	3	3
SBST on armoured laterite	1	1	1	1
Sand-seal on SBST on hand-packed stone roadbase	2	2	3	3
SBST on WBM roadbase	2	2	2	3
DBST on WBM roadbase	2	2	3	3
DBST on hand-packed stone roadbase	2	2	3	3

Notes A: Traffic volume resistance: (low = 1; medium = 2; high = 3)
B: Axle loading resistance: (low = 1; medium = 2; high =3)
C: Maintenance requirement: (high = 1; Medium = 2, low = 3; very low = 4)
D: Pavement's structural performance: A score is given from 1 (lowest) to 4 (highest) to express relative performance among trials options.

3.2.2 ILO OTTA Seal Trials

As part of an overall labour-based maintenance project the ILO undertook the trial construction of OTTA sealed natural gravel (laterite) roadbases. The trials were constructed during February to May 2007 in Otaka Commune in Battambang Province. Six trial sections of between 100m to 150m in length were constructed, as summarised in Table 3.

Table 3 ILO Pavement and Surfacing Trials: Battambang

Surface/Seal	Prime Seal	Base/Sub-base
Single Otta and Sand Seal	Yes	Laterite gravel
Double Otta Seal (Laterite)	Yes	Laterite gravel
Double Otta Seal (Laterite)	No	Laterite gravel
Double Otta Seal (Screened Laterite)	No	Laterite gravel
Double Otta Seal (Screened Laterite)	Yes	CSA over laterite gravel
DBST (Emulsion)	Yes	CSA over laterite gravel

These were essentially construction trials and no base-line data were collected for any ongoing performance monitoring. No performance monitoring is currently planned, although this is recommended (see Chapter 6)

First impressions from the construction phase (ILO 2008) were as follows:

1. The bitumen emulsion (CRS-2) seemed to bind well with the all-in natural laterite.
2. Trials sections were "quite dusty" immediately after construction.
3. In the natural laterite sections much over-size gravel was evident on the seal surface. This was not the case for the screened laterite sections.

4. Bitumen began to become visible in the wheel tracks after two weeks of traffic.
5. Those trials sections with a prime coat appeared to be performing better.

Visual impressions gained from a site visit by the SC19 team in March 2008 indicated that the performance of the Otta Seal sections did not appear to be as good as the DBST sections. There were longitudinal cracks on the Otta Seal sections, some of which had apparently occurred soon after construction and had already been repaired at the time of the visit. However, it is not appropriate to form any firm conclusions until proper detailed investigations are carried out.

3.2.3 NRDP Stabilisation Trials

Demonstration trials of laterite stabilised by lime and by lime with cement have been undertaken as part of the ADB-funded North-western Rural Development Project (NRDP). These trials took place during March-April 2007 with technical assistance by NZAID on sections of provincial road in Banteay Meanchay Province (NZAID, 2008). The trial options are summarised in Table 4 and further details can be found in SEACAP 19, Technical Report 3[8].

No as-built independent condition data or subsequent performance survey information are available, hence no immediate conclusions can be drawn from this demonstration.

Table 4 NRDP Stabilisation Options

Surface/Seal	Base/Sub-base	Comment
No seal	Lime stabilised laterite	3% lime
No seal	Lime and cement stabilised laterite	2% lime + 1 % cement
DBST	Lime stabilised laterite	3% lime
DBST	Lime and cement stabilised laterite	2% lime + 1 % cement

3.3 Rural Road Surfacing Trials (RRST) in Vietnam

Two main phases of RRST construction have been completed between 2004 and 2006 within an overall Rural Road Surfacing Research (RRSR) programme through cooperation between the MoT, World Bank and DFID (SEACAP). Over 140 km of trial roads have been completed from which a representative 107 sections of between 80m to 200m length have been selected for ongoing performance and whole-life-cost monitoring.

The RRST-I programme concentrated on four roads in the Mekong Delta and the Central Coastal area. Short lengths (100-200m) of different pavement options appropriate to the province were constructed on each trial road under the close instruction and supervision of the specialist consultants. Each trial road had, in addition, short lengths (100m) of control sections of unsealed road or penetration macadam sealed road.

The RRST-II programme was undertaken in a wider set of physical environments in the Northern Highlands, Central Highlands and the Red River Delta as an extension of the RRST-I programme. It involved much longer lengths of trial and control sections, from 500m to more the 2 km, and was seen as an important step in the roll out and mainstreaming of sustainable and appropriate rural surfacing solutions.

[8] M O’Connell,2008 Stabilisation Techniques to Improve Local Materials for Rural Road Pavements in Cambodia, SEACAP 19 report for DFID

Full details of the trial designs and construction are contained in the SEACAP 1 Final Report (Intech-TRL, 2007) and a list of the component pavement layers making up the overall trials matrix is presented in Table 5.

Table 5 RRST Trial Options

Layer	Layer Option
Surface seal	SBST(E)+ SS(E); DBST(E) DBST; Pen-Mac
Base	WBM; DBM; CSA Cement Stabilised Sand Bitumen Emulsion Stabilised Sand Lime Stabilised Clay Soil Armoured Natural Gravel Natural Gravel
Sub-base	WBM; DBM; CSA Sand; Cement Stabilised Sand Lime Stabilised Clay Soil Quarry Run Natural Gravel
Block	Fired Clay Bricks; Concrete Bricks Dressed Stone Setts; Cobble Stones
Concrete	Bamboo Reinforced Concrete Steel Reinforced Concrete Non-Reinforced Concrete
Unsealed surface	Natural gravel WBM

The representative monitoring sections have been regularly surveyed since construction and a report on the outcomes form this work is due for issue in February 2009[9]. Interim conclusions from this monitoring have been included within the overall assessments in Chapter 4 of this Technical Paper. Major issues that are of note can be summarised as follows;

1. Unsealed gravel and WBM sections in the Central Coastal and Mekong Delta regions suffered significant early deterioration.
2. Fluctuating water-tables in the Mekong Delta region are considered to be a principal reason for strength deterioration in the lime-stabilised pavement layers in that region.
3. Sand seals on block pavements have tended to deteriorate within 1-2 years.
4. Sand-jointed block pavements that have lost their seals tend to deteriorate rapidly in areas of high rainfall. Mortared joints are more resistant, Plates 3 and 4.
5. The early deterioration of a trial road in the Central Highlands occurred primarily due to gross traffic overloading and lack of effective drainage.
6. The bitumen-sand sealing between rigid concrete slabs requires regular routine maintenance.
7. Concrete slabs laid on poor clayey gravel sub-base tend to crack under the pumping action of heavier traffic.

[9] Rolt J and Cook J, 2009. Technical Report on the Interim Condition and Performance of the RRST Trial Sections, Vietnam. SEACAP 27, Technical Report for DFID.

Plate 3: Seal Eroded from Concrete Block Paving: Mortar Joints

Plate 4: Seal Eroded from Concrete Block Paving: Sand Joints

3.4 LVRR Pavement Trials in Lao PDR

The SEACAP 17 project involved the construction of a number of trial pavements in Bokeo province of Lao PDR. The trial options are listed below:

- Unsealed Gravel
- Bamboo Reinforced Concrete
- Geocell (manufactured plastic formwork)
- Hand-Packed Stone (mortared and un-mortared)
- Concrete Blocks
- Bitumen Sand Seal
- Otta Seal
- Engineered Natural Surface

Construction was completed in June 2007 and a baseline survey of pavement condition then undertaken[10]. No performance data from this trial are currently available. Comments on construction of the trial sections include the following general points:

- The need for Contractors to be fully trained prior to any proposed innovative procedures and for designs to be within the capabilities of available construction plant.
- The EOD (Spot Improvement) design approach is eminently suitable for the variable terrain encountered in these trials.
- In order to draw conclusions in respect of specific pavement types, the medium and long term monitoring of the trial sections is of critical importance.

3.5 Summary

Table 6 summarises the recent regional trials of alternative LVRR pavement and surfacing options. Continued monitoring of the SEACAP trials and the initiation of monitoring for the ILO and NRDP trials will be result in significant useful information becoming available for the more effective selection of appropriate LVRR options for Cambodia. This is discussed further in Chapter 6 and in the research Concept Note (Appendix A)

[10] Roughton International Ltd, 2008. SEACAP 17 Rural Access Roads on Route No.3, Module 2 – Completion of Construction Report. Final report to the Ministry of Public Works and Transportation, Lao PDR

Table 6 Summary of Regional Trials

Type of Surface/Roadbase	Cambodia			Vietnam : SEACAP 1		Laos
	Puok	ILO	NRDP	RRST-I	RRST-II	SEACAP 17
SEALS						
DBST					2006	
DBST (E)	2004**		O		2006	
SBST (E)+SS(E)				2005		
SS (E)	2004**			2005	2006	
Otta Seal		O				2008*
UNSEALED SURFACES						
Gravel Wearing Course	2004**			2005	2006	2008*
WBM				2005	2006	
Hand Packed Stone						2008*
Lime Stabilised Gravel			O			
Engineered Natural Surface						2008*
SEALED BASES & SUB-BASES						
WBM	2004**			2005	2006	2008*
DBM				2005	2006	
Emulsion Stabilised Sand				2006		
Cement Stabilised Sand				2005		
Lime Stabilised Gravel			O			
Lime Stabilised Clay				2005		
Lime & Cement Stabilised Gravel			O			
Armoured Gravel				2005	2006	
Graded Crushed Stone		O				
Sand				2005		
Sand-Aggregate Mix	2004**					
Gravel	2004**	O		2005	2006	
BLOCK SURFACES						
Stone Setts	2004**			2005		
Cobble Stone					2006	2008*
Fired Clay Brick				2005	2006	
Concrete Brick				2005	2006	2008*
CONCRETE						
Steel Reinforced				2005	2006	
Bamboo Reinforced	2004**			2005	2006	2008*
Non-Reinforced	2004**				2006	
Cast in Situ Blocks (Hysen Cells)						2008*

Notes

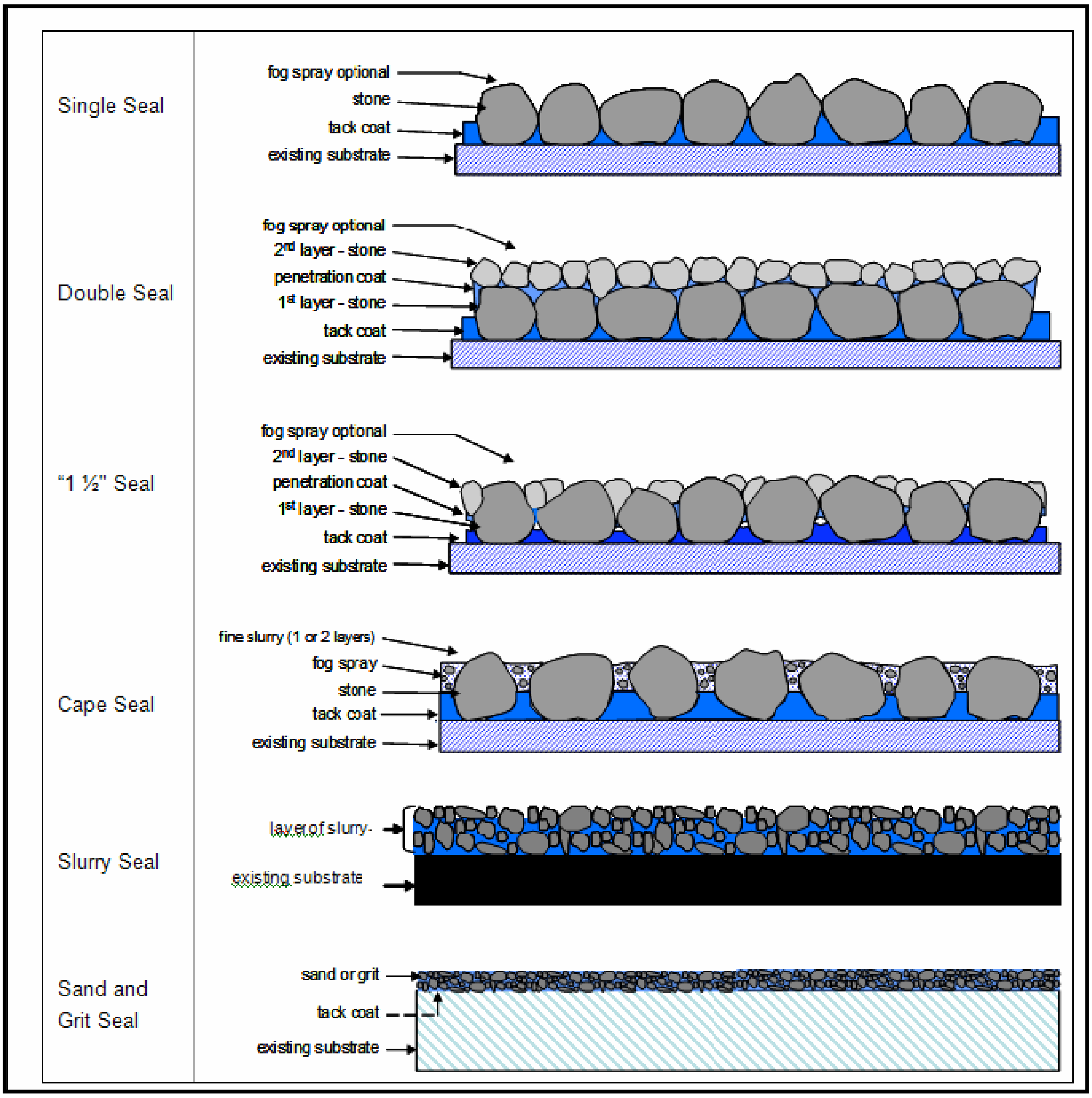
Notes	**2005 etc**	**Start of performance monitoring**
	*****	**Planned**
	******	**Intertmittent only**
	O	**No monitoring**
	(E)	**Emulsion**

4 Pavement Option Review

4.1 Bituminous Seals

Seals are essentially the combination of a bitumen film with stone or sand embedded into it. Seals are flexible and easy to maintain surfaces but may require imported processed material (bitumen) and good quality screened and crushed stone or sand (Figure 3). However, sand seals and low grade natural aggregates have been successfully used in a number of regions in appropriate circumstances.

Figure 3 Some Typical Seal Options (Van Zyl, 2008)



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

Bitumen may be penetration grades, cutback or (labour friendly) bitumen emulsion, depending on the particular circumstances. Tables 7 and 8 summarise key characteristics.

A recent conference on sealed surfaces contained a number of papers reviewing the current diversity of pavement surface seals[11]. Particular attention is drawn to the following:

- *Holtrop W.* Sprayed Sealing Practice in Australia - an overview of current sealing practice in Australia, types of sprayed seals and their selection.
- *Gunderson, B.* Chip-sealing Practice in New Zealand. The use of chip-seals is discussed and typical performance outlined.
- *Overby, C and M Pinard.*. The Impact of Using Otta Seal Surfacing in the Development of the Botswana Road Network- outlines the origin, properties, design and construction of the Otta seal and discusses its implementation impacts and its sustainability
- *Van Zyl, G.* Selection of the Most Appropriate Seal Type. - specific recommendations regarding the most appropriate and cost-effective seal type with guidelines provided to cater for local road environment variations.

Table 7 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 Vietnamese trials used a combination of SS (E) and SBST(E). Indications are that they do not generally perform as well as the DBST options.

[11] 1st Sprayed Seals Conference, July 2008 Adelaide, Australia

Table 8 Advantages and Concerns for Standard Hot Bitumen Seal Types

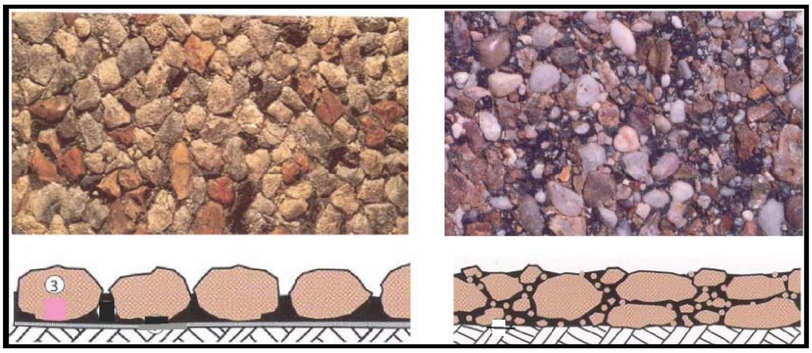
Description	Principal Advantages	Principal Concerns
DBST (hot bitumen)	Well known and established procedure in Cambodia.	Generally very poor site control of bitumen application temperature which affects durability. Significant health and safety hazard.
Triple bitumen surface treatment (hot bitumen)	Locally developed procedure in Vietnam.	Costly use of bitumen in what is effectively similar to a semi-penetration macadam in thickness. Care required in matching application rates to actually available stone sizes and shape. Generally very poor site control of bitumen application temperature. 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 (Box 3)	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

Box 3: OTTA Seal

Otta seal is a bituminous sprayed seal incorporating a graded aggregate instead of the generally used one sized crushed rock aggregate (see Figure 4). 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 (Overby and Pinard 2008).

Figure 4. Comparison of SBST and Single OTTA Seal (Pinard, 2008)



4.2 Stabilised Base and Sub-base Layers

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 they may be effectively improved in order to increase strength and bearing capacity by treatment with an additive such as cement, lime, bitumen or by mechanically mixing with stone aggregate (mechanical stabilisation).

Selection of the appropriate chemical stabilisation option is usually based on material grading and plasticity characteristics. 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 or emulsion stabilisation, Table 9. Further details on the relevance of stabilisation in the Cambodian context are contained in SEACAP 19 Technical Paper 3.

Table 9 Chemical Stabilisation Options

Type of Stabilisation	**Soil Properties**					
	More than 25% <0.075 mm			Less than 25% < 0.075mm		
	PI < 10	10<PI<20	PI > 20	PI < 6; PP < 60	PI < 10	PI > 10
Cement	S	S	M	S	S	S
Lime	M	S	S	X	M	S
Bitumen/Emulsion	M	M	X	S	S	X

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

S: Suitable M Marginally Effective

X: Not Suitable

The advantages of stabilisation and principal concerns are listed in Table 10.

Table 10 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.
Emulsion stabilisation	Utilises locally available materials with little haulage. Can use locally available agricultural equipment for on-site mixing.	Not possible to undertake during the rainy seasons Conventional soil mechanics testing is not appropriate, hence design requires specialist knowledge and testing facilities. Specific care needs to be taken to ensure correct dosage of emulsion. Requires adequate amounts of water to be added to ensure effective mixing. Likely to be expensive unless local source of emulsion is established.
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.

4.3 Non-Stabilised Base and Sub-base Layers

A range of materials can be used in their natural or mechanically processed state to provide sub-bases and road bases of adequate quality and characteristics. The principal requirements relate to strength, durability, plasticity and moisture susceptibility. Where these materials are available within reasonable haul distances, they are often the cheapest and most cost-effective construction solution. Their advantages and concerns are listed in Table 11.

Table 11 Non-Stabilised Materials: Advantages and Concerns

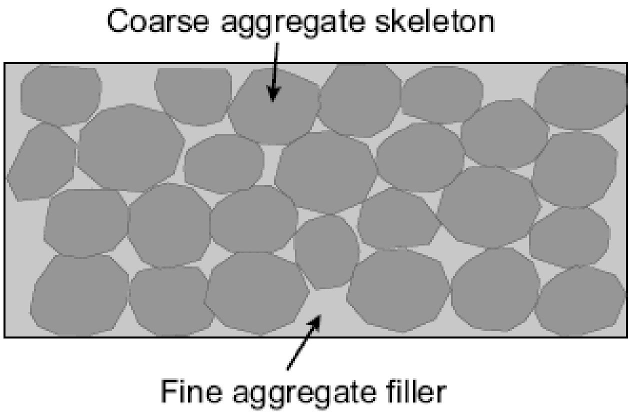
Description	Principal Advantages	Principal Concerns
Dry-bound macadam (DBM)	Straightforward well-proven construction techniques. Recommended for weak moisture-susceptible sub-grades. An appropriate base for bitumen or emulsion sealing.	Requires the use of both static and vibrating compaction machinery; 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.
Hand-packed stone	Local labour employment in construction. Good durability, load bearing load spreading characteristics. Suitable for staged construction options.	Requires available labour with some basic experience. Requires close supervision to achieve uniform results.
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 gravel may not achieve technical requirements unless stabilised.

Box 4: Macadam

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 base courses, 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.

4.4 Block Options

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. Advantages and concerns are shown in Table 12.

Table 12 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).

4.5 Concrete Pavements

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. Table 13 lists the advantages and the concerns.

Table 13 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. General concreting procedures 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
Geocells	High strength, low maintenance option. Repairs are easier that with conventional concrete pavements	High cost, especially if proprietary imported geocells are used. Requires significant curing time following initial construction with consequent traffic diversion implications
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[12].	

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

Box 5: Geocells

In Geocell construction, manufactured plastic formwork is used to construct in-situ concrete paving. The plastic formwork is sacrificial and remains embedded in the concrete creating a form akin to that of a flexible block paving.

The resulting pavement is of a high strength and therefore offers long serviceability with little maintenance. Because it is a flexible pavement it does not crack in the presence of subsurface deficiencies but will deform and, providing the deformation is not too great, should always offer an all weather surface similar to that of block paving.

Plate: www. roughtons.com

5 Upgrade Option Summary

5.1 The Road Environment

It has become increasingly recognised that the life-time performance of LVRRs is influenced to a greater extent than higher volume roads by the impacts of what is termed the Road Environment, Table 14. It follows that any summary of the options for upgrading LVRRs should include an assessment of these road environment factors.

Table 14 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/rainfall.	The prevailing climate will influence the supply and movement of water. Climate impacts upon the road in terms of direct erosion through run-off and influences the groundwater regime (hydrology).
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 availability of materials and resources.
Subgrade conditions	The sub-grade is essentially the foundation layer for the pavement and the assessment of its condition is fundamental to the road design.
Traffic	Although recent research indicate that the influence of traffic on LVRRs is often less than that from other road environment parameters, due consideration still needs to be given to the influence of traffic and, in particular, the risk of axle overloading.
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. 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.

5.2 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[13,14]. In general terms these Quaternary deposits 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 (see below).

Hydrology

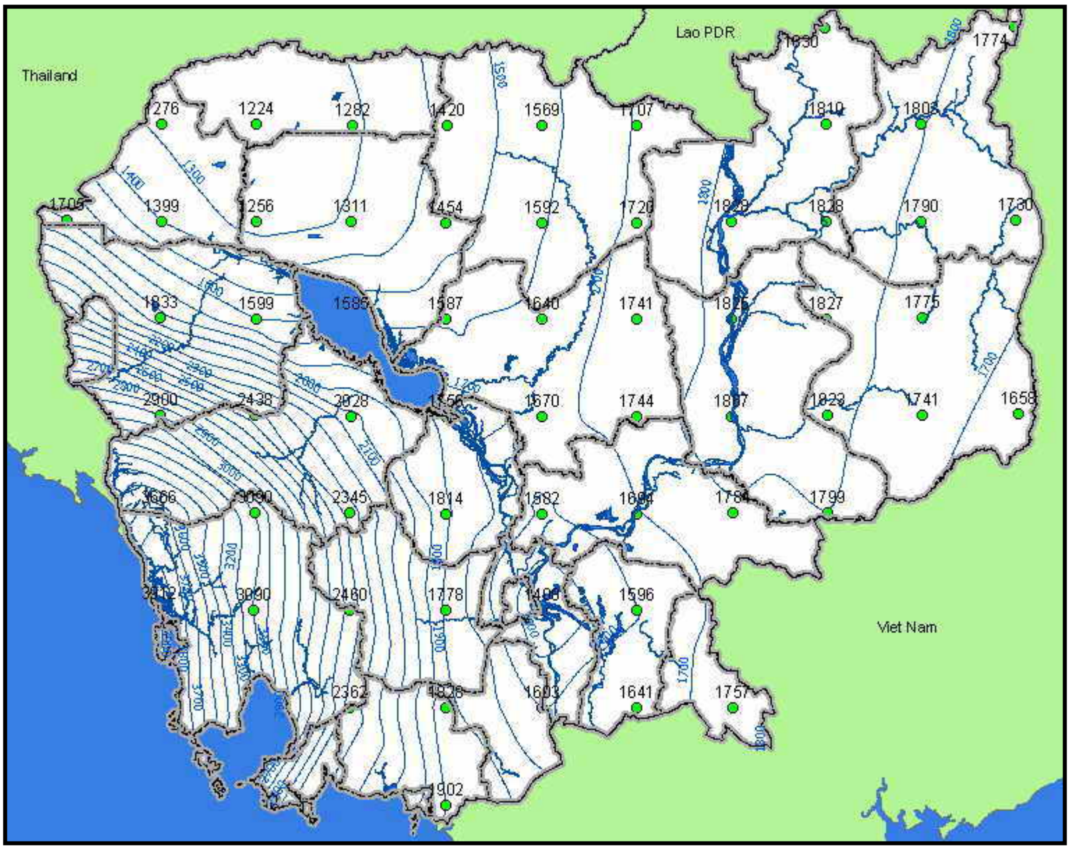
1. Significant areas of the Lower Mekong basin in Cambodia are subjected to serious flooding.
2. SEACAP 19 Technical Paper 6[15] notes that the hydrology effects in the Lower Mekong are…. "*… complex, and although floods occur every year, they vary greatly in height and intensity. Some of the lower lying 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.*"

---

[13] 1: 1,000,000 geological map of S E Asia
[14] Atlas of Cambodia; National Poverty and Environment Maps, Danida, 2006
[15] Howell, J, 2008. Study of Road Embankment Erosion and Protection, SEACAP 19 report to DFID

3. 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.

Figure 4 Rainfall Patterns in Cambodia (Atlas of Cambodia)



Terrain

There are distinct terrain divisions within Cambodia as follows;

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.
4. There is evidence that some local authorities may appreciate the need for traffic management measures to protect LVRRs, see for example Plates 5 and 6.

Plate 5 Heavy traffic barrier, Puok, Cambodia

Plate 6 Heavy traffic control, Ninh Binh, Vietnam

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.

5.3 Key Pavement and Surfacing Options

As indicated in the previous Chapter there is a wide matrix of LVRR surfacing and pavement layer options potentially available for use in Cambodia. It would be prudent, however, at this stage, from the point of view of design, construction supervision and general road management, to concentrate development on a more limited range of options.

A list of these options is shown in Figure 5 in relation to key construction, performance and sustainability criteria. Table 15 shows how this matrix of options could be adapted to some typical Cambodian road environments.

Figure 5 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

Table 15 Matrix of Upgrade Options and Typical Cambodian Environments;

Typical Road Environment	Likely Up-grade Options	Comments
Flat terrain, adequate supplies of good quality gravel	Sealed armoured gravel	Low to moderate traffic, with few heavy trucks, no overloading.
	Sealed gravel base/sub-base	Low traffic no heavy trucks
	Sealed lime stabilised gravel base/sub-base	Low-moderate traffic; overloading risk assessed in design
	Unsealed gravel wearing course	Not recommended in high rainfall Southeast. Maintenance essential
Flat terrain subject to flooding. No gravel or aggregate nearby; some sand deposits	Non-reinforced concrete on cement stabilised sand sub-base	High resistance to flooding (shoulders are a key issue) and overloading
	Stone sett/cobble stone on cement stabilised sub-base	High resistance to flooding and overloading but requires importation of stone
	Sealed WBM over cement stabilised sand sub-base	Moderate resistance to flooding (requires trials), requires imported stone
	Sealed cement stabilised sand base-sub-base	Low-moderate traffic; overloading risk assessed in design. Not yet trialled in Cambodia
Rolling terrain to hilly terrain with variable quality hill gravel.	Sealed lime stabilised gravel base/sub-base	Low-moderate traffic; overloading risk assessed in design
	Sealed WBM or DBM base/sub-base	Low-moderate traffic; overloading risk assessed in design
	Sealed WBM or DBM base, gravel sub-base or lime stabilised gravel sub-base.	Low-moderate traffic; overloading risk assessed in design
	Unsealed gravel wearing course	Flat sections in EOD designs with selected gravel. Not recommended in Southeast. Maintenance required
Hill terrain, locally steep with aggregate sources and variable hill gravel	Sealed WBM/DBM base, sub-base.	Low-moderate traffic – overloading assessed in design
	Non-reinforced concrete on stabilised or non-stabilised gravel sub-base	High resistance to traffic and overloading risk. Difficult spots in EOD design
	Stone sett/cobble stone on gravel sub-base	Resistant to erosion, traffic. were suitable stone – can be overlain in staged construction

6 The Way Forward

6.1 General

In recent years there have been a number of Cambodian rural infrastructure programmes, either pavement research oriented or containing significant elements of pavement research within them. As regards options for upgrading LVRRs , there is a now a clear need to bring this work together into a comprehensive body of knowledge that is readily accessible to Cambodian rural engineers.

The SEACAP 19 Task 4 review has indicated that there a number of key gaps that should be addressed to take full advantage of already completed projects, namely;

- Performance monitoring of existing trials and additional sections of recently constructed rural roads
- Analysis of data from the above monitoring and other recovered information
- Mainstreaming of the information at both National and Provincial/District

In addition, there are sound research and development reason for considering the construction and performance monitoring of further combinations of pavement or surfacing type and road environment.

This work should then be brought together into practical Guideline on the selection and design of LVRRs in Cambodia.

6.2 Development Proposals

Proposals for addressing the identified knowledge and application gaps are contained in a concise Concept Note attached as Appendix A to this Technical Paper. This Concept Note summarises a possible way forward through a number of Modules that could be adopted singly or in combinations. These Modules are;

I Performance Monitoring

II Additional Trial Design and Construction

III Data Analysis and Interpretation

IV Dissemination and Mainstreaming

V Training of Upgrading Procedures

Details of the aims and possible modus operandi for these modules are contained with the Concept Note.

REFERENCES

Cook, J R, 2003. LCS Working Paper No 18, Puok Market Trial Road Investigation.

CSIR, 2001. Guidelines for the Selection, Design and Construction of Waterbound Macadam Base Layers. Guideline Document DP-2000/5 for the South African National Road Agency Ltd.

Danida, 2006. Atlas of Cambodia; National Poverty and Environment Maps,

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

ILO, 2008. Mainstreaming Labour-based Road Maintenance to the National Road Network in Cambodia; TA-9048. Annual Progress Report 2007.

Intech-TRL, 2006, SEACAP 2, Final Report,

Johnston & Salter D, 2001. Rural Road Investment, Maintenance and Sustainability A case study on the experience in the Cambodian of Province of Battambang. The ILO, Upstream Project, ILO CMB/97/M02/SID,

NZAID, 2008. Northwester Development Project, Summary Report – Trial Stabilisation project. NRDP Report to Ministry of Rural Development, Cambodia.

O'Connell, M, 2008. Stabilisation Techniques to Improve Local Materials for Rural Road Pavements in Cambodia, SEACAP 19 Technical Paper No 3 for DFID.

Rolt, J, (2008). Bamboo Reinforced Concrete Pavements. SEACAP 19, Technical Paper No 1 for DfID.

Rolt J and J R Cook , 2009. Technical Report on the Interim Condition and Performance of the RRST Trial Sections, Vietnam. SEACAP 27, Technical Report for DFID.

Roughton International Ltd, 2008. SEACAP 17 Rural Access Roads on Route No.3, Module 2 – Completion of Construction Report. Final report to the Ministry of Public Works and Transportation, Lao PDR

SADC, 2003. Guidelines on Low-Volume Sealed roads

World Bank, 2005. Surfacing Alternatives for Unsealed Rural roads

World Bank, 2007. Country Review Paper: Cambodia

DEVELOPMENT OF LOCAL RESOURCE BASED STANDARDS

Low Volume Rural Road Upgrade Options

Appendix A

Further Research Concept Note

Further Research Concept Note

A1 General Introduction

Technical Paper 4 has reviewed and summarised current information on the pavement options for upgrading the existing Cambodian LVRR network. It has also identified some technical knowledge gaps that can best be addressed by through a number of modules, namely:

I Performance Monitoring

II Additional Trial Design and Construction

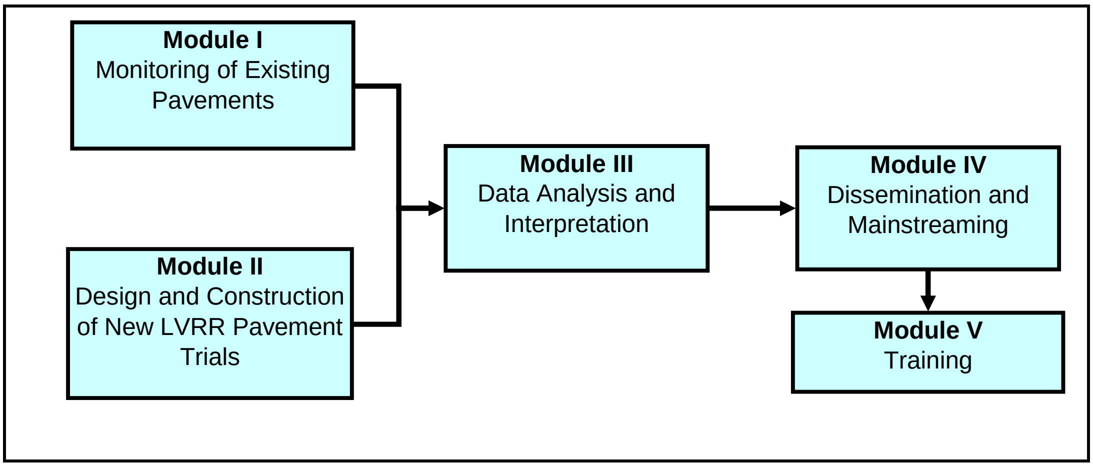
III Data Analysis and Interpretation

IV Dissemination and Mainstreaming

V Training

These are summarised in Figure A1 and detailed in the following sections.

Figure A1 Further LVRR Upgrade Modules



A2 Module 1: Monitoring of Existing Pavements

It is recognized research fact that it is only when road pavements have been in service for a reasonable proportion of their planned service lives that their performance can be properly assessed and compared with alternative designs. Most importantly, it is only then that firm conclusions can be drawn concerning their overall whole life costs and relative cost effectiveness. There is in this context a significant gap in the Cambodian LVRR knowledge base that requires attention

Monitoring of existing pavements could involve:

1. Monitoring of existing trials
2. Condition assessment of selected sections of existing paved roads

There are currently three sets of trial roads that are likely to yield valuable information relating to the selection of appropriate options for LVRR upgrading:

Puok trials: These have been intermittently monitored since 2003 and further data collection would be able to build on the existing knowledge base.

Neither the **ILO OTTA seal trials** in Batambang Province nor the **NRDP stabilisation trials** in Banteay Meanchay Province have as yet yielded any performance data and a monitoring programme would have to start from base level.

There is merit in selecting a number of recently constructed paved road sections to obtain data on the performance of sealed roads from a range of Cambodia road environments. The advantages of this "snapshot" approach to performance assessment have been illustrated by SEACAP 4 (RRGAP) in Vietnam and by Task 2 (ENS) from SEACAP 19 in Cambodia.

The pavement monitoring procedures would be based on those developed for the RRST trials in Vietnam and recently upgraded under the SEACAP 27 project. There would be an additional need to develop a Cambodian database of LVRR information. This could be linked to, or developed from the existing ENS database developed under Task 2 for SEACAP 19.

From a research viewpoint the monitoring programme should continue for a minimum of 5-6 years, although a number of shorter length modules may be considered attractive for contractual and interim dissemination reasons.

Key technical tasks to be undertaken in this Module would be

- Pavement-surfacing data collection
- Traffic data collection
- QA of site data
- Input of data into an appropriate database

A3 Module II: Additional Trial Design and Construction

Existing pavement trials in Cambodia have been constructed in a limited range of road environments. The Puok trials, which are currently the only ones that have delivered any useable research data, comprise very short lengths of a limited number of surfacing options on flat terrain. There therefore is a strong argument for expanding the Cambodian trials research matrix in order to develop a knowledge based strategy for the upgrade of LVRRs and the effective application of appropriate Standards and Specifications.

The following additional elements should be considered for inclusion in the expansion of the LVRR research matrix

- Steep terrain
- Higher rainfall areas
- Range of rural traffic patterns
- Additional pavements and surfaces such as
    - Mechanical and chemical stabilised base/sub-base
    - Non-reinforced concrete
    - Dry-bound macadam
    - Clay brick options

Trial sites in the wet and steep terrain of the South West and in the high terrain of the North East would seem to offer the best opportunities for an effective extension of the Cambodian LVRR research. There are obvious links to be made with the extension of other SEACAP 19 research task such Engineered Natural Surface and Stabilisation.

Key technical tasks to be undertaken in this Module would be

- Identification of sites
- Selection of appropriate options
- Collection of design data from sites

- Design of trial sections
- Supervision of construction
- As built surveys
- Database upgrade

There would also be a significant requirement for non-technical in put to liaison at central and provincial-district level as well coordination between any funding agencies. The contractual aspects of the trials construction such bidding and contractor negotiation may also have to be considered, although for the purposes of this Concept Note it has been assumed that this would be handled separately.

A4 Module III: Data Analysis and Interpretation

Collecting data on LVRR trials is simply not enough; there has to be an associated data analysis and interpretation programme. Ideally this should be combination of periodic database updating linked to data analysis and the enhancement and expansion of cost and performance models. SEACAP 27 in Vietnam has developed a number of procedures for updating and analysing trials data that could be suitably modified to interpret Cambodian trial information.

Key technical tasks to be undertaken in this Module would be:

- Collation of cross-checking of recovered data
- Analysis of key pavement/surface parameters
- Traffic analysis
- Interpretation of analysed data based on key performance and road environment factors
- Development or upgrading of performance models
- Development or upgrading of a whole-life cost

There would in addition be associated liaison and administration activities.

A5 Module IV: Dissemination and Mainstreaming

Dissemination is commonly acknowledged as a critical objective for most research programmes. Paradoxically however, it is frequently "tacked-on" as a late stage activity to these research programmes and consequently is often not given the focus and attention it demands. Follow-on mainstreaming, which should be the final aim of any practical research outcomes, then frequently becomes difficult to achieve effectively.

It is strongly recommended that effective dissemination and consequent mainstreaming of the results of further Cambodian LVRR research should be accorded the highest priority; hence the proposal for a Dissemination and Mainstreaming Module separate from other project reporting and liaison activities.

It was noted during the 2008 SPM in Vientiane[16] that there although may be few overall "Knowledge Gaps" in LVRR engineering there are significant gaps in the application of this knowledge. This is particularly true with respect to the dissemination of research knowledge at provincial and district levels where many of the crucial decisions on LVRR upgrading will be made. It is considered therefore that particular emphasis should be placed on targeting dissemination at not only central practitioners but also provincial and district engineers.

Key elements of this module should be

[16] Knowledge Gaps in Research – key note paper by Dr J Rolt, SEACAP Practitioners Meeting, Vientiane, Lao PDR, November 2008.

1. Drafting of an appropriate LVRR guideline that encompasses current research and presents LVRR upgrading procedures it in a practical manner and takes in to account or amends existing Standards and Specifications.
2. Trialling of this guideline under practical real-time situations.
3. Ensure widespread exposure of the LVRR Guideline by means of workshops and posting on accessible websites in both English and Khmer.

A6 Module V: Training in Upgrading Procedures

This module is closely linked to Module IV but has been separated from it in the perception that the training activities may best be undertaken by specialists in adult learning with the support of LVRR experts. In other words, LVRR upgrading research and related dissemination documentation should be led by experienced LVRR professionals, but the related training should be led by experienced professionals in that field. This training should be delivered in the National Language

Key elements of this module should be,

- Preparation of training materials on LVRR upgrading by the principal authors of the Upgrade Guideline with support from training specialists.
- Development of suitable training programmes that involve both classroom and field activities by a combination of LVRR and training specialists.
- Delivery of training programmes by experienced trainers with the active support of LVRR upgrade specialists.

A7 Resources

The following Table A1 presents an outline of the likely key technical resources required for the above Modules based on the following assumptions:

- Monitoring will involve two complete rounds of data collection within a 12 month period
- The extent of the monitoring is as indicated in the notes
- Construction costs of any additional trials is handled under separate arrangements
- No administrative, liaison or management time is included
- Additional technical support will be required from provincial and district staff.

Table A1 Key Technical Resources

	Man-months required per Module								
Expertise	**I**			**II**	**III**			**IV**	**V**
	a	b	c		a	b	c		
Rural Road Specialist	1.0	1.5	2.0	3.0	2.0	3.0	4.0	4.0	2.0
Senior Road Engineer	1.0	3.0	4.0	6.0	1.0	2.0	3.0	4.0	2.0
IT Specialist	0.5	0.5	1.0		1.0	1.0	1.0	0.5	
Engineer-Technicians	2.0	4.0	6.0	12.0	1.0	1.0	1.0	2.0	
Training Specialist									4.0
Training Engineers									6.0

a Only existing trials
b Existing site + additional road sections
c Exist trials + additional road sections + 2 new trial areas