Intech Associates
CONSULTING ENGINEERS

TRL

Department for International Development SEACAP PROGRAMME

Managed by
Crown Agents

SEACAP 8
CAMBODIA Low Cost Surfacing Phase 2

FINAL REPORT

July 2006

Intech
Associates
CONSULTING ENGINEERS

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Our Ref: 0370/VA5

Your Ref: SEACAP 8

31 January 2007

Attention Excellency Suos Kong
Secretary of State
Ministry of Rural Development
Chairman, SEACAP Steering Committee
Chairman, CNCTP

Dear Excellency Suos Kong,

RE: SEACAP 8 FINAL REPORT

Please find attached a copy of the Final Report for the Low Cost Surfacing, Phase 2 (SEACAP 8), which incorporates the comments received on the drafts.

We hope that some of the recommendations of this report will be able to be applied in Rural Road design and construction practices and taken up by future road sector initiatives.

We would like to thank everybody involved with the Puok trials and SEACAP 8 for their support and contributions.

Yours sincerely

Robert Petts
Project Manager

cc H.E. Lim Sidenine, MPWT, Vice Chairman SEACAP Steering Committee
Dr. Om Romny, ITC, Member SEACAP Steering Committee
Peter O'Neill, DFID, UK
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Resident Representatives, WB, ADB, KfW

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ABBREVIATIONS AND ACRONYMS

ADB	Asian Development Bank
ADT	Average Daily Traffic
AFEO	Asian Federation of Engineering Organisations
ALD	Average Least Dimension
ARTIC	Articulated
ASEAN	Association of Southeast Asian Nations
AusAID	Australian Agency for International Aid
CBR	California Bearing Ratio
CFRTD	Cambodia Forum for Rural Transport Development
CNCTP	Cambodia National Community of Transport Practitioners
CSIR	Council for Scientific and Industrial Research
DFID	Department for International Development
DST	Department of Science and Technology
DTW	A Mechanical Engineering NGO
EDC	Economically emerging and Developing Country
Eng	Engineering
EU	European Union
FAO	Food and Agriculture Organisation
FFW	Food For Work
GMSARN	Greater Mekong Sub-region Academic & Research Network
GTZ	German Agency for Technical Co-operation
hp	horsepower
HQ	Head Quarter
IFAD	International Funds for Agricultural Development
IFG	International Focus Group (for Rural Road Engineering)
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
JFPR	Japanese Fund for Poverty Reduction
JICA	Japanese International Co-operation Agency
KaR	Knowledge and Research
km	kilometre
kW	kilowatt
LB	Labour Based
LBAT	Labour-Based Appropriate Technology
LBRIRMP	Labour-Based Rural Infrastructure Rehabilitation and Maintenance Project
LCS	Low Cost Surfacing
M	metre
MARD	Ministry of Agriculture and Rural Development
MoF	Ministry of Finance
MoT	Ministry of Transport
MPW&T	Ministry of Public Works and Transport (Cambodia)
MRD	Ministry of Rural Development (Cambodia)
NCP	National Community of Practitioners
NFG	National Focus Group (for Rural Road Engineering)

NGOs	Non-Governmental Organisations
NPA	Norwegian People's Aid
NPRD	National Programme to Rehabilitate and Develop Cambodia
NRDP	North-western Rural Development Project
ODA	Official Development Assistance
ORN	Overseas Road Note
PCU	Percentage Car Unit
PDP	Provincial Development Programme
PDRD	Provincial Department of Rural Development
PIARC	World Road Association
PIP	Public Investment Programme
PMU	Project Management Unit
PRASAC	Programme de Rehabilitation et d'Appui au Secteur Agricole du Cambodge
PRDC	Provincial Rural Development Committee
PRIP	Provincial and Rural Infrastructure Programme
RD&RP	Rural Development and Resettlement Project
RDS	Rural Development Structure
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
RT2	Rural Transport 2nd Project, Vietnam
SEACAP	South East Asia Community Access Programme
SEDP I	First Five-Year Socio-Economic Development Plan, 1996-2000
SEDP II	Second Five-Year Socio-Economic Development Plan, 2001-2005
SEILA	Multilateral donors - Government Rural Infrastructure Development Programme
SIDA	Swedish International Development Agency
SWOT	Strengths, Weaknesses, Opportunities & Treats
TDSI	Transport Development Strategy Institute
TEDI	Transport Engineering Design Incorporation
TKP	Transport Knowledge Partnership
TMP	Transport Mainstreaming Partnership
ToR	Terms of Reference
TRIP	Tertiary Roads Improvement Project
TRL	Transport Research Laboratory
UK	United Kingdom
UN	United Nations
UNCDF	United Nations Capital Development Fund
UNDP	United Nations Development Programme
UNICEF	United Nations Children's Fund
VDC	Village Development Committee
WB	World Bank
WD	Worker-days
WBM	Water Bound Macadam
WFP	World Food Programme
WSP	A firm of International Management Consultants
ZOPP	German acronym for Goal Orientated Project Planning

FOREWORD

THE LOW COST ROAD SURFACING INITIATIVE

The Low Cost Road Surfacing (LCS) initiative aims to provide documentation and international guidelines on the provision and maintenance of low cost road surfaces and basic access for rural communities in economically emerging and developing countries (EDCs). It is based on a research project funded principally by the British Department for International Development (DFID) under its Knowledge and Research (KaR) programme and more recently South East Asia Community Access Programme (SEACAP). The initiative is led by UK-based specialist consultants Intech Associates in association with TRL Ltd. Collaboration was established with a number of organisations with interests or experience in the sector, including CSIR, ILO/ASIST, the ILO-SIDA funded Upstream Project and Ministry of Rural Development Cambodia, Ministry of Transport Vietnam, Greater Mekong Sub-region Academic Research Network, The Institute of Technology of Cambodia (ITC), Chieng Mai University Thailand, the Committee C20 (Appropriate Development) and Committee TC2.5 (Rural Roads and Accessibility) of PIARC (World Road Association) and the International Focus Group (IFG) for Rural Road Engineering. The LCS programme is being implemented over a 5-year period from 2001 to 2006.

The LCS programme is concerned with supporting sustainable improvements in low cost road surfacing and basic access to support poverty reduction initiatives in rural communities. This implies the effective use of local resources, particularly human resources, locally available and alternative materials, and readily available and low cost intermediate equipment wherever possible. In the situation of scarce financial resources, it also requires the application of affordable and appropriate standards and adoption of techniques suitable for use by the indigenous private sector (particularly small domestic construction enterprises) and local communities. The application of good management practices coupled with adequate technical inputs are necessary to achieve appropriate and sustainable access.

It is intended that dissemination of the guidelines will be through electronic media as well as more traditional publication routes.

SEACAP

A substantial programme of DFID funded research projects is underway in South East Asia. In Cambodia this is being carried out in cooperation with, and supporting, the Royal Government of Cambodia (RGC). At present projects operate under the South East Asia Community Access Programme (SEACAP) and follow on from the now discontinued Infrastructure and Urban Development (IUD) Engineering Knowledge and Research (EngKaR) programme. SEACAP builds upon the successful DFID collaborative research projects already completed in Cambodia and Vietnam on identifying ways to improve sustainable access to rural communities to facilitate access to health, education, trade, social facilities and services, thereby creating opportunity for pro-poor growth and escape from poverty.

The objectives of the Programme are ‘Livelihoods of poor and vulnerable people in SE Asia improved sustainably’ and include empowering local ownership of their access. This includes initiatives that allow roads to be constructed and maintained in a sustainable way by local people using local materials, local labour and skills, and simple, low cost equipment. More affordable in capital and recurrent costs, these rural road solutions have become the spine of local government policy and this programme is designed to expand the successes of the initial research work.

SEACAP advocates two simple premises for achieving sustainable community access. One is maximizing the use of local resource based technologies. The other is minimizing full life cycle costing. The SEACAP research work carried out provides sound evidence for stakeholders on the technical, financial and economic viability of the premises.

GLOBAL TRANSPORT KNOWLEDGE PARTNERSHIP

The global Transport Knowledge Partnership (gTKP) is a global initiative that has the broad aims of making knowledge more accessible to its partners, providing a global transport resource, and encouraging a greater up-take of existing knowledge. A main principle of gTKP is that it will work in support of existing initiatives and structures. gTKP will also work principally for the benefit of developing countries, giving them greater voice in the way that knowledge is generated and managed, and providing them with greater and more appropriate access to knowledge.

Further information may be obtained from:- www.gtkp.org

TRANSPORT LINKS

DFID and previous UK government administrations have a long history in funding, promoting and disseminating transport research for developing countries and countries in transition. Through the Knowledge and Research (KaR) programme, DFID has supported a range of research projects addressing technical, economic, management and policy issues in transport development.

Many of the research outputs may be downloaded from:

www.transport-links.org

CAMBODIA NATIONAL COMMUNITY OF TRANSPORT PRACTITIONERS

CNCTP is a partnership of organisations and individuals that share a concern for good management and use of rural road network assets in Cambodia and whose interests are best served and developed through a common platform that has strong government recognition. The CNCTP is also a network of transport development stakeholders seeking to accelerate the implementation of effective, efficient and equitable transport services in Cambodia through broader integrated information and communication of transport knowledge.

Many of the research outputs and documentation related to the transport sector in Cambodia may be downloaded from:

www.cnctp.info

THIS REPORT

This report is the Final Document for Phase 2 of the Low Cost Road Surfacing (LCS) initiative (KaR7782) implemented as SEACAP 8. It relates to a contract financed by DFID and managed by Intech Associates and TRL through the SEACAP initiative with contract management by Crown Agents. The report incorporates the reporting on the component: Maintenance Strategy and Whole Life Cost Monitoring of the Trials. Previous reports covered the other project components of: Immediate Repair and Maintenance to the Trial Sections and Axle Loading and Pavement Design Strategy Workshop.

The LCS Project welcomes dialogue with engineers, managers, organisations, communities and individuals active or interested in the rural transport sector with the objective of the promotion of a sustainable rural access approach for EDCs.

Contact: rob@intech-consult.demon.co.uk

This document is an output from a project funded by the UK Department for International Development (DFID) for the benefit of developing countries. The views expressed are not necessarily those of the DFID.

The ToRs required the consultant inter alia to carry out the following:-

"The Consultant will prepare a report on proposed maintenance strategy options for the 3 km of Puok trial pavements for the period 2004 – 2006. This will include proposed arrangements and monitoring of maintenance and repair works and costing of these. Whole life cost monitoring arrangements will also be proposed based on the works costs and traffic costing based on HDM4 roughness related relationships. The consultant will also make recommendations on other socio-economic and

environmental aspects that could be brought into an equitable and poverty reduction focused, whole life assessment.

After agreement of the Strategy with MRD and DFID, the Consultant will organise the maintenance and monitoring work and document the research findings."

CAMBODIA LOW COST SURFACING TRIALS PHASE 2 COMPLETION REPORT

First Edition: July 2006

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EXECUTIVE SUMMARY

The construction of Pouk Low Cost Surfacing Trials in Siem Reap Province, Cambodia was completed in September 2002 under a cooperation agreement between Intech Associates and ILO Upstream Project, utilising DFID funding provided under the EngKaR programme. The work was carried out under the authority of Ministry of Rural Development (MRD) and in cooperation with the Ministry of Public Works and Transport (MPW&T), Cambodia using local resource based approaches utilising two local contractors with the aim of demonstrating techniques that maximise the use of local labour and materials.

An objective was to trial more sustainable rural road surfacing alternatives to problematic gravel/laterite, in view of the widespread scarcity of good gravel materials in Cambodia, long gravel haul distances, high rates of gravel losses from road surfaces and problems of funding and achieving maintenance of gravel roads.

An initial monitoring of the surfacing trials was undertaken in April-May 2003, all trials road sections were found to be in good condition.

In February 2003, a sand deposit was discovered close to the road trial site and a commercial extraction operation was commenced to exploit the sand to supply many of the buildings and hotels being constructed in Siem Reap; the large provincial town nearby. Large 3-axle trucks with extended bodies were used with excessive axle loading to haul along the trial road; well beyond the rural road design criteria used for the trials site. Discussions took place with the Pouk District authority; the Project Research Engineer warned that the excessive overloading would damage the Trial Road and it was agreed that the District Authority would advise the principal haulage company to reduce their payloads. Despite these efforts the heavily overloaded trucks continued to carry sand through the LCS trials. This was exacerbated in the rain season as the sand was wet and the road was at its weakest state in the annual climatic cycle. In August 2003[1] during the routine monitoring visit, the first signs of failure appeared on Section 4 with cracking affecting two areas of approximately 4 square metres. By October 2003 the damage was already extensive and Intech carried out the first investigations of the pavement distress and causes.

In January 2004, an Intech Associates technical team visited the trial site to carry out a full survey. It was found that 80% of Trial Section No 4 and 20% of Trail Section No 9 had become severely damaged and some of the other sections were also showing signs of distress.

After the January visit, a rehabilitation and repair proposal was submitted to DFID through the SEACAP programme. The proposal has been approved as “SEACAP-8 Cambodia Low Cost Surfacing Phase II”.

The rehabilitation and repair of Phase II was started in May 2005 and the major surface work items were completed in late July 2005. Monitoring of the trial continued until March 2006 with a regular visit programme of every 2 months. It has been necessary to carry out deterrent measures to prevent the large trucks from continuing to use the route.

Monitoring of the trials is planned to continue and the findings of this study will contribute to the development of international guidelines for the selected trial sections constructed.

1 *In Cambodia, the rain season is usually from July to November*

RECOMMENDATIONS OF THIS FINAL SEACAP 8 REPORT INCLUDE:-

1. A programme of annual monitoring of the trial roads should be set up as recommended by this report, to enable the whole life costing assumptions to be verified or modified.
2. The Low Cost Surfacing trials have clearly demonstrated that there are a number of rural road surfacing options and alternatives to problematic gravel/laterite that make good use of local resources, can be constructed by labour-based methods by small locally based contractors with limited equipment holdings, with local employment and community benefits, with low maintenance and good whole life costs attributes. Government policy and road network management strategy should be reviewed to encourage and increase the application of these alternatives, and to limit the use of gravel as a road surface to those locations where it can be clearly shown to be cost effective and sustainable.
3. The findings of this Report and the Low Cost Surfacing trials in Cambodia and Vietnam should be used to develop the Cambodia rural roads design guidelines, standards and specifications, and contribute to development of international guidelines on rural road surfacing, under the planned future road sector initiatives.
4. Further research on rural road surfaces, road maintenance, Vehicle Operating Cost (VOC), axle loading and socio-economic issues is required to provide the knowledge and stronger justification for a wider range of surface options and improved management of the rural road network to reduce transport costs and rural poverty in Cambodia.
5. Amendment to the national Legislation and regulation should be considered to categorise any route that will be used for construction materials haulage or timber extraction as such, in consideration of the severe damage caused by construction materials haulage and logging trucks. In certain circumstances (such as for rural roads) the pit or quarry developer could be made responsible for the necessary upgrading of load capacity of the road and maintenance as long as the quarry/extraction licence continues. Costs could be recovered by the resource operator/manager from the sale of the minerals.

SEACAP 8 - LCS WORKING PAPER No. 24

LOW COST SURFACING, CAMBODIA, PHASE 2 COMPLETION REPORT

PUOK MARKET TRIAL ROAD – SIEM REAP PROVINCE, CAMBODIA

1 INTRODUCTION

Under the previous KaR 7782 Project Phase 1, and subsequent SEACAP 8, investigations were carried out and guidelines are being developed on alternative low cost rural road surfaces, which in appropriate circumstances will have lower whole-life-costs than traditional gravel. The alternative surfaces can also have better local resource use attributes; with the effect of injecting more of the road works costs into the local community through labour employment, use of local materials and enterprises. The rationale for this approach is set out in detail in LCS Working Paper No 1 (Reference 16).

As part of the Phase 1 work, 10 sections of alternative paving were constructed at Puok Market, Siem Reap Province in Cambodia on a tertiary rural route (refer to Figures 1.1, and 1.2). The Puok Market paving trials have been constructed under a cooperation initiative between Intech Associates, ILO Upstream Project, Ministry of Public Works & Transport and Ministry of Rural Development, Cambodia, with principal funding from DFID and SIDA support. Two local contractors, using the minimum of equipment and the maximum input of local unskilled and skilled labour, constructed the trials in mid 2002.

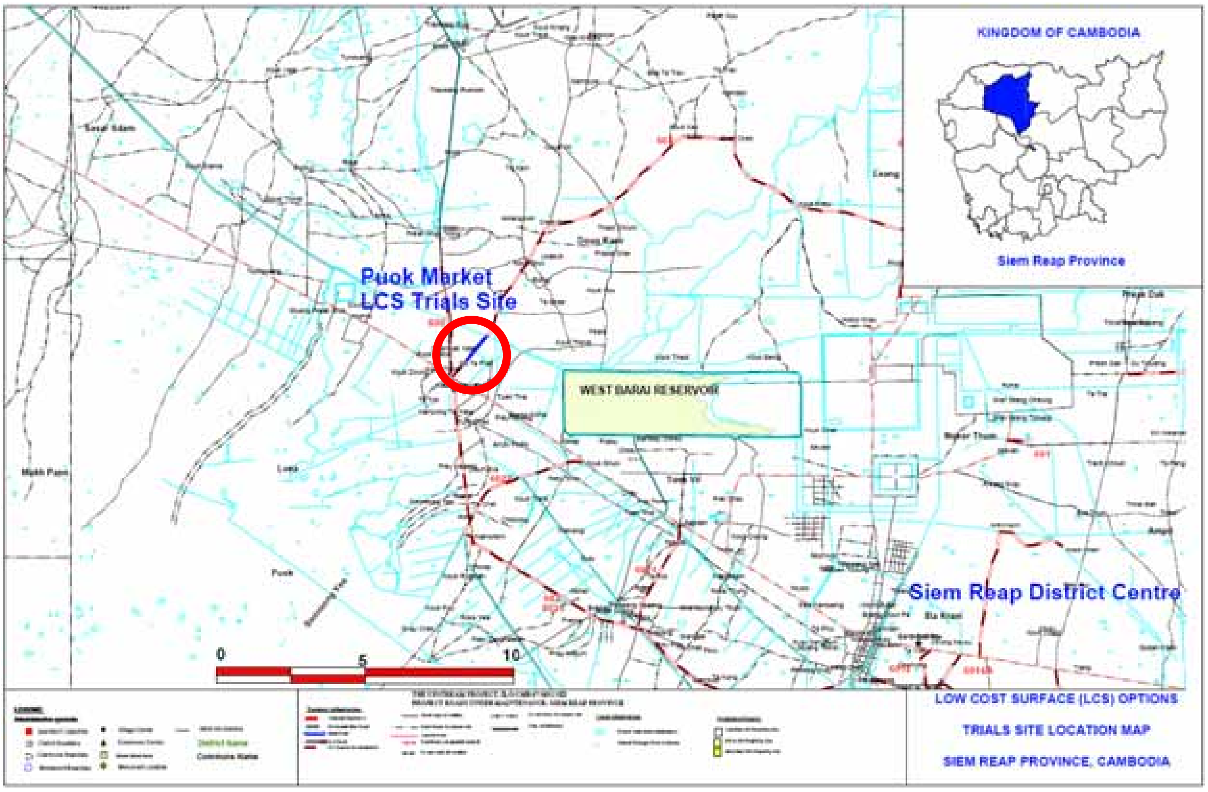


Figure 1.1: Location of Puok Trials (marked in thick blue line –)

Figure 1.2: Puok Trials Construction Works

The aim of the paving trials was to investigate and demonstrate the construction of a range of paving techniques as an alternative to gravel/laterite, suitable for secondary and minor roads using local-resource-based techniques wherever possible. The trials will also be the basis of assessing whole life costs of the various paving options.

The characteristics of the trial road site are shown in Table 1.1 below.

Environment Factor	**Puok Area**
Terrain	Inland flat flood plain
Climate	Seasonal Wet. Rainfall 1,500 – 1,800 mm/year. Principally from (May) to (November)
Design Traffic	Year 2000: ADT approx 500. Predominantly 2 wheel vehicles representing a flow of about 2,000pcu.
Sub-Grade	Clay. Low embankment; CBR strength 7% (soaked) and 20-40% in situ protected
Cross Section	4.0 metre carriageway and 0.5 metre shoulders
Local materials	Local sand available, otherwise laterite gravel @ 55 km distance and stone @ 57 km distance
Maintenance Regime	No effective regime in place
Construction Regime	To utilise small scale local contractors

Table 1.1: Characteristics of the Puok Market Surfacing Trials Location

The construction of the Puok Market trial sections was completed in September 2002. Initial monitoring of the trials was carried out in April-June 2003 and they were found to be in good condition (Low Cost Surfacing Working Paper No 17, August 2003).

During the mid year 2003 wet season, the Puok Trial sections were subjected to loading by significant numbers of sand haulage trucks. It was apparent that these trucks are heavily overloaded, hauling wet sand, and used the road on a regular daily basis. The result has been that one section of the trials (No 4) became severely damaged and some other sections also showed signs of distress.

Figure 1.3: Overloaded Truck on the Puok Trial Road (Section 4)

In October 2003 a preliminary assessment of the condition of trial pavements was undertaken by Intech Associates and reported in LCS Working Paper 18. The report advised:-

> *"The evidence from the current investigation indicates that the rapid deterioration of Section 4 pavement, and the onset of Section 9 deterioration, is primarily the result of excessive traffic loading. This loading is well beyond that used for the design of the pavements and over twice the legal loading for provincial roads (a higher category than the Puok trial route). The excessive loading failure rationale is supported by the nature of the deterioration and its coincidence with the running of overloaded sand trucks on the trial sections since July 2003."*

In January 2004, an Intech Associates technical team comprising, Mr Robert Petts, Mr Heng Kackada and Dr Jasper Cook, visited the trial site. The principal objective was to assess the trials condition at and adjacent to the ILO-Upstream-built (in year 2000) bamboo reinforced concrete trial road sections, and to assess locally available construction materials. In addition, it was intended especially to discuss with Pouk District officials the future arrangements of monitoring of the trials and how to protect the trials from heavily overloaded trucks in the future after the repairs were carried out (Phase II).

After the January 2004 visit, a proposal was submitted to DFID through the SEACAP programme for Low Cost Road Surfacing Trials Phase 2 which comprised three modules:-

1. Immediate Repair and Maintenance to the Trial Sections
2. Maintenance Strategy and Whole Life Cost Monitoring of the Trials
3. Axle Loading and Pavement Design Strategy Workshop

The Intech-TRL research engineer carried out site investigations of Phase II in January 2005 to assess the Trials condition at the end of the dry season of 2005 and to plan for repair and maintenance to be carried out under Phase II. The physical works (repair and maintenance) was started in April and all the main sub-contractor's works were completed in July 2005 while the monitoring continued at regular intervals (every 2 months) by the research engineer, until the end of the Phase II contract in March 2006.

2 REPORT OBJECTIVES

This report principally covers Module 2 of the Cambodia Low Cost Surfacing Trials Phase II. It also provides summary information on the works carried out under Phase II and lessons learned after three and a half years of monitoring after initial construction was completed in September 2002.

Module 1 reporting was contained in LCS Working Paper No 20 - Cambodia Phase 2 Low Cost Surfacing Trials, Inception Document, SEACAP 8 (Reference 10).

The outcome of Module 3 has been reported in the Proceedings of the Workshop on Axle Loading and Pavement Design Strategy. This workshop was jointly organised in November 2004 by the Ministry of Rural Development and the Ministry of Public Works and Transport with technical assistance from the SEACAP-8 project and the NRDP-IRAP project. Detailed documentation of this workshop (Reference 11) can be downloaded from www.cnctp.info

3 PREPARATION AND ARRANGEMENTS FOR PHASE II

The inception, preparation and management of the trials were carried out from the SEACAP-8 project office in Phnom Penh. These involved successive meetings with the local authority (Pouk District), re-assessment of the condition of the trial sections, local resources identification, planning for repair and maintenances works, design and compilation of specifications and standards works, and preparation of the contract documents to be used to engage the local contractor that had previously constructed part of the Trial in 2002.

One of the two contractors who carried out the original work was identified as the contractor most suitable for this repair and rehabilitation works. He was directly appointed on a negotiated basis, as was the case in the original trials. Repairs were funded principally by DFID through SEACAP-8. Intech-TRL prepared a contract document based on the format of the original trials construction. Supervision of the work was carried out by Intech-TRL.

Recording of rehabilitation works data on site during Phase II was carried out on a daily basis through the site control sheets. These were completed by the contractor's supervisor. The site control sheets were submitted to the Intech Site Engineer who was based in Siem Reap province. The amount of labour, materials and tasks carried out per day were recorded on these site control sheets for every process of the works. Dynamic Cone Penetrometer (DCP) readings were taken for the subbase layer after compaction. In addition, levels were taken before the works were started to establish a benchmark and later during the construction to check the thickness of each pavement layer as it was constructed.

Photographs of the construction processes and the operations on site were also taken at regular intervals following the works progress.

4 OVERLOADING PROBLEM AND LOCAL SOLUTION

Lessons learned from the failure of Sections 4 and 9 have shown that it was crucial for the trials that the issues of the heavily overloaded trucks be resolved. The excessively overloaded trucks had caused the failures of Section 4 and Section 9 and distress of other Sections. These loading conditions of up to more than 50 tonnes on a 3 axle truck were beyond the researched limits of regional pavement design and performance, particularly for rural roads. Cambodia's national roads are not designed for such levels of overloading. The Axle Loading workshop organised under SEACAP 8 (Reference 11) reveals the scale and challenge of the problem.

Meetings carried out at the Pouk District Office were arranged to seek local solutions to prevent the Trial Roads being used by heavy trucks in the future.

An agreement was made and based on an inter-ministerial declaration of MPW&T and MRD that recommended using a vehicle size restriction of 2.30 metre clearance on rural roads as a positive measure for preventing the usage of these excessively loaded heavy trucks. Therefore the vehicle-size restriction was incorporated into the Phase II construction plan (Figure 4.1). This measure would not only reduce the damage on the route due to uncontrollable vehicle loading, but also contribute to a reduction of long term road maintenance needs.

Figure 4.1: Vehicle side-restriction barrier, Puok Market Trials

5 SITE INVESTIGATION AND SURVEY UNDERTAKEN IN PHASE II

5.1 Local Resources Survey

Material investigations were carried out in January 2005 in order to source suitably available material that could be used for reconstruction and repair of the trial road sections under Phase II. Five construction material sources in Siem Reap and Banteay Meanchey province were visited in order to gauge the availability, cost and suitability of materials for the trial road rehabilitation. Details of the material investigations and laboratory testing are attached to this report as Appendix-A.

It was also identified that local labour and contractors have had experience in constructing a so called "macadam road-base" with bitumen surface treatment on urban, main and secondary roads. However, investigations and experience of the Research Engineer revealed that the design and construction methods used were not appropriate for the following reasons:

- The large broken stone pieces are laid on a compacted surface without a cushion layer. This method makes individual stones unstable and the layer as a whole is not dense, with considerable voids left beneath the stones, making it susceptible to long term irregular consolidation and settlement, especially under heavy traffic.
- Plastic material (clayey soil) is used to fill the voids in between the stone pieces. The interlocking effect of the plastic material is very poor and it affects the strength of the entire layer, particularly if moisture is allowed to penetrate (e.g. through a poorly maintained surface seal). Refer to Figure 5.1.
- Multiple layers of single size aggregate are used to blind the stone and make a relatively smooth finished surface. These materials remain loose and porous when a bituminous surface is applied, and are an inherently weak feature of the practice.

Figure 5.1: Poor Macadam roadbase construction technique filling the voids between stones with plastic fines

The technique is however fundamentally labour-based and therefore has desirable local employment benefits. Despite the above factors, the local contractor selected for the repairs, and the labour had experience in the construction of paved roads with hand-packed stone roadbases. This local knowledge could therefore be adapted to build a more durable road pavement with an appropriate design and construction methods.

After the material investigations, three pavement roadbase options were identified as possible solutions for the rehabilitation of Section 4 and Section 9:

1. Option 1 [2] was to use sand from Daun Koe, which is near the Trials Road, stabilised with cement as a roadbase.
2. Option 2 was to use natural gravel subbase from Phnom Dey and hand packed stone from the manual production quarry at Phnom Leap.
3. Option 3 was similar to the pavement design of Trial Section No 2 and Section No 6 which have a sand-aggregate roadbase.

2 Sand samples were taken for cement stabilization tests. See appendix A for details of test results

The last option was not selected because this option had already been trialled. While the first option was not selected either due to following reasons:

- The cement stabilisation option would have raised significant training, testing and organisational issues and for the short sections of the Puok trial this was not considered viable within the time and budget constraints.
- The Pouk Trial road has many adjacent houses located along its route and has very narrow shoulders. It was not possible to divert the relatively high volume of traffic at reasonable cost, which would have been necessary to ensure traffic free curing of the sand-cement stabilised materials.

Despite these comments it is proposed that sand-cement stabilisation should be further considered as an option for future research in the extensive areas of Cambodia with no hard stone natural resources.

Therefore the pavement structure as indicated by Figure 5.2 was adopted for the reconstruction of Section 4 and Section 9.

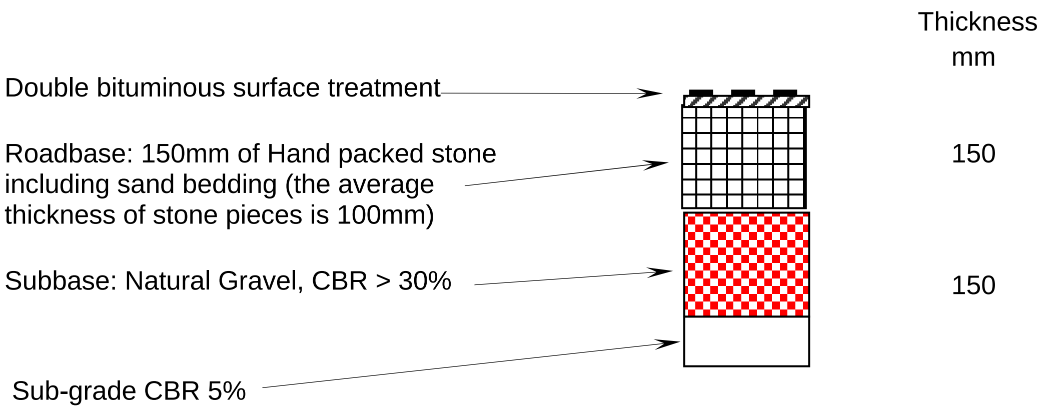


Figure 5.2: Rehabilitation Pavement structure design with hand-packed stone

5.2 Trial Condition Assessment and Plan for Civil Works

The condition of the trial sections 4 & 9 deteriorated further since the inspection visit carried out by Intech-TRL team in January 2004. A re-assessment of the trial sections was carried out in February 2005 to update its conditions and re-plan the works to be carried out under Phase II.

After the end of the rainy season of 2004 when the second site investigations took place, 80% of Sections 4 [3] and 20% of Section 9 [4] were in extremely poor condition with deep rutting and no effective surface sealing.

Section 3 and Section 5, the dressed-stone sections, were to be upgraded from a rough surface of dressed-stone to bituminous surfacing, thus demonstrating the possible stage construction strategy option using this technique.

3 *Section 4 original design: 200 mm thick of laterite subbase armoured by 70mm from well graded crushed aggregate paved with SBST.*

4 *Section 9: this section had a similar pavement structure to Section 4 but it was paved with a single bitumen Sand-Seal.*

A general overlay was to be applied on Section 2 of the sand-aggregate road base. After this upgrading Section 2 will have a different surfacing from Section 6 which was paved with a single bituminous surface treatment.

Two small potholes of about 1 m^2 in size developed on Section 6, which resulted from excessive traffic loading during the previous 3 years.

Edge failure was another problem at isolated locations on the carriageway. This problem affected all Trial Sections with bituminous surfacing. It was identified that mostly edge failure occurred at the access points to individual houses where the owners/tenants possess a car or small truck. Those locations were reinstated and flush concrete kerbs were placed to prevent this problem in the future (Figures 5.3 and 5.4).

Figure 5.3 & 5.4: Edge failure and construction of flush concrete kerbs

The laterite on the control Section No 10 was totally eroded from the surface. As remedial work, this section was overlaid with 100 mm of compacted laterite from Phnom Dey quarry.

Grass growing and debris accumulating along the shoulder prevented the efficient flow of rain water off the roadway. Those affected lengths were to be cleared. There were also locations where the laterite shoulder had been worn by traffic creating damage to the surface-level along the edge of the surfacing. Those areas were maintained with additional material and compaction.

Embankment erosion was identified and mostly occurred at access to rice fields and to houses which were located further away from the road. The identified areas were repaired with suitable trimming, refilling with in-situ soil and compacting and finally finished by turfing. At access points, a gentle ramp was constructed and covered with compacted laterite.

The final slab of the (year 2000 constructed) ILO bamboo reinforced concrete paving adjoining the 2002 trials was extensively cracked. This was the only slab in the approximately 2 kms of such paving. It was assessed to be due to the impact loading of heavy trucks with no anchorage or load transfer arrangement at the end of the slab abutting the adjoining laterite surfaced transition section. It is suggested that for future designs of un-reinforced or reinforced concrete paving, such start-end slabs should have reinforcement to resist these substantial impact loads.

Further details of road conditions and civil works undertaken by the sub-contractor under Phase II are given in Table 5.1 following.

Table 5.1: Summary of Road Condition and Proposed Works for each Section

SECTION	DESCRIPTION OF ORIGINAL DESIGN	CONDITION SUMMARY	PROPOSED ACTION (REPAIR AND MAINTENANCE OPTIONS)	ASSOCIATED RISKS OR COMMENTS
ILO	Bamboo Reinforced Concrete Pavement	No deterioration apart from cracking at the end of the last (transition) slab (Figure 6.1) and one other slab with a minor crack Minor cracking of bitumen seal joints	Reconstruction of last slab with un-reinforced concrete pavement (4m long).	None anticipated
Transition gap	10.1 metres long gap of Laterite surfacing between ILO-built BRCP and the start of the LCS Trials	Laterite surfacing level is below adjacent sections. Some surface erosion	Excavate approx 150-200mm existing laterite and reconstruct with 150mm thick of un-reinforced concrete pavement.	None anticipated
Trial Section No 1	Bamboo Reinforced Concrete Pavement (BRCP)	No deterioration apart from minor cracking of bitumen seal joints	Monitoring of construction joints Clearing grass and material accumulated on shoulders.	None anticipated
Trial Section No 2	Sand-Aggregate Roadbase & Single Bitumen Stone Chip Seal	Edge broken at access points to people's houses	General overlay with bitumen emulsion sand seal. Small areas of patching along the edge of surfacing and install concrete kerb at those problematic locations to prevent future edge failure (access to houses along this section).	None anticipated
Trial Section No 3	Dressed Stone with Bitumen-Sand Sealed Joint	No significant deterioration. Localised shallow depressions	Provide diluted emulsion tack coat, overlaid with thin layer of well graded crushed aggregate as regulating layer. The surface is then to be primed and paved with DBST (14mm and 8mm stone chipping). Clearing grass and material accumulated on laterite shoulder.	Peeling of regulating overlaid layer if poor adhesion with existing dressed-stone road surface
Trial Section No 4	Armoured Laterite Roadbase & Single Bitumen Stone Chip Seal	Severe rutting and 80% of the Section had failed Erosion occurred on the slope of the embankment.	Excavation and reconstruction of whole section with 150mm of hand packed stone blinded with sand/fine aggregate, primed with diluted emulsion prime coat and sealed with double treatment of SBST (14mm stone chipping) and sand seal. Install concrete kerbs at accesses to houses along this section (64.5 linear m.). Repair embankment slope erosion. and Turfing	Cracking if individual stone pieces are not well packed, blinded and compacted properly.
Trial Section No 5	Dressed Stone Pavement & Bitumen-Sand Seal Joint	No significant deterioration. Some shallow localised rutting	Provide diluted emulsion tack coat followed by an overlaying of thin layer of well graded crushed aggregate as a regulating layer. The surface is then to be primed and paved with double treatment of SBST(14mm stone chipping) and sand-seal.	Peeling of regulating overlaid layer if poor adhesion with dressed-stone road-base.

Trial Section No 6	Sand-Aggregate Roadbase & Single Bitumen Stone Chip Seal	Potholes. Minor pavement edge erosion Shallow rutting not impacting on the integrity of the seal.	Repair 2 No. potholes. Minor edge repairs and install concrete kerb at those problematic locations (22.5 linear m.).	None anticipated
Trial Section No 7	Telford Water Bound Macadam & Single Bitumen Stone Chip Seal	Minor pavement edge erosion, shallow rutting not impacting on the integrity of the seal. Standing water on deck of concrete box-culvert in the middle of Section 7.	Levelling decks of box-culvert with un-reinforced concrete overlay, the surface is to be primed with bitumen emulsion and paved with SBST to provide bituminous surfacing continuity for trial section No 7. Minor edge repairs and install concrete kerb at those problematic locations (27.6 linear m.)	None anticipated
Trial Section No 8	Water Bound Macadam & Double Bitumen Stone Chip Seal	Minor pavement edge erosion, shallow rutting not impacting on the integrity of the seal.	Minor edge repairs and install concrete kerb at those problematic locations (10m long).	None anticipated
Trial Section No 9	Armoured Laterite Roadbase & Sand Seal	Severe rutting and break-up of surface affecting 20% of this section. Significant rutting in one wheel track.	Excavation and reconstruction of whole section with 150mm of hand packed stone blinded with sand/fine aggregate, prime with diluted emulsion prime coat and sealed with DBST (14mm and 8mm stone chippings) Install concrete kerb at access point to houses (40 linear m.)	Cracking if individual stone blocks are not well packed, blinded and compacted properly.
Trial Section No 10	Hand-Packed Stone with Laterite Wearing Course	Severe loss of laterite wearing course	Replacement of wearing course with 100mm of specification compliant laterite gravel from Phnom Dey. Install level bench-mark for reference of gravel loss monitoring.	Monitors loss of gravel wearing course every 2 months with auto-level.

6 CIVIL WORKS UNDERTAKEN IN PHASE II

The civil works carried out under this phase II consisted of demolition and reconstruction of one broken concrete slab (BRCP) built by ILO-Upstream Project in the year 2000 (Figure 6.1) and upgrading of the adjacent transition laterite surfaced gap with un-reinforced concrete pavement, reconstruction of failed section No 4 and Section No 9, upgrading Section 3 and Section 5 from dressed-stone surfacing to smoother bituminous sealed surfaced standard, pothole repairs, minor pavement-edge erosion repairs and installing concrete kerbs in limited locations, locally clearing grass and debris on shoulders, repair of embankment erosion and turfing.

Figure 6.1: Final BRCP slab of ILO paving trial which had suffered cracking due to high impact loading by heavy trucks.

6.1 Upgrading Section 3 and Section 5

Section 3 and Section 5 were initially built from nominally 200mm thick Dressed-stone blocks with bituminous or sand joints. These sections both performed well under the heavily overloaded trucks that travelled along the trial road. The pavement performed satisfactorily, however the surface was relatively rough. Discussion with local stakeholders and users indicated that it was not ideal for bicycle, motorcycle or steel-wheeled cart traffic from a comfort and safety aspect, despite providing reliable all-weather passage. Therefore it was decided to upgrade these two sections in order to provide a smooth bituminous surfacing.

Figure 6.2: Dressed Stone Paving Section 5 before Phase II overlay work (note the previously installed concrete obstructions to deter shoulder use)

There were two main concerns for the upgrading of these two sections:

1. The finished level, after upgrading, of the two sections 3 and 5 could not be raised too much to avoid excessive differences in level with their adjacent trial Sections No 2 and 6 (the finished levels of which would remain unchanged). It was therefore decided to raise the finished level of Sections 3 and 5 by only 30mm above the adjacent sections.
2. With localised depressions, the regulating layer varied from 30mm to 70mm in thickness. Despite the existing dressed-stone surface in entirety having a comparatively rough surface, the surface of individual stone blocks was smooth (micro-texture) after three years exposed to the traffic. With the thin overlay, especially along the centreline, and with the smooth surface of individual stones, this caused concern that the thin overlay may not adhere completely to what would become the dressed-stone road base. Anticipating this as a potential problem, a general application of bitumen tack coat was envisaged to provide a complete adhesion face between the dressed-stone surface and the regulating layer of well-graded crushed stone aggregates.

The upgrading works of Section 3 and Section 5 consisted of the following activities:

1. <u>Level survey with Auto Level</u>: the objective was to ascertain details of surface deformation and localised depressions. This level data was used to determine the average thickness of the regulating layer, finished shape, camber and ramps at each end of the adjacent section, and lastly to determine the quantities of overlay material.
2. <u>Surface clean up</u>: Prior to the application of the tack coat, the dressed-stone surface was cleaned using labour and hand-brooms.
3. <u>Application of tack coat</u>: After the surface was cleaned from all loose material, the tack coat was applied. Prior to applying the tack coat, the surface was lightly wetted. The binder used was slow setting cationic bitumen emulsion with a content of

approximately 65% of bitumen. To reduce the viscosity and ensure a uniform spread rate, water was added to the emulsion with a mix ratio of 1:2 (Emulsion:Water). The application rate of tack coat was three litres of the emulsion-water-mixture per square metre.

4. Spreading and compacting the regulating layer: After the tack coat was spread and had become black an sticky (emulsion break), the aggregate for the regulating layer was laid, spread on one half side of the carriageway, watered and compacted with a one tonne pedestrian vibrating roller to the required thickness and camber. After, the work on one side had been completed, the other side followed with the same works sequence, actually with completion the following day. The finished regulating layer was cured for approximately 3 days where traffic was allowed to proceed at low speed. Graded aggregate of maximum size 20mm was used.

5. Application of prime coat: the prime coat was constructed utilising the same type of bitumen emulsion and spread rate as the tack coat (Refer to 3. above). The Bitumen-emulsion-water mix was applied with a watering can and spread with a broom to achieve a relatively uniform spread rate over the entire surface of the compacted regulating layer. Local sand was spread on the prime coat following the progress of the emulsion spreading so that traffic passage could be maintained during the curing period. Traffic was allowed on the surface the following day. The prime coat was applied to one half of the carriageway at a time to allow traffic to continue to use the other side.

6. Construction[5] of the first application of bituminous surface treatment:

   Samples of stone chipping (14mm) were taken from the stockpile for ALD determination and calculation of stone chippings and bitumen emulsion spread rates in accordance with the recommendation of ORN3. A small area of bituminous surface treatment was trialled with the spread rates determined from the calculations. After this trial, it was found that the bitumen-spread rate caused bleeding and therefore the bitumen-spread rates were adjusted to 1.3 Kg/m^2 for the 14mm (and 1.0Kg/m^2 for 8mm chippings to be used for the second seal on Section 3).

   To assure uniformity of bitumen spreading on the surface, the viscosity of the bitumen must also be suitable to be used with hand-tools and with a safe working environment.

   It had been identified that CRS2[6] bitumen emulsion has a relatively high viscosity which makes bitumen spraying with a watering can difficult to achieve a uniform spread rate and thus the viscosity needs to be reduced. This can be achieved by heating[7] or adding fresh water into the emulsion. The bitumen supplier advised that 15% to 20% of water can be added without too much influence to the CRS2 characteristics especially the breaking time. However, the LBAT was the technology option of the Pouk Trials and thus the use of bitumen at high temperatures which is a labour safety issue was consequently excluded. It was therefore decided to apply bitumen at an ambient temperature and 20% of water was added into the emulsion to reduce its viscosity. It was observed that the breaking time with additional water was

5 *Trial Section No 3 was paved with DBST (14mm and 8 mm stone chippings)*
Trial section No 5 was paved with single treatment of SBST(14mm chippings) and bitumen sand-seal.

6 *CRS2 is the commercial name of bitumen emulsion used in Cambodia i.e. Cationic Rapid Setting bitumen emulsion.*

7 *National road projects where machine base methods are adopted for the construction of bituminous surface treatment, both bitumen emulsion and stone chippings were spread by machine, the emulsion was heated up to 60^o Celsius and the breaking time is about 5 minutes after the emulsion had been sprayed on the surface.*

15 minutes (about 5 minutes increase compared to the raw emulsion breaking time of about 10 minutes).

The construction of the first bituminous surface treatment was initially started with cleaning of the primed surface from any loose material and debris or excess sand used in curing of the prime coat.

Labour-based methods were adopted for this construction operation and hand tools such as manual pump, small container with known volume and watering can for spraying emulsion and hand-broom for spreading to achieve a uniform bitumen spread rate. The surface area corresponding to each watering can was marked to a control area to be covered by each can. Following the progress of emulsion spreading, stone chippings were spread using a hand basket and spreader (smooth-rake). Before rolling, the supervisor checked the uniformity of the spreading and for any areas which were not fully covered by aggregate; additional materials were added.

The rolling was carried out by 1 tonne pedestrian roller and without vibration. Each point received 5 to 6 passes of rolling with a speed of around 1.5km/hour.

After rolling, the finished half carriageway was closed to traffic for 24 hours. It was opened to traffic the following day at low speed while construction of the other half side of the carriageway was taking place.

7. Construction of the second application of bituminous surface treatment.

   The construction of the second application was carried out about 2 weeks after the first application had been completed. Many bituminous surface treatment guidelines recommend a longer time (about 2 to 3 months). However for the Pouk Phase II the construction schedule specified a shorter time because the rainy season was imminent. However the engineer and the contractor took precautions by having additional rolling at the hottest time of the day, which occurred on the road surface (around 2 pm).

   The construction of the second layer was started with removal of excess chippings from the first treatment, then followed by bitumen spraying and spreading of 8 mm chippings (for trial Section No 3) or coarse sand (for Trial Section No 5).

Table 6.1: Aggregates and bitumen emulsion spread rates

	Stone chipping		Bitumen spread rate	
	ALD (mm)	Spread rate per m^2	Calculation after ORN3	Actual spread rate after trial section
Surface treatment with 14mm chippings	9.35mm	15.4 Kg or 0.01 m^3	1.38 Litre/m^2	1.3 Litre/m^2
Surface treatment with 8 mm chippings	5.33mm	8.56 Kg or 0.005 m^3	1.15 Litre/m^2	1.0 Litre/m^2
Sand-seal	NA	7.5 Kg or 0.005m^3	NA	1.5 Litre/m^2

6.2 Reconstruction of Section 4 and Section 9

Section 4 and Section 9 were initially built from 200mm of compacted laterite covered by 70mm thick of armouring layer from well-graded crushed aggregates with single bituminous surface treatment (14 chipping SBST for Section 4 and Sand-seal for Section 9). These two trial sections have failed under excessively overloaded trucks and these Sections were reconstructed under Phase II.

6.2.1 Excavation and Preparation of Subbase

Before the start of the works; control arrangements for all works levels had first to be established. A temporary level benchmark was installed at each end of the trial sections. Simple level control tools such as wooden pegs, string lines, spirit level, and profile board were used during the construction to control finished levels and the cross fall (camber) of each layer.

The removal of the existing broken road pavement by labour was found to be unattractive as the work output was slow, which made this task expensive for the contractor with the prevailing labour daily wage. The contractor proposed to use an excavator for excavating the existing pavement to the design level of the finished subbase. Labour and hand tools were used to trim and obtain a regular surface with a 3% camber. After removing and trimming, the laterite surface was watered and compacted with a 1 tonne vibrating roller.

6.2.2 Construction of Hand-packed Stone Road-base

The Pouk Trials road has a considerable volume of traffic and a cost-effective diversion was not possible. Thus the construction of the hand-packed stone road base as well as the bituminous surfacing had to be undertaken on only one half of the carriageway at a time to allow continuity for the traffic.

Broken stones were delivered to the Pouk trials road site, obtained from a labour-based production stone quarry and the sizes of stone pieces varied in size and shape. Some of the stone pieces were flat; some were oversized or too small. The sizes of aggregate specified was 100/150 type, which meant that the individual stones should have their dimensions between 100mm to 150mm in size. However, the actual sizes supplied to Pouk were in between 50mm to 200mm. If the specifications were to be strictly followed, half of the stones would have had to be rejected or the contractor would have had to select or screen for suitable stones from the quarry, which complied with the requirement of the specification. However the net cost of the stones would have been approximately double and therefore the cost of the hand-packed stone roadbase would also have increased proportionately. Recognising this fact, it was therefore determined that for flexibility it would be permitted to use the different stone sizes in an appropriate way. Hence the technique would then be economical and convenient.

Thus the hand-packed stone roadbase of Trial Section No 9 was constructed with 100mm to 200mm stone sizes which were laid in a single layer, while the smaller stone sizes (50 to 70mm) were used for Trial Section No 4 for which stone pieces were packed in two layers to get the total average hand-packed stone layer thickness to approximately 100mm thick.

Hand-packed stone road base packed in single layer

1. Setting out pegs and string lines: After the subbase was completed, a level control had to be established to ensure that the final thickness and camber of the roadbase would be to specification. Wooden or steel pegs and string lines were used. Pegs were installed at every 5 metres along the centre and edge of the carriageway. String lines were attached to those pegs 150mm above the finished level of the subbase

(the thickness of the hand-packed stone including the sand cushion) which was checked with a camber board or straight edge, spirit level and tape.

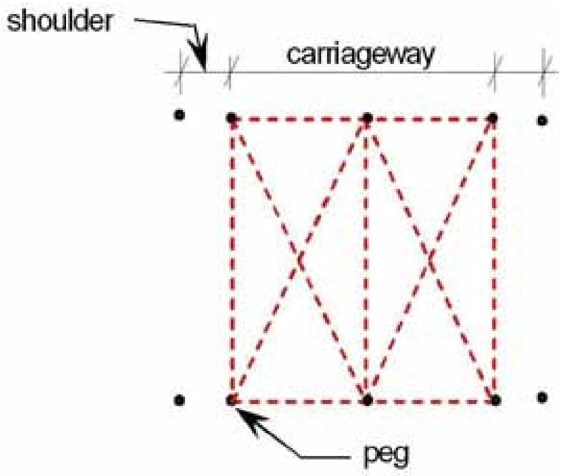


Figure 6.3: Pegs and String lines Layout Plan using 5 metre bays

2. Sand cushion: Local sand was laid on the finished subbase. Spreading of the sand material was carried out by manual methods to slightly above the screed levels. The sand was lightly compacted with one pass of a vibrating plate compactor or vibrating roller. The compacted thickness of the cushion layer was 50mm.
3. Packing stone: It was important to note that the shoulder must be constructed first to provide an edge restraint to the hand-packed stone. The hand packed stones were laid in one layer only, using aggregate size 100/200. Oversized stones (too thick) were broken manually into smaller pieces to provide the design thickness of stone blocks of about 100mm (and overall layer thickness including sand cushion of 150mm). The larger sized stones were first laid by experienced labour along the edge of the pavement against the shoulder and the centreline construction was carried out on one half side of the road to enable continuous traffic flow on the other. It is important that these first laid stone lines were well packed and level because they would be used as the level reference for other stone laying that would be packed later between these initial stone lines. Other stone pieces were packed inside the lines. Each large piece would be lightly tapped into position with a mason's hammer, to ensure initial bedding. When a small area of stone pieces were in place they would be wedged with smaller stone pieces by labourers with hammers and consolidated in position prior to compaction with 2 to 3 passes of a 1 tonne vibrated pedestrian roller.
4. Spreading, blinding and dry compaction: when there was a sufficient surface of packed stones completed, the surface was blinded with blinding material of well graded crushed stone aggregate (20mm down grading) and followed by 6 to 8 passes of dry compaction with a 1 tonne vibrated roller.
5. Wet compaction: after dry compaction, water was added and compacted with 8 to 10 passes of a vibrated 1 tonne roller. Additional blinding material was added if necessary.

6. After this final compaction, the paving was cured with regular watering for 3 days. Traffic was allowed on the pavement at low speed during the curing period while the construction of the other side of the road was completed.
7. The completed hand-packed stone roadbase was exposed to traffic for a month before the surface was primed and sealed with bituminous surface treatment.
8. The application of prime coat and bituminous surface treatment followed the same procedures that have previously been described in Section 6.1.

Hand-packed stone laid in two layers:

1. Setting out pegs and string lines: as before.
2. Sand cushion was spread to the thickness of 50mm.
3. Packing first layer of stone pieces: Stones of 50 to 80 mm size were first laid on sand bedding. Then blinding material was spread and followed by 3 to 4 passes of dry vibrated compaction. This primary vibrated compaction allowed blinding material to fill in the voids between the stone blocks of the first layer. Another bedding layer of 30 mm thick from well-graded crushed aggregates (20mm down graded) was laid on top of this first layer.
4. The second hand-packed layer was laid and bedded into cushion onto the first layer. Smaller stone blocks, 40 to 60mm size, were used. The finished level and camber of this layer were regularly checked to comply with the engineering design.
5. Blinding material was spread on the surface of the second layer and followed by 6 to 8 passes of dry compaction. After dry compaction, water was added and the pavement was compacted for another 8 to 10 passes using a 1 tonne vibrating roller.
6. The finished surface was cured for 3 days with regular watering. Traffic was allowed during the curing period at low speed. The finished hand-packed stone roadbase allowed traffic for a month before it was primed and sealed.

Lessons learned from the two different construction techniques:

After the construction of these two sections, the site engineer observed that:

Both techniques which used different sizes of stones allowed the construction of a hand-packed stone roadbase which complied with the road base design requirements with a finished layer thickness of 150mm, including the cushioning. However the hand-packed stone laid in two layers has shown better results both in terms of construction speed and stability of the finished surface. Importantly, the two techniques can be applied on adjacent sections in any road construction site which adopts this design approach for hand-packed stone. The approach allows accommodation of the inevitable variability of size of stones delivered, particularly from a labour based operation quarry.

7 MAINTENANCE & MONITORING OF THE TRIALS

The monitoring of the trials had been scheduled since their construction was completed in September 2002 with regular site investigations and survey. It was expected that the evolution of the pavement deterioration indicators such as rutting, roughness, surface texture, laterite loss of the control section would correlate with the traffic accessing this road. However the level of overloaded heavy trucks utilising this road during the two years after its construction was extreme and resulted in the sudden deterioration of two sections and caused some distress to the other sections. This level of overloading was too excessive and made monitoring data collected previously unusable for the correlation between traffic and deterioration.

After the failure of the two sections, a solution to protect the road from overloading was agreed with the support from the local authority. This involved the installation of vehicle size restriction barriers and this prevented heavily overloaded trucks from accessing the trial road after the reconstruction of Phase II was completed.

A Long-term monitoring plan was developed and consists of initial trial condition assessment after the completion of Phase II and future site investigations at regular intervals.

In addition to theses physical surveys, it is necessary to collect data on any maintenance activities carried out on each trial section, the resources used and the costs thereof.

Arrangements for the continued funding and organisation of this monitoring and its interpretation need to be agreed.

Furthermore, it will be necessary to establish reasonable maintenance arrangements for the trials road. Due to the nature of the surfaces constructed, and reconstructed after the damage by heavy vehicles, the establishment of the vehicle restrictors, and awareness creation with the local authority, it is expected that the amount of maintenance required on the trials road will be modest. However arrangements should be agreed to identify the maintenance needs, mobilise the resources to carry out the maintenance, and then implement it. The Document prepared by Intech-TRL under SEACAP 2 (Reference 12) highlights the problems and challenges encountered in trying to achieve effective road maintenance in Cambodia. It is hoped that under the forthcoming projects, that some basic rural road maintenance systems will be developed in a sustainable manner, and applied to the Puok trials in cooperation with the local authority and community.

Table 7.1: Proposed Long Term Monitoring Programme

Activities	Frequency	Tools and Equipment	Remarks
Laterite loss monitoring	Every two months	Auto level	
Visual inspection	Twice per year – end of dry and wet season	None	Before and after rainy season
Road roughness measurement	Twice per year – end of dry and wet season	Merlin	
Rutting	Twice per year – end of dry and wet season	3 m straight edge	
Traffic count and axle loading survey	Twice per year – end of dry and wet season	Portable weighbridges	

The Long Term monitoring programme set out in Table 7.1 will allow maintenance requirements to be identified, quantified and the necessary funds and resources sought to carry out the works.

7.1 Traffic Count and Axle Loading

Traffic surveys were carried out for a period of 7 consecutive days starting from 4th March 2005. All motorized and non-motorized vehicles[8] were recorded. The traffic counts started from 6 AM and continued to 6 PM each day. The conversion factor of 1.1 was adopted from previous studies to convert from 12 hours traffic counts to 24-hour traffic volumes. The objectives of the traffic counting were to:

- Establish a traffic benchmark for Phase II trials.
- Record vehicle types and distribution of rural traffic. The distribution of different rural transport means and particularly the percentage of heavy axle load vehicles and their implication on pavement design and costing. This is necessary to gauge the impact of heavy traffic on rural paved road design, construction and maintenance.
- Make preliminary assessment of the Economic Benefit of the different Trial Options.

This traffic survey confirmed previous surveys that the Pouk Trials Road is remarkably busy for its tertiary road category in Cambodia. The volume of traffic using this road may in fact be higher than that of many other provincial roads in Cambodia.

Traffic counting and axle loading surveys that were previously carried out on Pouk Market Low Cost Surfacing Trials have shown that the majority of rural traffic were light vehicles and their axle loading rarely exceeded the legal limit of axle loading.

For socio-economic purposes (not engineering design) the following PCU equivalents have been adopted (Table 7.2).

Table 7.2: Conversion factors of each vehicle into PCU's for rural traffic flow calculations [9]

Type of Vehicle	Bicycle	Bicycle-Trailer	Animal Cart	Motorcycle	Motorcycle-trailer	Passenger Car	Light Vehicle / Van	Mini-bus (4 tyres)	Bus (> 4 tyres)	Koyun [10]	Medium Truck (6 tyres)	Heavy Truck (> 6 tyres)
Equivalent value in PCU's for rural traffic flow calculations	0.3	0.4	0.4	0.4	0.6	1	1	1.1	2.25	1.5	2	2.5

8 *For pavement design, only vehicles of unladen weight of more than 3 tonnes are to be considered. The non-motorized vehicles and other light and heavy vehicles are all required for HDM4 cost benefit analysis.*

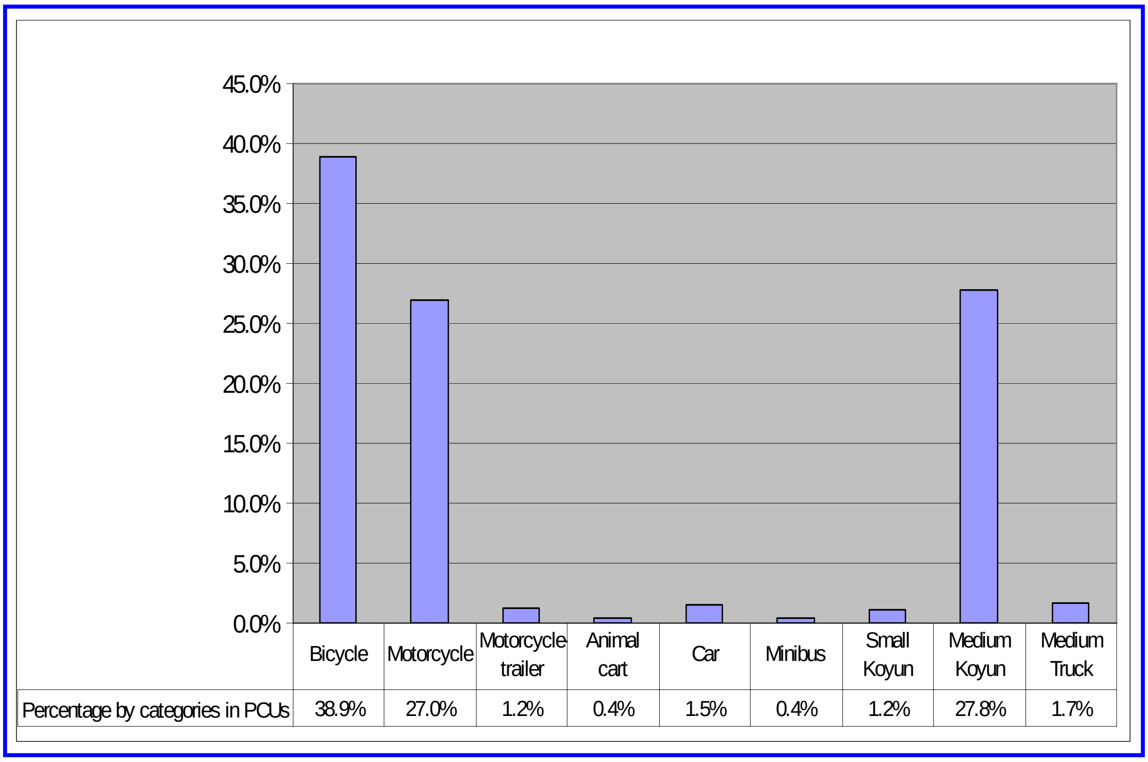
9 *Interim Rural Road Standards, Ministry of Rural Development – Cambodia, Reference 18.*

10 *Koyun is a locally assembled truck, with various laden capacities. Small Koyuns are designed to carry 3 to 5 tonnes of payload and the biggest Koyuns can carried up to 10 tonnes or more.*

Table 7.3: Traffic on Pouk LCS Trials Road (March 2005)

Type of Vehicle	Bicycle	Motorcycle	Motorcycle-trailer	Animal cart	Car	Minibus	Small Koyun	Medium Koyun	Medium Truck	Total
Average 12 Hours count	2,291	1,193	35	20	27	6	14	245	15	3,845
24 Hour traffic (+10%)	2,520	1,312	38	22	30	7	15	270	16	4,230
Converted factor to PCU	0.3	0.4	0.6	0.4	1	1.1	1.5	2	2	-
ADT in PCUs	756	525	23	9	30	7	23	540	32	1,945
Percentage by categories in PCUs	38.9%	27.0%	1.2%	0.4%	1.5%	0.4%	1.2%	27.8%	1.7%	-

Figure 7.1: Distribution of different vehicle types after conversion to PCUs



7.2 Roughness Measurements

Road roughness measurements were undertaken in August 2005, approximately one month after the pavement rehabilitation and repairs were completed.

Table 7.4: Trial Sections Roughness Measurements (August 2005)

Section No.	From Chainage to Chainage	Section Length in m	Wheel path	Roughness Index		
				Merlin scale D in mm	**IRI in m/Km (IRI = 0.593 + 0.0471 D)**	**Average IRI**
2	0+040 - 0+140	100	To Daunkeo	125	6.5	6.2
			To Pouk	115	6.0	
3	0+140 - 0+190	50	To Daunkeo	115	6.0	5.9
			To Pouk	110	5.8	
4	0+190 - 0+290	100	To Daunkeo	100	5.3	5.4
			To Pouk	105	5.5	
5	0+290 - 0+340	50	To Daunkeo	120	6.2	5.7
			To Pouk	95	5.1	
6	0+340 - 0+440	100	To Daunkeo	120	6.2	6.5
			To Pouk	130	6.7	
7	0+440 - 0+547.2	107.2	To Daunkeo	105	5.5	5.3
			To Pouk	95	5.1	
8	0+547.2 - 0+647.2	100	To Daunkeo	105	5.5	5.4
			To Pouk	100	5.3	
9	0+647.2 - 0+697.2	50	To Daunkeo	110	5.8	6.2
			To Pouk	130	6.7	
10	0+697.2 - 0+747.2	50	To Daunkeo	85	4.6	5.3
			To Pouk	115	6.0	

7.3 Laterite Loss Survey

The control section No 10 was re-gravelled during Phase II with laterite from Phnom Dey borrow pit. A laterite sample was sent to the ITC geotechnical laboratory for testing; e.g. soil classification, sieve and CBR. Details of the laterite testing are given in Appendix A.

The monitoring of the loss of gravel confirms an unsustainable rate of loss indicating annual losses of more than 5cm per year.

Control Section 10 (Figure 7.3) was designed with a hand packed stone base and a “wearing course” of laterite gravel. With the awareness of limited maintenance capacity, it will be of interest to monitor the residual hand packed stone surface after the gravel has completely worn away. The intention was to develop a surfacing technique that would be smooth initially while the gravel survives, however remain passable in all weathers as hand packed stone, albeit with a rough surface, in the scenario of a low maintenance regime. **This type of “hybrid” surface seems to present a workable intermediate cost, reasonably durable solution for a low maintenance environment .**

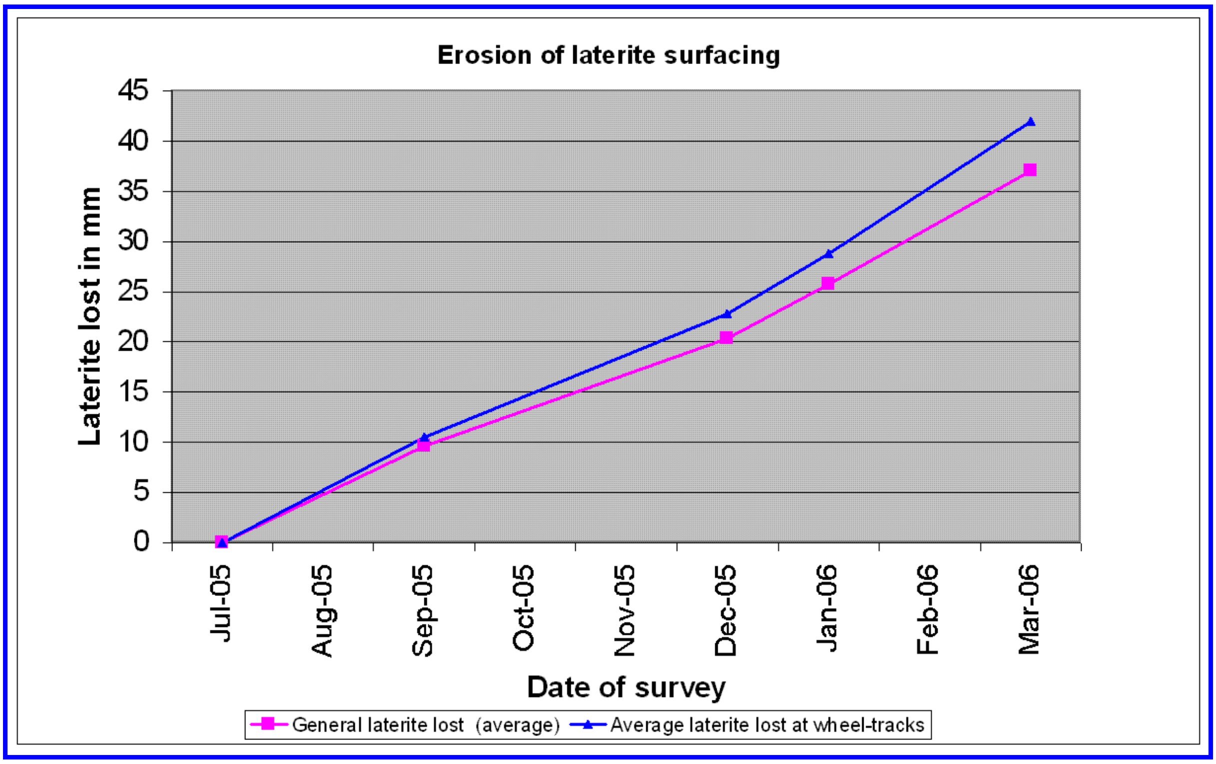


Figure 7.2: Cumulative Average Gravel Lost from Trial Section No 10

Figure 7.3: Trial Section 10: Gravel surface over hand packed stone

8 AXLE LOADING AND RURAL ROAD DESIGN

Bituminous (flexible) pavement design is normally based on assessment of the expected **vehicle axle loading** during the 'life' of the road pavement in combination with **subgrade strength**. Axle loading by heavy vehicles is of particular concern for all paved routes. Both national and rural roads in Cambodia usually suffer from widespread vehicle overloading, and consequential accelerated deterioration and premature loss of investments. Efforts to control axle loading in developing countries are generally unsuccessful[11] and in Cambodia the particular factors of driver/operator practice, weak legal framework, weak subgrades, shortages of good construction materials, quality assurance regime, adverse weather and drainage, and low maintenance capability, in combination make this a serious problem. It is therefore necessary to be aware of the situation and influence of overloading and cost implications on low volume road design and maintenance.

It is important to appreciate the situation with respect to loading and low volume road pavements in Cambodia. Nearly all of the research on axle loading and pavement damage has been conducted in developed countries. Factors such as climate, flooding, range of loading, road user discipline and control, construction techniques, construction quality control and maintenance regimes etc. can have a significant effect on pavement performance.

Therefore there is considerable uncertainty regarding the prediction of the effects of any particular level of significant loading in Cambodia.

Furthermore, there is the basic problem of predicting traffic growth[12], the mix and loading of vehicles, and even vehicle technology well into the future, to assess what the particular level of loading will be through the design period of a road pavement.

In consequence of the foregoing there is a fundamental problem in the accurate prediction of the axle loadings and their effects over the 'design life' of the road pavements in Cambodia (Reference 11).

The Cambodia legislation and regulatory framework does however allow for traffic restrictors to be constructed on some rural roads. Where this is desirable and possible without the avoidance or demolition by heavy vehicle operators, then there are considerable cost savings to be made in road construction and maintenance (and consequently reduced transport costs to the community) by the adoption of lighter road construction. This is especially important in such a constrained resource environment.

A further fundamental factor influencing pavement or surfacing performance is the **road maintenance regime**. Experience in Cambodia (including the Upstream Project), in Vietnam (Rural Road Gravel Assessment Programme - RRGAP)[13] have shown the futility of constructing gravel roads without an adequate maintenance regime being assured. Furthermore some types of paving are better able to withstand the consequences of poor or no-existent maintenance. This factor must therefore also be accommodated in any rational and realistic design process.

Quality Control at construction stage and issues of corrupt practices are also influential in the performance of road paving and surfacing. However, design guidelines necessarily have to assume that in future adequate measures will be made to minimise the adverse affects of these factors.

It is beyond the Terms of Reference for this project to develop national pavement designs for the range of surface options trialled at Puok Market. Nor is it possible to predict the

11 Reference 2: The Control of Axle Loading in Tanzania, R C Petts, IRF Conference, Cairo, 1986
12 Normal, diverted and generated traffic and growth.
13 Reference 22.

performance of the various surface options from the very limited time period elapsed since the completion of the trials and the reconstruction of the failed sections.

However, it is possible to make some preliminary recommendations on an appropriate design concept and approach for the specific and challenging Cambodia rural road environment. Without such a new approach the evident past widespread premature deterioration of road investments will continue with considerable wastage of public funds and constrained efforts to reduce rural poverty.

It is also possible to set out preliminary recommendations on preferred surface options and to highlight some of the alternatives more likely to be able to resist the gross overloading commonly experienced in Cambodia, and the pavement types likely to have a greater risk of failure if overloaded.

It is anyway necessary to make some assumptions regarding the likely performance of the various pavement types for the prediction of Whole Life Costs, which is part of the requirement of this assignment.

The following Table 8.1 and Figure 8.1 therefore provide a concept for developing a surfacing/paving design approach for rural roads for Cambodia, which should be developed further under the planned future projects. It provides provisional recommendations of pavement structures with regard to the three principal local influencing factors of:-

- Traffic and Vehicle Loading Regime,
- Subgrade Strength/Conditions,
- Maintenance Regime.

These preliminary concepts are based on international documentation and experience, coupled with local experience and the pavement performance of various trials options after they experienced extreme overloading caused by heavy trucks since their construction completion in September 2002 and until mid 2005.

After monitoring the Puok pavement trials for some years, and also consulting data planned to be derived from the SEACAP-1 Vietnam Rural Road Surfacing Trials (RRST), and from further research planned under future projects, it should be possible to review and refine these provisional recommendations into guidelines for Cambodian rural road design.

Table 8.1 - Provisional Rural Road Pavement Design Concept for Cambodia – Part 1

Catalogue of surfacing/paving options (to be developed)		**Effective maintenance system and funding**			**Unreliable maintenance system (5)**		
Design Options	Description	Light traffic (1)	Medium traffic (2)	Heavy traffic (3)	Light traffic (1)	Medium traffic (2)	Heavy traffic (3)
Gravel/Laterite	Use Engineering Selection Criteria in Figure 8.2	(4)	(4)		**DO NOT USE**		
Paved Option 1-A	70 mm armouring with single surface treatment	(4)					
Paved Option 1-B	70mm amouring with double surface treatment	(4)			(4)		
Paved Option 2-A	200mm of sand-aggregate roadbase with single surface treatment	(4)	(4)				
Paved Option 2-B	200mm of sand-aggregate roadbase with double surface treatment	(4)	(4)		(4)	(4)	
Paved Option 3-A	200mm of WBM roadbase with single surface treatment	(4)	(4)				
Paved Option 3-B	200mm of WBM roadbase with double surface treatment	(4)	(4)		(4)	(4)	
Paved Option 4-A	200m thick of Dressed-stone with single surface treatment	(4)	(4)				
Paved Option 4-B	200m thick of Dressed-stone with double surface treatment	(4)	(4)	(4)	(4)	(4)	(4)
Paved Option 5-A	100mm of hand-packed stone with single surface treatment	(4)	(4)				
Paved Option 5-B	100mm of hand-packed stone with double surface treatment	(4)	(4)		(4)	(4)	
Paved Option 6-A	150mm of hand-packed stone with single surface treatment	(4)	(4)				
Paved Option 6-B	150mm of hand-packed stone with double surface treatment	(4)	(4)	(4)	(4)	(4)	(4)
Paved Option 7-A	200mm of hand-packed stone with single surface treatment	(4)	(4)				
Paved Option 7-B	200mm of hand-packed stone with double surface treatment	(4)	(4)	(4)	(4)	(4)	(4)
Paved Option 8	200 mm un-reinforced concrete pavement	(4)	(4)	(4)	(4)	(4)	(4)
Paved Option 9	150 mm steel or bamboo reinforced concrete pavement	(4)	(4)	(4)	(4)	(4)	(4)

(1): Light: Mainly non-motorised, motorbikes & less than 25 motor vehicles per day, with few medium/heavy vehicles. No access for overloaded vehicles.

(2): Medium: Up to 100 motor vehicles per day including up to 20 medium (10t) goods vehicles, with no significant overloading (design according to Cambodian MPW&H or international standards)

(3): Heavy: Accessible by all vehicle types including heavy and overloaded trucks, Construction materials haulage routes. Specific design guidance to be developed. (restrict to designs such as concrete and hand packed stone roadbase with double bituminous surface treatment, or dressed stone with DBST)

(4): Suitable.

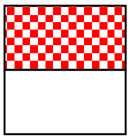
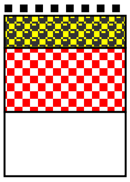
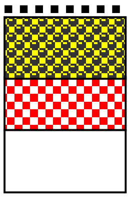
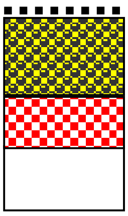
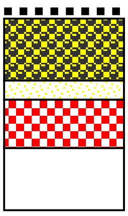
(5) Effective Maintenance is understood to mean that the funding and arrangements are in place to achieve at least 65% of the assessed annual maintenance requirements of the roads concerned.

(6) Base/sub-base thickness can be varied in response to traffic/sub-grade assessments e.g. for light traffic Un-reinforced concrete could be reduced to 150 or 175mm.

(7) Good drainage system and subgrades should always be at least 0.5m above high flood or ground water level.

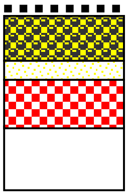
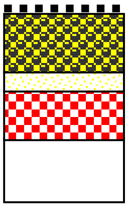
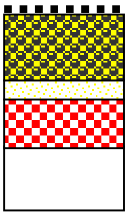
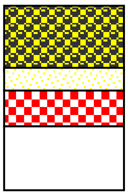
Remarks: *Some of the pavement structures have not been constructed at Pouk LCS Trials Road Site. However, they are provided from research elsewhere for the situation where a low volume road will be designed to resist overloaded trucks. The following concept Figure 8.1should be developed to accommodate the traffic/axle loading and subgrade condition options. The design approach needs to take account of the difference between insitu in performance strength of subgrades measurable by low cost, practical DCP methods (weakest rain season condition) and more expensive and potentially less reliable laboratory test results.*

Figure 8.1: Detailed Pavement Design Options Concept – Part 2

Design Options		Thickness (mm)	Remark
Laterite surfaced road		Thickness (mm)	
Laterite surfacing CBR>30%		200	
Sub-grade minimum CBR 5%		200	
Design Option 1:		Thickness (mm)	Initial design and construction of Trial sections No 4 and No 9 with surfacing type A. These sections failed partly due to extreme overloading. These sections have been reconstructed with Design Option 5.
Surfacing (A or B)			
Armouring Layer (Crushed Stone)		70	
Laterite gravel base CBR>30%		200	
Sub-grade minimum CBR 5%		200	
Design Option 2:		Thickness (mm)	Trial Section No 2 and Trial section No 6
Surfacing (A or B)			
Sand-Aggregate Base (30%+70%)		200	
Laterite gravel base CBR>30%		150	
Sub-grade minimum CBR 5%		200	
Design Option 3:		Thickness (mm)	Trial section No 7 and Trial Section No 8
Surfacing (A or B)			
Water Bound Macadam Base		200	
Laterite gravel base CBR>30%		150	
Sub-grade minimum CBR 5%		200	
Design Option 4:		Thickness (mm)	Trial section No 3 and No 5 after upgrading to bituminous surface undertaken by Phase II
Surfacing (A or B)			
Dressed-Stone Pavement		200	
Sand Bedding		50	
Laterite gravel base CBR>30%		150	
Sub-grade minimum CBR 5%		200	

Surfacing Type A: Single treatment (Bitumen stone chip seal or sand-seal)
Surfacing Type B: Double treatment (DBST or SBST and Sand-Seal)

Figure 8.1: Detailed Pavement Design Options Concept – Part 2 (continued)

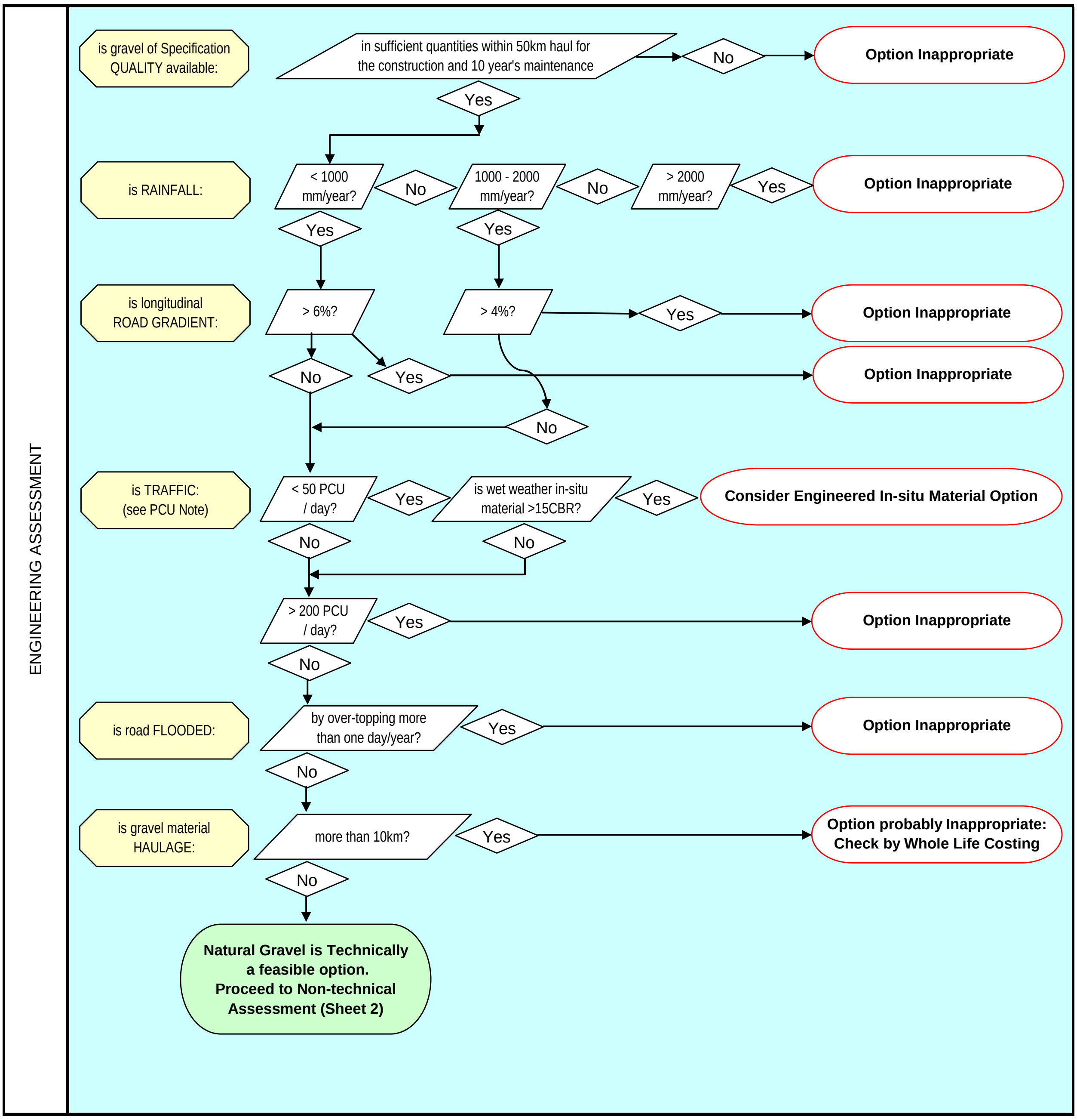
<u>Design Option 5:</u> Surfacing (A or B) Hand-Packed Stone Base Sand Bedding Laterite gravel base CBR>30% Sub-grade minimum CBR 5%		Thickness (mm) 100 50 150 200	Trial section No 4 and No 9 after reconstruction of Phase II
<u>Design Option 6:</u> Surfacing (A or B) Hand-Packed Stone Base Sand Bedding Laterite gravel base CBR>30% Sub-grade minimum CBR 5%		Thickness (mm) 150 50 150 200	
<u>Design Option 7:</u> Surfacing (A or B) Hand-Packed Stone Base Sand Bedding Laterite gravel base CBR>30% Sub-grade minimum CBR 5%		Thickness (mm) 200 50 150 200	
<u>Design Option 8:</u> Un-Reinforced Concrete Pavement Sand Bedding Laterite gravel base CBR>30% Sub-grade minimum CBR 5%		Thickness (mm) 200 50 100 200	Trial section no 1

Surfacing Type A: Single treatment (Bitumen stone chip seal or sand-seal)
Surfacing Type B: Double treatment (DBST or SBST and Sand-Seal)

Figure 8.2

Decision Flow Chart for the Consideration of Natural Gravel as a Rural Road Surface Option

SHEET 1 - Engineering Assessment



NOTES: PCU = Passenger Car Unit (other vehicle types to be converted from traffic surveys and maximum predicted daily flows for next 3 years).
CBR = California Bearing Ratio - Strength in situ measured by DCP, or to be decided by visual assessment
DCP = Dynamic Cone Penetrometer
Engineered Insitu Material = Earth Road Standard with maintained camber and effective drainage system

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9 ECONOMIC BENEFIT AND POVERTY IMPACT ASSESSMENT

9.1 Introduction

This section of the report addresses the important and hitherto considered to be inadequately evaluated aspects of whole life costs of alternative surface options, and the socio-economic aspects of choice of rural road surfacing/paving. The figures and analysis are intrinsically provisional due to the limited data and knowledge basis of rural road Whole Life Costing in Cambodia, and the lack of long term performance information on the various trial paving options at this time. However it does demonstrate a new and useful approach to whole life costing and accommodation of socio-economic factors.

There are two approaches to the assessment of Whole Life Costs for rural roads, which 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/Rehabilitation** and **Maintenance** of a particular road and pavement over a selected assessment period. It would also incorporate estimation of residual infrastructure value, to avoid undue asset wastage. This assessment would be of interest to an asset manager such as a Provincial Head of Rural Development or Public Works, particularly in a severely constrained resource environment. Such an assessment would allow the manager to aim for an optimum deployment of the available scarce resources between construction/rehabilitation and maintenance.

A more comprehensive Whole Life Transport Cost assessment would bring in the component of user **Vehicle Operating Costs (VOCs)**, and maybe other economic or socio-economic factors (e.g. user time savings, socio-economic or environmental impact). This assessment would probably 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 developing the relationships incorporated in the evaluation. It is evident that for Cambodia rural road evaluation, the general confidence in the available cost data is moderate or limited for construction components for the various provinces of the country[14]. However, the knowledge and confidence are poor for both maintenance cost components of various road surface options and user VOCs.

For the purposes of this assignment, estimation of initial financial costs of construction was based on the contracted Bills of Quantities of the Low Cost Surfacing Trials Phase I and Phase II, and the PRIP Project. All data was updated to include inflation and current market conditions, which is a reasonably accurate representation for the various provinces where there is a competitive market for material supply and civil works. However, there were no reliable data available for the evaluation of economic costs.

Reference 12 highlights the problems and challenges encountered in trying to achieve effective road maintenance in Cambodia. The lack of an effective maintenance system also constrains the ability to develop realistic road maintenance costing for the Cambodian situation. The very limited data available on the performance of the trial sections to date also prevents long term maintenance relationships being developed. The proposed long term monitoring of the Puok trial sections should allow this to be achieved in due course.

14 From contract Bills of Quantities.

With regard to general Whole Life Costing for rural roads in Cambodia, for application of the SEACAP project knowledge using the available HDM4 and RED economic analysis models, there are a number of VOC constraints to be considered:-

- HDM4 is primarily motor vehicle orientated and roughness driven, and is more appropriate for assessment of high traffic category routes dominated by motor vehicle use,
- VOC relationships for HDM4 and RED have been developed primarily from experience in Africa, and South America, not South East Asia, where there are climatic, traffic, environmental, operational and cultural differences.
- *"The models are limited in their ability to deal with the problems of very basic access; Many of the key road deterioration and VOC cost relationships tend to break down for rough earth roads and tracks and very poorly maintained roads"* [15].
- The models do not have VOC relationships for motorcycles and bicycles, which account for a substantial proportion of the traffic on the Puok trial and rural roads in general in Cambodia (refer to Figure 7.1).
- The 'commercial' vehicles commonly used on rural roads are mainly locally-made, light and relatively slow moving trucks, for which VOC-road condition relationships are not researched.
- Robust VOC-road condition knowledge is not available for the Cambodian, or indeed South East Asia conditions[16].
- VOC-road condition relationships can vary by substantial factors[17]. It is likely that the fundamental factors of the local Cambodian environment regarding **vehicle life and depreciation, repair capability and culture, spares availability and refurbishment practices, value of time, traffic regulation/control** and **load carrying and personal/commercial decision making** would vary substantially between the previously researched regions and the current Cambodia situation, thereby influencing VOC relationships in a different way and degree.
- The issue of seasonal passability is particularly relevant in the instances of roads that become flooded for short or long periods (particularly Mekong Delta and Cambodian Lake Basin areas), and gravel roads on weak subgrades that can become impassable to motorized traffic when severely deteriorated.

This current situation therefore limits the accuracy and confidence of Whole Life Costing assessment that can be made at this time in Cambodia. The following text exploring Whole Life Costs, cost benefit analysis and socio-economic aspects should be read in the appreciation and understanding of this situation. In view of the foregoing assessment of the situation, analyses have focused on the Whole Life Costs and Cost-Benefit relationships for the Road Asset; to include construction cost, maintenance costs and residual value. Interpretation should be treated as indicative only, pending improved knowledge availability after the planned trials monitoring and further investigations.

9.2 Initial Investment Cost Analysis

The interim rural road standards of MRD were adopted for the calculation of initial investment and maintenance costs for each design option of the Pouk Trials. This interim standard recommends a 5 metre wide carriageway and 1 metre wide shoulders and thus the analysis roadway width adopted is 7 metres. The cost of each design option is based on the pavements scheduled in Figure 8.1. All design options have been subject to 10 years whole

15 Source: TRL documentation.
16 Analysis of Vehicle Operating Costs on Rural Roads, Rural Transport Strategy Study, Vietnam, I T Transport, 1999.
17 Research by TRL found that unit road freight transport costs varied by factors of 4 to 6 between some African countries and Pakistan. Rizet, C and J L Hine, 1993.

life cycle cost analysis, in comparison to a laterite surfaced road. The relatively short time period is considered to be appropriate for analysis considering the various factors and uncertainties in Cambodia.

All costs relating to earthworks below formation level, drainage and non-paving works have been excluded for the analysis purposes. Costs have been based on current market rates and the experiences of the Puok trials.

All costs have been broken down to identify the separate labour cost components, taking in to account the labour content of material production at quarry, through to the construction and finishing at site. This cost allocation is useful especially for a developing country such as Cambodia, where employment and poverty issues are important Government and development agency concerns. The cost analysis also provides two different cost scenarios of technology choices between Labour-Based Appropriate Technology (LBAT) and Machine-Based (MB) to demonstrate the advantages and disadvantages of different technology approaches with regard to design options. Most construction operations within a paving type allow choices between labour and machine orientated methods at each step of the construction process. Appendix C, Table C.1 shows how each construction option has a choice of technology. This will influence the works costing.

The initial construction (or investment) costs in financial cost terms of each construction option by technology are shown in Table 9.1, and graphically in Figure 9.1 for ease of comparison.

Refer to Table 8.1 for the technical descriptions of the various paving options.

Dressed stone (Option 4) and hand packed stone (Road base in Options 5, 6 and 7) are intrinsically labour based construction techniques. However the analysis accommodates labour and machine based options for the associated surface sealing treatments. Therefore both LBAT and MB options are shown for this LBAT orientated road base.

The analysis confirms the general knowledge that laterite surfacing is generally much cheaper than other paving options ***in initial cost terms***.

The analysis shows a slight cost penalty for LBAT for most paving options with the assumptions made on the circumstances of the Pouk site. The results reflect the realities of the current road sector market in that part of Cambodia and arguably the artificially low current rates for equipment hire due to oversupply of equipment compared to the low availability of work. There are also concerns that equipment costing does not reflect the true cost of capital investment in Cambodia. Costs in more rural areas away from the vibrant commerce of Siem Reap, and with higher equipment mobilisation and support costs, would be expected to tilt the technology costs in favour of LBAT. Nevertheless, the objective of the exercise is to demonstrate how technology and surface selection can influence cost, labour content and the cost of each worker day generated for employment creation and poverty reduction purposes. All of the LBAT options would generate substantially more employment than the equipment based options.

Figures 9.2 and 9.3 show the considerable employment and social benefits derived from the use of alternative surfaces and LBAT methods. Gravel road construction and maintenance operations as usually practiced in Cambodia involve very little labour in the gravel excavation haulage and deposition operations. The other surface options generate between 3 and 38 times the direct employment of machine based gravel/laterite construction. If LBAT options only are considered, then the alternative surfaces generate between 1.6 and 6.3 times as much employment as LBAT gravelling.

In terms of employment generation and policy support for rural development within a limited resource environment, Figure 9.3 shows that the investment cost of each worker day generated is between 4.8 and 14.7 times cheaper than for Machine based gravel surface construction.

Table 9-1: Construction cost for each design option

Proposed Design Options	Technology option							
	Machine based				LBAT			
	Cost of road (US$/km)	Percentage of cost allocated to employment	Worker Days generated for local labour	Investment capital per WD generated (US$/WD)	Cost of road (US$/km)	Percentage of cost allocated to employment	Worker Days generated for local labour	Investment capital per WD generated (US$/WD)
Laterite surfaced road	$16,344.21	1.30%	116	140.4	$18,443.27	4.99%	1027	18.0
Paved Option 1-A	$35,381.22	3.14%	384	92.1	$38,447.48	6.64%	1984	19.4
Paved Option 1-B	$41,184.77	3.21%	420	98.1	$44,538.46	7.14%	2184	20.4
Paved Option 2-A	$47,251.69	4.0%	734	64.4	$49,780.2	6.7%	2303	21.6
Paved Option 2-B	$53,055.24	3.9%	770	68.9	$55,871.2	7.1%	2503	22.3
Paved Option 3-A	$47,953.07	3.7%	1049	45.7	$50,481.6	6.4%	2618	19.3
Paved Option 3-B	$53,756.62	3.7%	1085	49.5	$56,572.6	6.8%	2818	20.1
Paved Option 4-A	$52,124.02	17.8%	4188	12.4	$54,410.2	18.9%	5267	10.3
Paved Option 4-B	$68,545.71	14.6%	4471	15.3	$68,060.1	17.0%	5845	11.6
Paved Option 5-A	$42,824.66	13.0%	2419	17.7	$45,248.1	15.3%	3926	11.5
Paved Option 5-B	$48,628.21	11.9%	2455	19.8	$51,339.1	14.7%	4126	12.4
Paved Option 6-A	$38,883.58	17.0%	3179	12.2	$41,060.4	18.3%	4193	9.8
Paved Option 6-B	$55,305.28	13.2%	3463	16.0	$58,121.2	15.8%	5196	11.2
Paved Option 7-A	$48,904.02	16.2%	4203	11.6	$51,496.4	17.5%	5399	9.5
Paved Option 7-B	$65,325.72	13.2%	4486	14.6	$68,557.3	15.6%	6402	10.7
Paved Option 8	$72,296.84	9.0%	1667	43.4	$74,125.6	9.9%	2546	29.1
Notes: WD : Worker-day					Average labour cost 1.25 US$ per day			
Assumed Hauled distance for all material is 50 kms.								

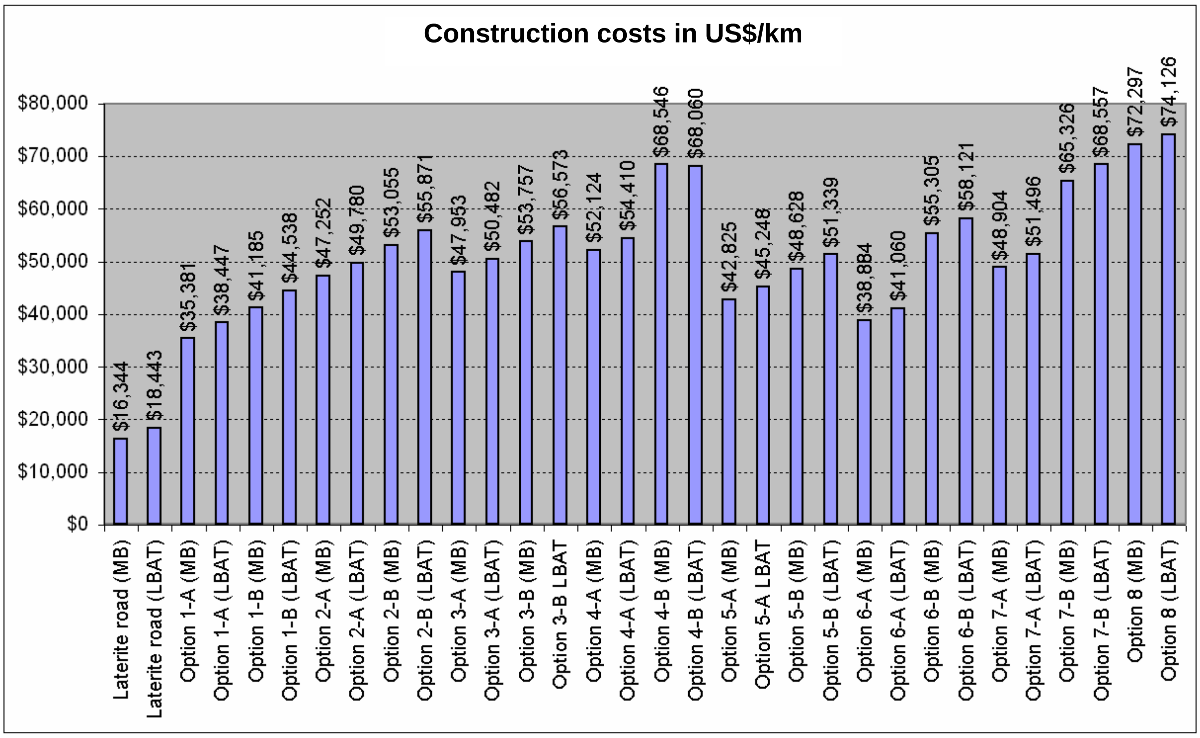


Figure 9.1: Financial cost of construction of each improvement option

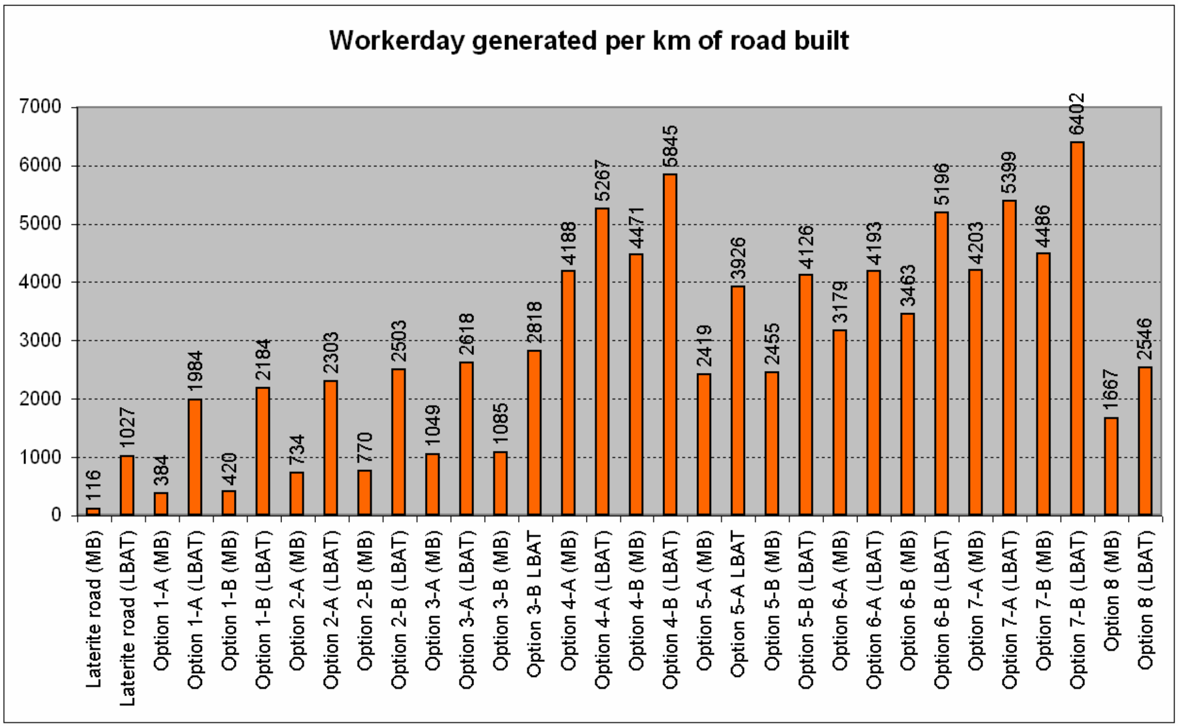


Figure 9.2: Worker-day generation of each construction option

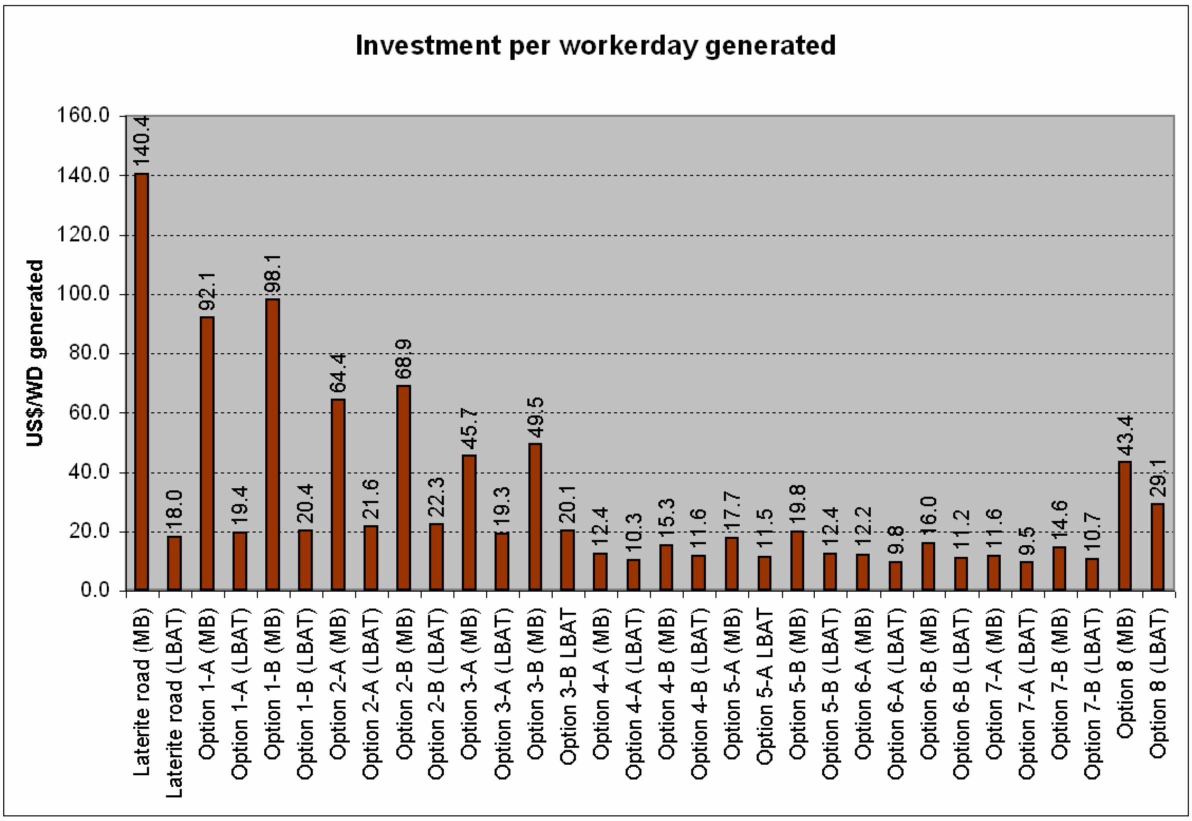


Figure 9.3: Investment Cost per worker-day generation of each construction option

If material haul distances are reduced, the overall investment costs per km are lower and the labour components due to non-transport components would increase relatively. This of course supports the use of local materials resources wherever possible (as well as local labour). Options such as hand packed stone and concrete paving also reduce the amount and sophistication of equipment required, and thus the capital tied up in the equipment required. This would allow local building contractors to be realistically considered for the surfacing work (with suitable training/awareness creation), further enhancing the potential for recycling of costs into the local economy. These issues deserve further research in the local Cambodian context.

9.3 Asset Whole Life Cycle Costs

The construction of Pouk Low Cost Surfacing Trials (Phase I) was completed in September 2002. The LCS trials road subsequently suffered trafficking by heavily overloaded trucks which caused destruction of Trial Section 4, Trial Section 9 (partly), and some distress to others sections. All trial sections were brought back to fully serviceable condition under SEACAP 8 (Phase II) and vehicle size restriction barriers were installed to deter future use by heavy trucks.

The level of overloading experienced was excessive and prevented rational compilation of monitoring data suitable for the correlation between traffic and deterioration, and assessment of maintenance requirements.

The rehabilitation and maintenance carried out under Phase II were completed in July 2005 and a long-term monitoring plan was developed that envisaged trial section condition assessment and specific site investigations at regular intervals.

At the time of preparing this report, there was still insufficient data from the Trials Road to assess the actual or typical cost of maintenance and asset whole life cycle costs for all the alternative Trial Pavements constructed at Pouk Market.

Therefore asset whole life cycle costs have been estimated based on the assumptions in Table 9-1 and Table 9-2. These tables provide a preliminary assessment of asset WLC based on experiences in the local Cambodia sector and assumptions regarding maintenance needs for each pavement option. Actual maintenance requirements and costs for each pavement option should be available for refinement of these assumptions after a period of a number of years, when sufficient knowledge should be collected from the planned monitoring of the Trials.

Fortunately the maintenance requirements for the base reference gravel option are better understood, due to the relatively rapid deterioration of this surface monitored in the trial site conditions, and the extensive investigations and documentation of gravel road performance in Vietnam under the SEACAP 4 project (RRGAP).

The asset WLC include the direct initial investment, routine and periodic maintenance after upgrading, and assumed salvage values at the end of the pavement design life and assessment period of 10 years.

The experiences of the Pouk Trial and similar roads confirm a representative gravel loss rate in excess of 5cm per year[18] for the trial site (Figure 7.2). Therefore 5cm/year loss has been used for the WLC assessment in this report. For the analysis, the lost material was assumed to be replaced in a timely manner by regular periodic maintenance regravelling. Routine maintenance including regular grading to maintain the camber and shed rainwater has also been assumed for the gravel surface option.

The asset WLC assessment excludes the environmental and other mitigation measures undertaken during construction which will vary from one option to another. In addition, the costs of management and supervision associated with the initial construction and long term maintenance operations which have not been included in the WLC analysis. The maintenance overheads are particularly difficult to realistically assess from the current operational environment, and are intrinsically higher per unit of work carried out than for construction. It is however evident that a more robust road design will require less maintenance and thus the costs for management and supervision will also be lower if compared to light pavement structures or gravel/laterite.

18 Surface gravel loss rates have been shown to depend on a range of factors (RRGAP – SEACAP 4).

Table 9.2: Assumed whole life maintenance operations and cost per km of road

Type of Road Pavement	Type of maintenance works	Unit cost (financial)	Sub-Total cost of maintenance operations for 10 year life cycle (undiscounted)	Total maintenance cost (undiscounted) [(a)]
Gravel or Laterite surfaced road	Routine maintenance	US$600/km/year	US$6,000	US$42,750
	15cm re-gravelling every 3 years from end of year 2	US$12,250/km /regravelling	US$36,750	
Paved road with thin roadbase and single bituminous surface treatment [(b)]	Routine maintenance ▪ General expense	US$100 /km/year	US$1,000	US$12,262
	▪ Pothole patching from 2^{nd} to 5^{th} year (assumed 1% of surface affected annually)	US$12.54 /m^2	US$2,508	
	▪ Pothole patching from 7^{th} to 10^{th} year (assumed 0.5% of surface affected annually)	US$12.54 /m^2	US$1,254	
	Resealing with SBST at 5^{th} years	US$1.5 /m^2	US$7,500	
Paved road with thin roadbase with double bituminous surface treatment [(c)]	Routine maintenance ▪ General expense	US$100 /km/year	US$1,000	US$5,076
	▪ Pothole patching from 2^{nd} to 6^{th} year (assumed 0.5% of surface affected annually).	US$12.54 /m^2	US$1,568	
	▪ Pothole patching from 7^{th} to 10^{th} year (assumed 1% of surface affected annually).	US$12.54 /m^2	US$2,508	
Paved road with robust roadbase and single bituminous surface treatment [(d)]	Routine maintenance ▪ General expense	US$100 /km/year	US$1,000	US$11,008
	▪ Pothole patching every 2 years from 2^{nd} to 5^{th} year (assumed 0.5% of surface affected annually)	US$12.54 /m^2	US$1,254	
	▪ Pothole patching every 2 years from 7^{th} to 10^{th} year (assumed 0.5% of surface affected annually)	US$12.54 /m^2	US$1,254	
	Resealing with SBST at 5^{th} years	US$1.5 /m^2	US$7,500	
Paved road with robust roadbase with double bituminous surface treatment [(e)]	Routine maintenance ▪ General expense	US$100 /km/year	US$1,000	US$1,941
	▪ Pothole patching every 3 years (assumed 0.5% of surface affected each time)	US$12.54 /m^2	US$941	
Concrete pavement [(f)]	Routine maintenance ▪ General expense	US$100 /km/year	US$1,000	US$1,400
	Periodic ▪ Joint replacement at 5^{th} Year	US$0.5/m	US$500	

Note: (a) – Management and supervision cost are not included.
(b) – Design Options: 1-A and 5-A
(c) – Design Options: 1-B and 5-B
(d) – Design Options: 2-A, 3-A, 4-A, 6-A and 7-A
(e) – Design Options: 2-B, 3-B, 4-B, 6-B and 7-B
(f) – Design Option 8

The results of the outline asset Whole Life Cost analysis **without discounting** are shown in Table 9.3. A number of interesting observations can be made:-

- The Gravel/laterite surface option is by far the cheapest in terms of initial costs, however the maintenance costs over a ten year period are almost 2.5 times as much as the initial gravel road construction costs. The undiscounted whole life costs for gravel are well in excess of any of the other surface options at US$50,922/km. This has important implications for an operational environment where maintenance is poorly funded and anyway difficult to achieve. In the current circumstances, the considerable gravel road maintenance needs would anyway be unlikely to be funded or carried out in an adequate or timely manner. In reality, further more costly rehabilitation would be required which would substantially raise the asset Whole Life Costs. There are also important environmental issues with regard to ongoing gravel material extraction and haulage to build and maintain a “wasting” surface.
- The un-reinforced concrete pavement (Option 8), despite having the highest initial costs, has the lowest undiscounted whole life costs.
- There is a relatively small spread of asset WLC over the range of paved options analysed; from a low of US$23,189/km (Option 8: un-reinforced concrete), to a high of US$37,070/km (Option 4A: dressed stone pavement with single surface seal).
- The assessed 10 year costs of maintenance for the various paved options compared to gravel/laterite are between only 3.5% (for the un-reinforced concrete) to 29% (for Options 1A and 5A: single bituminous surface treatment on light roadbases). This places in focus the enormous costs and challenges of maintaining a gravel rural road surface in Cambodia and the greater feasibility of the less onerous maintenance of other options being arranged and achieved.

Table 9.3: Asset Whole Life Cycle Costs (undiscounted)

Analysed Design Options	Initial investment cost (US$/km) A	Maintenance cost over 10 years (US$/km) B	Salvage value at 10th Year C = % * A		Whole life cycle cost US$/km D = A + B - C
			Percentage to initial investment	Value in US$/km	
Gravel/Laterite surfaced road	$16,344	$42,750	50%	$8,172	$50,922
Paved Option 1-A	$35,381	$12,262	40%	$14,152	$33,491
Paved Option 1-B	$41,185	$5,076	40%	$16,474	$29,787
Paved Option 2-A	$47,252	$11,008	50%	$23,626	$34,634
Paved Option 2-B	$53,055	$1,941	50%	$26,528	$28,468
Paved Option 3-A	$47,953	$11,008	50%	$23,977	$34,984
Paved Option 3-B	$53,757	$1,941	50%	$26,879	$28,819
Paved Option 4-A	$52,124	$11,008	50%	$26,062	$37,070
Paved Option 4-B	$68,546	$1,941	50%	$34,273	$36,214
Paved Option 5-A	$42,825	$12,262	50%	$21,413	$33,674
Paved Option 5-B	$48,628	$5,076	50%	$24,314	$29,390
Paved Option 6-A	$38,884	$11,008	50%	$19,442	$30,450
Paved Option 6-B	$55,305	$1,941	50%	$27,653	$29,593
Paved Option 7-A	$48,904	$11,008	50%	$24,452	$35,460
Paved Option 7-B	$65,326	$1,941	50%	$32,663	$34,604
Paved Option 8	$72,297	$1,500	70%	$50,608	$23,189
Note: Asset Whole Life Cycle Cost does not include the management and supervision cost					

- In the current environment of very poor maintenance achievement, decision making should be influenced more towards low maintenance surface options for asset managers. These managers are generally not interested in the aspects and influences of 'discounting' and are more likely to be interested to minimise the total costs of construction, maintenance and asset wastage on an ongoing basis over the whole network.
- The WLC assessment period used was only 10 years. Longer assessment periods (although naturally embodying less confidence in the data assumptions) would tend to amplify the differences in undiscounted asset whole life costs.

The results of the outline assessment are tentative as discussed earlier in this chapter, however they largely concur with the experiences and views of local knowledgeable practitioners.

A slightly different result is obtained when the future costs are **discounted** to reduce the influence of future costs (Table 9.4). A discount rate of 10% has been used.

Table 9.4: Asset Whole Life Cycle Costs (discounted)

Analysed Design Options	Initial investment cost (US$/km) A	Discounted Maintenance cost over 10 years (US$/km) B	Salvage value at 10th Year C = % * A		Whole life cycle cost US$/km D = A + B - C
			Percentage to initial investment	Discounted Value in US$/km	
Gravel/Laterite surfaced road	$16,344	$27,132	50%	$2,849	$40,626
Paved Option 1-A	$35,381	$7,639	40%	$4,935	$38,086
Paved Option 1-B	$41,185	$2,817	40%	$5,744	$38,257
Paved Option 2-A	$47,252	$6,736	50%	$8,238	$45,750
Paved Option 2-B	$53,055	$1,160	50%	$9,250	$44,966
Paved Option 3-A	$47,953	$6,736	50%	$8,360	$46,329
Paved Option 3-B	$53,757	$1,160	50%	$9,372	$45,545
Paved Option 4-A	$52,124	$6,736	50%	$9,087	$49,772
Paved Option 4-B	$68,546	$1,160	50%	$11,950	$57,755
Paved Option 5-A	$42,825	$7,639	50%	$7,466	$42,998
Paved Option 5-B	$48,628	$2,817	50%	$8,478	$42,967
Paved Option 6-A	$38,884	$6,736	50%	$6,779	$38,840
Paved Option 6-B	$55,305	$1,160	50%	$9,642	$46,823
Paved Option 7-A	$48,904	$6,736	50%	$8,526	$47,114
Paved Option 7-B	$65,326	$1,160	50%	$11,389	$55,097
Paved Option 8	$72,297	$925	70%	$17,646	$55,576
Notes: Asset Whole Life Cycle Cost does not include the management and supervision cost. Discount rate used = 10%.					

The above table indicates that for the assumptions made which modelled the Pouk Trial location, the discounting process changes the ranking of the surface options:-

- Gravel is no longer the most expensive WLC option.
- Three of the analysed surface options (1A, 1B and 6A) are still cheaper than gravel.
- The un-reinforced concrete pavement (Option 8) becomes the most WLC expensive option.

If VOC would be incorporated in the evaluation to provide a Whole Life Transport Cost assessment, the substantially higher VOCs expected for the gravel surface would rank gravel much lower than the above table suggests. The considerable risks of not achieving the particularly high gravel maintenance interventions in a timely way would also further weigh against the choice of gravel as a surface option for asset managers.

9.4 Rural Unpaved Road Upgrading and Associated Risks

A number of paving options and environment scenarios were considered for whole life cycle cost-benefit analysis within the Pouk Trial Road Environment using the HDM4 model adapted for local conditions. The HDM4 analysis includes the consideration of construction/rehabilitation and maintenance costs for a base option (laterite surfacing) and various other surfacing options. Furthermore analysis was extended to include a number of maintenance and axle loading scenarios. Analysis results are shown in terms of IRR (Internal Rate of Return) against the base option of a maintained laterite road.

Table 9.5 summarises these scenarios. Lack of maintenance and the risk of vehicle overloading are scenarios that are perhaps normally given insufficient attention in WLC analysis in Cambodia. However both of these factors can substantially affect the life of road pavements and VOCs.

Table 9.5: Design Condition and Improvement Options

Upgrading Scenarios	Expected Maintenance and Overloading risk	Proposed Design for cost benefit analysis
Scenario 1	No overloading risk with reliable maintenance system	Design Option 1 – A 70mm armouring with single surface treatment
Scenario 2	No overloading risk with unreliable maintenance system	Design Option 1 – B 70mm amouring with double surface treatment
Scenario 3	Risk of overloading with unreliable maintenance system	Design Option 6 – B 150mm of hand-packed stone with double surface treatment
Scenario 4	Risk of extreme overloading with unreliable maintenance system	Design Option 8 200mm un-reinforced concrete pavement

9.5 Cost-Benefit Analysis

Conventional cost-benefit analysis was carried out in which net benefits were computed on the basis of vehicle operating cost and time savings between laterite road as the "without project scenario" and the proposed upgrading options as the "with project situation". A 10-year period was adopted for this cost benefit analysis.

The economic evaluation was carried out using the World Bank's (now PIARC's) HDM-4 model. The model was calibrated to be adapted to the local conditions and traffic of the Pouk Trial Road, vehicle fleets as well as Cambodian financial and economical parameters. The following tables (9.6 - 9.8) detail the input assumptions and data.

Table 9.6: Traffic composition of Pouk LCS Trials Road

Normal traffic and growth rate			%	Annual growth rates	
				2006 to 2010	2011 to 2015
Non motorized vehicles and motorbikes					
BICYCLE		2,291	63.2%	4%	3%
BICYCLE TRAILER		0	0.0%	4%	3%
OX & HORSE CART		22	0.6%	4%	3%
MOTOR BIKE		1,312	36.2%	4%	3%
Total Non-motorized vehicles		3,625	100.0%	4%	3%
Motorized vehicles					
MOTORBIKE TRAILER		38	35.8%	4%	3%
CAR, Pickup & minibus	Saloon car	10	9.4%	4%	3%
	Pickup private	5	4.7%	4%	3%
	Pickup commercial	15	14.2%	4%	3%
	Minibus	7	6.6%	4%	3%
LIGHT TRUCK		15	14.2%	4%	3%
MEDIUM TRUCK		13	12.3%	4%	3%
Over 20T (HEAVY TRUCK, dump truck and truck with trailer)	Heavy truck	3	2.8%	4%	3%
	Artic. Truck	0	0.0%	4%	3%
Total Motorized vehicles		106	100.00%		

Economic costs are usually computed for HDM4 inputs. These can be obtained by removing the assessed tax components of the financial costs. However, investigations found that there were no reliable data on companies detail accounting records for the range of surface options investigated, which can be used for the determination of economic cost, therefore a factor of 0.85 was adopted for the conversion from Financial to Economic cost as per previously adopted by the World Bank funded PRIP Project[19].

Table 9.7: HDM cost input

Proposed Design Options	Technology Option Construction Cost				Assumed Salvage value at the end of 10th Year
	Machine based Cost US$/ km		LBAT Cost US$/ km		
	Financial cost	Economic cost	Financial cost	Economic cost	
Laterite surfaced road (Base-case)	16,344	13,892	18,443	15,677	50%
Paved Option 1-A	35,381	30,074	38,447	32,680	40%
Paved Option 1-B	41,185	35,007	44,538	37,857	40%
Paved Option 6-B	55,305	47,009	58,121	49,403	50%
Paved Option 8	72,297	61,452	74,126	63,007	70%

19 Refer - Project Preparation Phase – Technical component, Provincial and Rural Infrastructure Project, Cambodia

Table 9.8: Maintenance Policies and Associated Costs

Type of maintenance application	Type of maintenance works	Economic cost US$	Financial cost US$	Design & effects of intervention
Without project: Laterite Road	- Routine maintenance - Regravelling every 4 years	510/km/year 10,413/km/ regravelling	600/km/year 12,250/km /regravelling	Final gravel thickness: 200 mm
With improvement to paved standard: Scenario 1	- Routine maintenance every year - Pothole patching every year - Resealing with SBST at 5^{th} years	85/km/year 10.66 /m^2 1.28/m^2	100/km/year 12.54 /m^2 1.5 /m^2	100% potholes patched SBST with 8mm chippings
Scenarios 2, 3 and 4	- Routine maintenance every year - Pothole patching every year - No Periodic Maintenance	85/km/year 10.66 /m^2	100 /km/year 12.54 /m^2	100% potholes patched

The traffic surveys for the Pouk LCS Trials Road confirm that the route is particularly busy for a tertiary rural road; with 106 cars and commercial vehicles daily (all motorized traffic excluding motorbikes) and 3,625 items of non-motorized traffic (including motor bikes). It is therefore not surprising that Table 9.7 shows that all paving options have an IRR greater than the minimum assessed to be required to justify economic benefit of 12%, when compared to the base option of a maintained laterite surface road.

The analysis also demonstrates the detrimental effects of overloading and the significant cost-effectiveness of maintenance (and the economic penalty of lack of maintenance).

Table 9.9: Cost Benefit Analysis with current traffic of Pouk LCS Trials Road

Scenario	Improvement options	Financial cost of Improvement US$/Km	Internal Rate of Return (IRR in %)
Scenario 1: Good maintenance management system and funding	Paved Option 1-A (Machine based)	35,381	35.6
	Paved Option 1-A (LBAT)	38,447	32.5
Scenario 2: Unreliable maintenance management system and funding	Paved Option 1-B (Machine based)	41,185	31.7
	Paved Option 1-B (LBAT)	44,538	29.1
Scenario 3: Unreliable maintenance management system and funding and with risk of overloading	Paved Option 6-B (Machine based)	55,305	23.1
	Paved Option 6-B (LBAT)	58,121	21.8
Scenario 4: Unreliable maintenance management system and funding and with risk of extreme overloading	Paved Option 8 (Machine based)	72,297	18.4
	Paved Option 8 (LBAT)	74,126	18.9

To test the sensitivity of the economic viability for different improvement options, the HDM4 Model of Pouk LCS Trial Road was tested with lower traffic of 25% and 50% reduction to Pouk Traffic. The outcome of the cost benefit analysis for each option is given in the following Table 9.10.

Table 9.10: Sensitivity of Internal Rate of Return

Expected Maintenance and Overloading risk	Improvement Options	Financial Cost of Construction in US$/Km	IRR (%) versus Traffic		
			Pouk Traffic [(a)]	25% lower than Pouk traffic	50% lower than Pouk traffic
Scenario 1	Paved Option 1-A (Machine based)	35,381	35.6	23.2	11.2
	Paved Option 1-A (LBAT)	38,447	32.5	20.9	9.7
Scenario 2	Paved Option 1-B (Machine based)	41,185	31.7	21.1	10.9
	Paved Option 1-B (LBAT)	44,538	29.1	19.1	9.5
Scenario 3	Paved Option 6-B Machine based)	55,305	23.1	14.9	7.2
	Paved Option 6-B (LBAT)	58,121	21.8	13.9	6.5
Scenario 4	Paved Option 8 (Machine based)	72,297	18.4	12.2	6.6
	Paved Option 8 (LBAT)	74,126	18.9	12.6	6.8
(a):106 Cars and commercial vehicles; 3,625 Non-motorized and motorbikes					

The analysis results in Table 9.10 show that:

1. For a rural road which has similar traffic to Pouk LCS Trials road; all paving options are economically viable.
2. If traffic is 25% lower than Pouk road, the economic benefit of the Improvement Option 8 (un-reinforced concrete pavement) is close to the selected minimum required of 12%.
3. If traffic is 50% lower than Pouk road, all Options have IRR lower than the minimum required.

The analyses have taken just one set of assumptions based on the Pouk Trials site. In practice, a number of factors will be different and unique to a particular road location as outlined in the following section.

9.6 Socio-Economic Impact of Different Options

In Cambodia and many other developing countries, poverty and unemployment especially in rural areas have very high rates of incidence. Where employment and poverty reduction is a target of government policy and rural road improvement projects, the traditional Economic Internal Rate of Return or whole life cycle cost analysis alone cannot provide the optimal design solution regarding social impact and creation of local employment, and thus enhancement of the local economy and poverty reduction.

Investigations and research under SEACAP 2 and 8 in Cambodia, and similar initiatives in Vietnam suggest that in future the best use of rural road investment funds will depend on careful consideration of the factors of:-

- Traffic and axle loading regime
- Subgrade conditions
- Rainfall and hydrology regime
- Materials locally available and haulage factors
- Labour and skills availability
- Contractor capacity and experience, and training needs
- Technology options
- Construction timescale and weather constraints
- Construction regime
- Maintenance regime and funding
- Logistical remoteness and market conditions

Table 9.11 provides a summary comparison of the various paving options analysed for the purposes of this assignment. It indicates how socio-economic assessments can augment traditional economic analysis of surfacing and paving options for rural roads in terms of percentage of cost allocation to employment generation, number of workdays generated for local employment and investment capital per workday generation.

Table 9.11: Summary Comparison of Socio-Economic benefit of analysed example construction options

Proposed Design Options	Initial Cost of Road (US$/km)	Percentage of cost allocated to employment	Worker Days generated for local labour	Investment capital per WD Generated (US$/WD)	IRR Pouk LCS Trial road
Laterite surfaced road (Machine based)	16,344	1.30%	116	140.4	Base Case
Laterite surfaced road (LBAT)	18,443	4.99%	1,027	18.0	
Improvement Option 1-A (Machine based)	35,381	3.14%	384	92.1	35.6
Improvement Option 1-A (LBAT)	38,447	6.64%	1,984	19.4	32.5
Improvement Option 1-B (Machine based)	41,185	3.21%	420	98.1	31.7
Improvement Option 1-B (LBAT)	44,538	7.14%	2,184	20.4	29.1
Improvement Option 6-B (Machine based)	55,305	13.2%	3,463	16.0	23.1
Improvement Option 6-B (LBAT)	58,121	15.8%	5,196	11.2	21.8
Improvement Option 8 (Machine based)	72,297	9.0%	1,667	43.4	18.4
Improvement Option 8 (LBAT)	74,126	9.9%	2,546	29.1	18.9

9.7 Costing Analyses Summary

The investigations carried out under this project have attempted to extend the traditional cost benefit analysis approach used for project evaluation of road investments. The analysis is primarily for demonstration purposes. Because costing depends on a wide range of factors that vary from site to site the values and rankings could change with different input assumptions.

However, the investigations have demonstrated and revealed a number of important issues with regard to rural road assessment in Cambodia. These include:

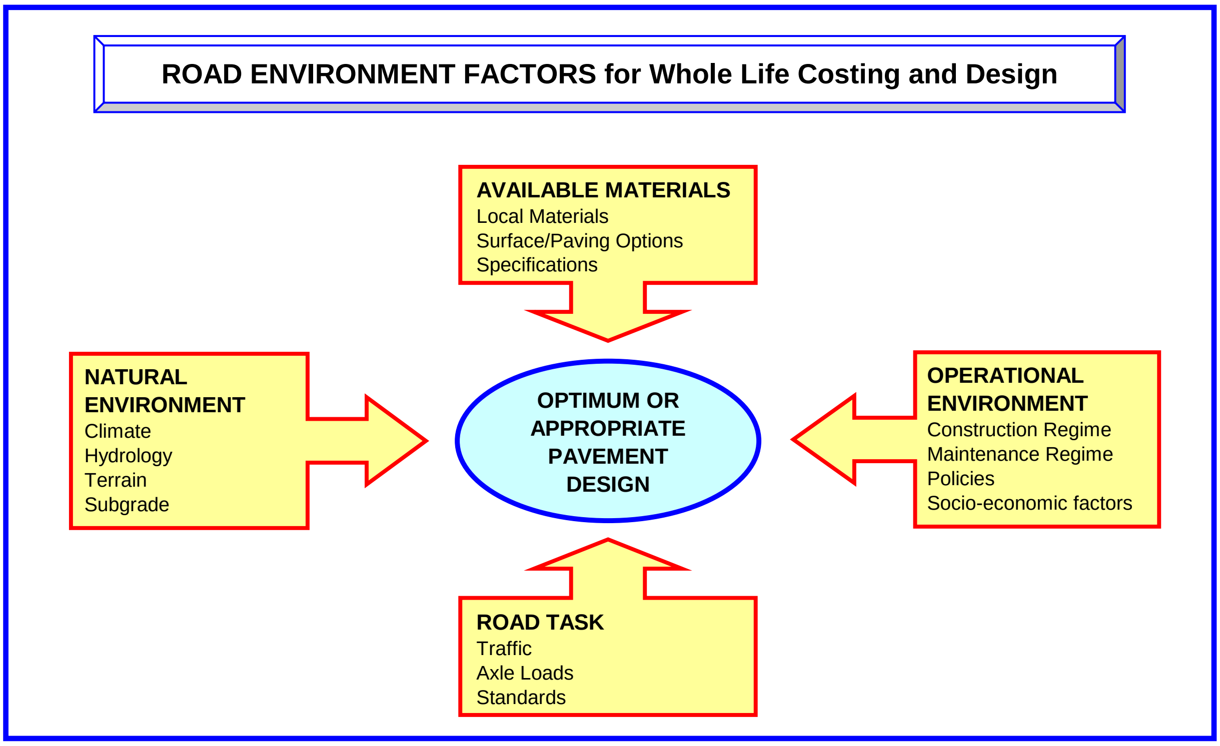
- The widespread inadequate rural road maintenance capacity in Cambodia is a substantial constraint to the evaluation and delivery of cost-effective rural road infrastructure and services to all communities and particularly the poor.
- There is a significant knowledge deficiency with regard to road maintenance and VOC relationships to support accurate assessments of Whole Life Costs in the Cambodian environment. Despite this situation, reasonable confidence can be made in evaluation of some fundamental factors that influence the performance of rural roads in Cambodia.
- A wide range of factors (refer to Section 9.5) influence the cost benefit relationship for a particular road location. Some of these have hitherto been given insufficient attention.
- Rural Road paving can be justified at modest traffic flows[20].
- LBAT and MB technology option cost comparisons depend on the local circumstances and factors.
- LBAT technology can bring substantial benefits in employment creation at construction stage compared to Machine Based technology. There are also further “multiplier effects” that are currently difficult to include in conventional economic evaluation.
- The investments required per worker day generated for LBAT options are substantially lower than for Machine Based technology options.
- The risks of overloading and lack of maintenance potentially have much greater effect than technology choice on the economic and social outcome of a project. More attention should be paid to these factors in project design and implementation, and their accommodation or amelioration.
- Further investigations are required in Cambodia to develop good VOC relationships and to monitor the Puok Trials to enable deterioration/maintenance relationships to be developed for improved Whole Life Costing of the various rural road surface options.
- More knowledge is required on the socio-economic benefits of employment through choice of technology for various pavement options, the maintenance requirements of each paving option (and whether manageable) and possibilities for small local contractors or communities themselves to be involved with the maintenance arrangements.
- Haul route deterioration and damage due to initial and repeated haulage of construction and maintenance materials along them are a particular concern for the circumstances of Cambodia.
- Road standards will substantially influence the cost benefit relationships for a road project and therefore it is important that appropriate standards are applied.

20 It is recommended that alternative surface options should be investigated for any traffic flows of more than 50 motor vehicles per day equivalent. Paving options could be justifiable against gravel in some circumstances at lower traffic flows.

- The quality control regime at the construction stage (and for maintenance) will substantially affect the performance and whole life costs of a road. A more realistic assessment of the QA regime in the road works should be made. For example it is invariably assumed that specification-compliant gravel is delivered to site, which various studies have shown to be erroneous.

The following flow chart suggests a framework of consideration of the various factors influencing the Whole Life Costs of Rural Road Surfacing Options and their design.

Figure 9.4: Recommended Framework for Whole Life Costing Assessment and Design



10 PROVISIONAL SPECIFICATIONS FOR RURAL ROAD SURFACE OPTIONS

Appendix B of this report contains Provisional Specifications for a number of rural road surface and paving options. These have been developed from the consideration of the experiences on the Puok Market rural road surfacing trials, experience elsewhere in Cambodia and the RRSR research and dissemination work carried out by Intech-TRL in Vietnam.

11 LESSONS LEARNED AND RECOMMENDATIONS

The Puok Market trials supported by DFID, ILO and SIDA have been a valuable experience for the Government of Cambodia and the development agencies concerned in supporting the initiative. The lessons and experiences are timely in the face of widespread concern about past inappropriate investment in non-sustainable surfaces such as gravel in many situations in South East Asia and elsewhere.

The trials have allowed a number of important issues to be identified and a strategy to be developed towards designing and providing more appropriate and sustainable rural roads for the Cambodian rural communities, and to strongly support Governments' employment and poverty reduction initiatives.

The principal lessons from the Puok Market trials to date are:-

- Rural road design in Cambodia is particularly challenging and the past simplistic and largely partially informed approach to rural road provision can no longer be tolerated or afforded in a severely resource constrained environment. A new design strategy is required for Cambodian Rural Roads.
- Factors of traffic and vehicle loading, local materials availability, local resource use technologies, quality control, sub-grade conditions, maintenance regime must be carefully considered in developing the appropriate construction and maintenance approach.
- Gravel/laterite should only be used where certain requirements, particularly regarding materials quality, haul distance and maintenance regime can be satisfied.
- There is a substantial range of alternative paving options with better whole life cost and social benefits than gravel/laterite in many situations. These can be constructed by small scale contractors with limited equipment resources and using local labour.
- Some paving types are more suitable for heavy vehicle overloading or a poor maintenance regime.
- Construction Materials haulage is particularly damaging to rural roads and consideration should be given to legislation and regulation to ensure that adequate arrangements are made to provide adequate designs and maintenance for these routes, possibly involving contributions from the resource development stakeholders.
- The Puok Market trials have been a valuable start in the quest for low cost and sustainable rural road surfacing. However considerable work still remains to be carried out to extend the experiences, monitor the performance of the trials and develop design approach most suitable for the Cambodian conditions.

The principal outputs from the Puok Trials are:-

- Low cost, sustainable surface options, trial-demonstration, road sections constructed.
- Recommendations on new rural road surfacing design strategy for Cambodian Rural Roads.
- Draft Specifications for selected rural road paving options.

- Recommendations on the restriction of the use of gravel/laterite for rural road surfacing.
- Recommendations on further surfacing research and design system development.

In particular detail some of the issues are summarised in the following text:-

Low Volume Sealed Road and Design Environment: It is important to appreciate the situation with respect to loading and road pavements in Cambodia. Nearly all of the research on axle loading and pavement damage has been conducted in developed countries. Factors such as climate, flooding, range of loading, road user discipline and control, construction techniques, construction quality control and maintenance regimes etc. can have a significant effect on pavement performance. Light or sub-standard road pavements which are suitable for rural traffic and loading can be quickly destroyed by overloaded trucks. Road financiers, designers and managers need to be informed of these issues. More attention is required to be given to the development of appropriate standards and specifications tailored to the local environment and economic circumstances of Cambodia.

Effective Overloading Control on Rural Roads: The problem of overloading on Pouk Trial had been identified soon after the opening of the sand quarry and before any of the trials section had deteriorated. Considerable efforts were made to stop the sand-haulage trucks through several meetings with the road authority as well as the district authority. Despite assurances from the local authority to control the overloading, sand haulage trucks continued to access the trial road fully loaded until the severe road damage became apparent. In subsequent discussions it was agreed that the vehicle width restricters would be constructed, and these were installed in August 2005 to prevent the further passage of heavy trucks. These have helped to prevent further overloading.

There has been considerable discussion of the issue of restrictions during the “Axle Loading and Pavement Design Strategy” workshop in November 2004. There are strong arguments both for and against such restrictions. Representatives from the Military Engineering Unit recommended that there should no barriers constructed at any type of roads. There appeared to be little understanding of the economic consequences of unlimited access and loading in the Cambodian conditions. From this workshop, it was clearly shown that there is need for public awareness of the impact of overloading on the road network and necessity to introduce controls for certain low volume sealed roads or the specific introduction of strengthening measures on routes at risk.

All stakeholders involved in road construction and management should be aware of the issues and support a common strategic plan for axle loading and control for each category of road with the necessary political support.

Road Investment and Employment Generation: there is considerable potential for employment generation from public investment in the road sector if at the design stage the availability of local materials and people’s skills are carefully considered. This should be considered to be an actively applied component of Government policy.

LBAT (Labour Based Appropriate Technology) and Machine-Based benefits: Developing countries in South-East Asia are quite different from Africa in a number of respects. In South East Asia, second hand machinery and spare parts are widely available from nearby dynamic markets. They are relatively cheap to procure and local people have developed skills and experiences which make maintenance and operating costs of those machines relatively low compared to the situation in many African developing countries. Locally made, small and intermediate commercial vehicles are also available at low cost.

The information available indicates that LBAT and MB approaches are currently competitive depending upon the local conditions. MB sometimes appears more attractive in the short term since normal market forces and costs are skewed or inapplicable when costs are calculated. For example real equipment costs are not reflected in the costs of construction when MB costs are reported. This is caused especially by a lack of use of practices and the circumstances normal in conventional markets for the finance of procurement and replacement of the largely second hand equipment by the contractors. Furthermore, MB approaches concentrate the project capital into the fewest of hands with the result that real practices and costs are less than transparent. Quality control with both options is a major problem further making comparisons difficult.

The example cost analysis using the actual labour rate of US$1.25/day for the Cambodia conditions has shown that LBAT is slightly more expensive in terms of investment financial cost for all of the construction options analysed for the selected assumptions. These findings were checked and confirmed with some of the LBAT trained contractors. However if the Government and Donor Agencies are serious about poverty reduction through employment generation on road sector projects, then greater efforts will be required to actively support the policy of LBAT, provide incentives and training, to achieve the identified socio-economic benefits of such an approach. There would probably be benefits in concentration of efforts on developing suitable LBAT arrangements with local enterprises and communities for spot improvement and maintenance strategies for rural roads, due to the advantages of smaller contract sizes and local mobilisation. More research is required to quantify the employment and other socio-economic benefits of the various surfacing/paving options with respect to issues of labour employment, multiplier effects, local resource use, environmental protection, maintenance arrangements feasibility risk and effectiveness.

Promoting LBAT by Specification: Certain paving techniques such as dressed stone and hand packed stone are intrinsically labour based. Specification of these durable, low maintenance surface options can provide socio-economic benefits in construction as well as through reduced maintenance liabilities. The Puok Market trials have demonstrated that these techniques can be used as a “stage construction” approach by providing an all weather surface using local labour and later upgrading to a smother bituminous surface.

Other Benefits from Reliable Access: It has been observed that there has been a considerable amount of new house construction along the Puok trial road after the upgrading of the route to an all-weather durable surface. Land values along this trial road have substantially increased too. These benefits which relate to road development have not been considered in the current economic assessment model.

Overloading and failure of Armoured Laterite Option (Trial Section 4 and Section 9): The failure of two of ten trials section initially caused concern to some practitioners in Cambodia regarding the performance of this paving option. However the extreme overloading conditions coupled with the minimal protection of the single surface chip-seals would not be expected to be compatible. This relatively inexpensive form of paving would be expected to perform well for rural roads not subjected to overloading.

Concrete Paving: Concrete slab paving has been shown to be resistant to heavily overloaded trucks if properly constructed, with minimal maintenance requirements. Options are available of un-reinforced, or nominally reinforced by steel or bamboo. Load transfer dowels are necessary at all slab transverse joints (they would also be required along the centre line joint if the pavement was to be constructed in two half widths). However the trials indicate that the end slab adjoining an un-surfaced or flexible paved section of road should have particular impact loading design considerations as this slab does not benefit from load transfer arrangements adjoining the non-concrete section of surface.

Further Trials and Research Required: The current trial options provide some alternative solutions for upgrading from laterite surfacing to durable surfaced road. However, generally the <u>initial</u> investment costs of those options are high compared to a laterite surface. Thus even though there will be greater benefits for the long term, with current financial constraints and many communities not yet connected to reliable access, the Government would be constrained to widely adopt these options for lower level roads (commune or village roads). Therefore further cheaper alternative options should be considered for the expansion of trials under the SEACAP programme. These paving types include:-

- **Engineered Natural Surface (Engineered earth road):** the majority of rural road network (approximately 14,576 km of the 24,028 km identified rural road network) in Cambodia are Earthen Roads. Those roads were constructed with in-situ materials found along the road alignment and many of them are only accessible in the dry season, while access during the rain season is often cut or very difficult. Successful research on appropriate construction and maintenance of engineered natural surfaces would have a considerable impact for rural communities to obtain low cost reliable access in many situations.

- **Laterite-aggregate mix**: Fine (non-specification compliant) lateritic gravel is not recommended for use as road surface. However good quality laterite is becoming scarce or expensive due exhaustion of resources and ever extending haul distances. This pressurises engineers or projects to accept low quality materials available nearby. The use low standard laterite surfacing material results in rapid deterioration caused by traffic and rainfall on the road after the construction. This poor quality laterite can be improved by adding stone aggregate mixed together and compacted. The stone aggregate will provide greater resistance against wear caused by vehicle tyres while fine material (clay) provides cementation and a degree of waterproofing. This is effectively a mechanical stabilisation process.
- **Nature surface armoured with hand-packed stone**: one of the problem of clay soils is that the few millimetres of the top surface become soft and slippery when wetted, which make traffic passage difficult and also leads to rapid deterioration in the rain period. The natural surface can be improved at low cost by armouring with hand-packed stone, without the subsequent bituminous seal adopted on the Puok Trials.
- **Compacted, shaped Earth or Laterite surface blinded with a layer of single size stone aggregates**: This option will be cheaper than laterite-aggregates mixture. 10mm to 20mm stone aggregate spread and compacted into an existing shaped earth or laterite surface. The stone aggregate will provide greater resistance against wear caused by vehicle tyres and also improve skidding resistance while the existing fine material (clay) will provide a degree of cementation and waterproofing.
- **Rice husk fired clay bricks**: Battambang and Banteay Meanchay are important agricultural provinces of Cambodia that produce rice and rice husk fired clay bricks are also produced locally for the building industry. This technique has recently spread to other provinces around the Tonle Sap lake when fire wood becomes increasingly expensive. The quality of the brick produced does not currently meet the higher quality standards for brick road surfacing However the trials in Vietnam (SEACAP-1) have demonstrated that bricks produced there using a similar technique have sufficient strength and quality. This technology and experience could be transferred to Cambodia through study tours and training. There would be benefit for both the road and building industry in Cambodia. This technique should have wide application in the lake basin and Mekong Delta areas of Cambodia where there are severe shortages of conventional hard stone road building materials.
- **Cement stabilised roadbase**: With adequate training and quality controls arrangements, this form of construction could be cost-effective in the large areas of lake basin and Mekong delta where there are few hardstone resources, yet sand deposits exist. The technique has been successfully used in Vietnam.
- **Rice Husk Ash**: potential to be used as a pozzolana for strengthening subgrades and bases.
- **Use of Recycled Rubber**: Rubber tyre waste is becoming an increasing environmental problem. There may be potential to use recycled tyre rubber in rural road works.

Future Trials Monitoring: It is necessary to agree arrangements and secure finance for the monitoring and maintenance arrangements for the Puok trials road sections so that designs and specifications can be verified or refined for wider application in Cambodia and elsewhere.

Other Research Required: As well as the additional surfacing and maintenance monitoring research identified above, there is an identified need for further research on feasible, affordable maintenance arrangements and locally applicable Vehicle Operating Cost relationships.

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APPENDIX A – Local Resources Investigation and Laboratory Testing

A-1 Local Materials

The construction, rehabilitation and maintenance of gravel roads during the last two decades have considerably depleted the laterite sources around Siem Reap province. To obtain good quality laterite, contractors have to haul from a long distance and for the Pouk Trials, the nearest acceptable quality of laterite was found at Phnom Dey which is located 55 km away from the Pouk Trials Road. Samples from this source were sent to the Public Works Laboratory for testing. Details of laboratory testing results are given as Appendix A-3 of this report.

Sand is available approximately 8 km away from the trial sections. This sand deposit is located in Doun Koev commune. This sand can be used as the bedding layer or a sand-aggregate road base; this technique had already been trialed on Section 3 and Section 5, or stabilised with cement for use as a road sub-base or roadbase, and for surface treatment. Samples were taken for laboratory testing which comprised sieve, CBR, and a cement stabilisation tests. Two different sand samples (fine grading and coarse grading) were taken for laboratory testing. Test results are provided in Appendix A3.

Different stone materials for roadbase and surfacing have been identified from three different quarries namely Phnom Leap (Q3), Phnom Toeuk Koub (Q4) and Phnom Thom (Q5).

There are various types of stone aggregates produced at Leap Mountain for both road and building construction. Two types of stone aggregates: 10 to 20mm gap graded stone sizes and broken stone of 100 to 200mm in size that can be used for road construction. The 10-20mm size can be mixed with sand and used as a sand aggregate road base. The broken stone is produced for the construction of stone masonry for the foundations of small buildings and in road construction as a macadam road base. The source locations are indicated on Figure A1-7.

Table A1-1: Material availability and cost at survey

Ref.	Name -Type	Product	Cost/m3 (at source)	Excavation	Processing	Distance to LCS Trials
Q1	Phnom Dey Laterite	Laterite gravel.	$2.2	Mechanical + manual		55 Kms
Q2	Doun Keov Sand	Fine sand Coarse sand	$2 (bedding) $3 (concrete)	Small dredge-pump	Labour-based	8 Kms
Q3	Phnom Leap Quartzite sandstone	Crushed rock aggregate and blocks	Aggregate.: $8 Broken Stone $5	Hand	Labour-based	57 Kms
Q4	Phnom Toeuk Khoub Medium grey with off-white inclusions moderately strong –strong Rhyolitic Tuff. Fine-medium sand sized matrix with angular gravel sized quartz/feldspar inclusions	Crushed rock aggregate	Well graded aggregates: $7 8mm stone chippings: $8 Crusher dust: $4	Drill/blast	Single crusher +screen and labour-based	55 Kms
Q5	Phnom Thom Medium grey moderately strong carbonate siltstone or fine grain Limestone and pale yellow orange moderately strong fine carbonate sandstone or Sandy Limestone	Crushed rock aggregate	Concrete aggregate: $9 14mm Stone chipping: $9	Drill/blast	Multiple jaw crusher + screen	115 Kms

Figure A1-1: Q1- Phnom Dey, Laterite borrow pit

Figure A1-2: Sand extraction near Pouk LCS

Figure A1-3: Q3-Hand broken Stone block (10-20mm size) from Phnom Leap

Trials Figure A1-4: Q3-Hand-broken stone aggregate 100 – 200 mm size from Phnom Leap

Figure A1-5: Q4-Stone from Phnom Toeuk Khoub

Figure A1-6: Q5-Stone from Phnom Thom

Figure A1-7: Map of Local Resources

A-2 Experience of Local Contractor and Labour

It was also identified that local labour and contractors have had experience in constructing a so called "macadam road-base" with bitumen surface treatment on urban, main and secondary roads. However, investigations and experience of the Research Engineer reveal that the design and construction methods used were not appropriate for the following reasons:

- The large broken stone pieces were laid on a compacted surface without a cushion layer. This method makes individual stones unstable and the layer as a whole is not dense, with plenty of voids left beneath the stones.
- Plastic material (clayey soil) was used to fill the voids in between the stone pieces. The interlocking effect of the plastic material was very poor and it affects the strength of the entire layer.
- Multiple layers of single size aggregate were used to make a relatively smooth finished surface. These materials remain loose and porous when bituminous surface was applied, and are inherently weak.


Photograph A2-1 and A2-2 – Road in front of the Provincial Department of Rural Development Siem Reap Town (Fine sandy-clay was used to fill voids in between stone aggregate)


Photograph A2-3 and A2-4: Road-base under construction: urban road in BMC province (Clayey soil was used to fill voids between hand packed stone)

A-3 Laboratory tests for laterite from Dey Mountain

I.T.C. GENIE CIVIL

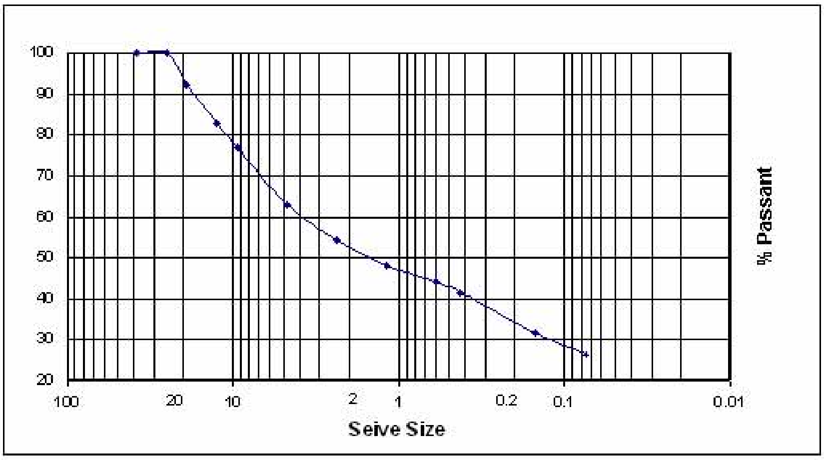
Laboratory of Material

Project :	SEACAP-8			
Subject :	SIEVE TEST (AASHTO T27)			
Location : Phnom Dey, SRSNo1		Description : Laterite		Sampling date : 20/02/2005
Client : IC	Made by :	KHEM Ratha		Date : 08/03/2005
	Checked By :	CHREA Rada		Date : 10/03/2005

Sieving test on laterite before Proctor test :

Total mass of oven-dried soil = 2114.2 g

Sieve Size	Mass retained	Mass passing	% Passing
mm	g	g	%
38	0	2114.2	100.00
25	0	2114.2	100.00
19	159.60	1954.60	92.45
12.5	201.30	1753.30	82.93
9.5	124.33	1628.98	77.05
4.75	299.16	1329.82	62.90
2.36	183.49	1146.33	54.22
1.18	131.33	1015.00	48.01
0.6	83.71	931.30	44.05
0.425	53.11	878.18	41.54
0.15	212.03	666.15	31.51
0.075	109.55	556.60	26.33
Fond	556.60	0.00	0.00

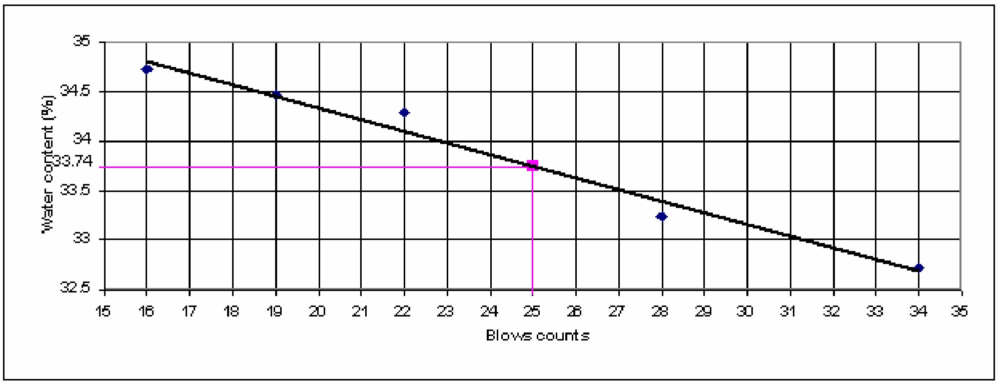


Type of soil: **SC** (Clayey sand, sand-clay mixtures)

Project	SEACAP-8		
Subject:	ATTERBERG LIMITS (AASHTO T90)		
Location: Phnom Dey, SRSNo1	Description: Laterite	Sampling date: 20-Feb-2005	
Client: IC	Made by: KHEM Ratha	Date: 8-Mar-2005	
	Checked by: CHREA RADA	Date: 10-Mar-2005	

The determination of liquid limit: (Casagrande Method)

Test No.	1		2		3		4		5	
Container No.	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
Mass of container (g)	13.32	19.51	14.14	13.76	15.87	14.58	14.62	15.42	13.7	15.85
Mass of container+ wet soil (g)	32.03	40.88	36.4	27.94	39.76	34.01	36.32	37.38	36.11	33.38
Mass of container+ dry soil (g)	27.22	35.36	30.72	24.29	33.66	29.05	30.91	31.9	30.57	29.07
Mass of water (g)	4.81	5.52	5.68	3.65	6.1	4.96	5.41	5.48	5.54	4.31
Mass of dry soil (g)	13.9	15.85	16.58	10.53	17.79	14.47	16.29	16.48	16.87	13.22
Water Content (%)	34.604	34.826	34.258	34.663	34.2889	34.278	33.2106	33.2524	32.839	32.602
Av. Water Content (%)	34.715		34.461		34.283		33.231		32.721	
Blows counts	16		19		22		28		34	



The determination of Plastic limit:

Test No.	1	2	3	4
Container No.	2°	3°	4°	J
Mass of container (g)	27.7	28.28	27.81	28.07
Mass of container+ wet soil (g)	32.8	32.86	32.81	31.61
Mass of container+ dry soil (g)	31.79	31.96	31.88	30.96
Mass of water (g)	1.01	0.9	0.93	0.65
Mass of dry soil (g)	4.09	3.68	4.07	2.89
Water Content (%)	24.694	24.457	22.85	22.491
Av. Water Content (%)	23.62			

Liquid limit : LL = **33.742** %

Plastic limit : PL = **23.62** %

Plastic Index : PI = LL - PL = **10.12** %

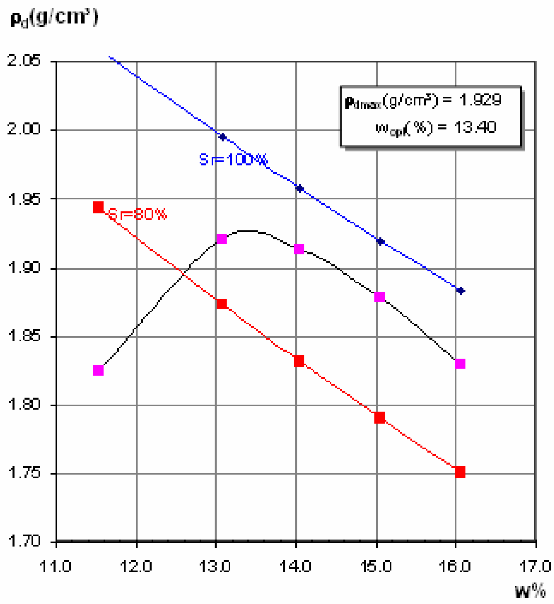
Type of soil: CL (Inorganic clays of low to medium plasticity)

PROCTOR TEST (AASHTO T180)

Project :	SEACAP-8
Sample No :	Phnom Dey, SRSNo1
Project Location :	Siem Reap Province
Sampling date :	30/07/2005
Tested by :	KHEM Ratha
Checked by :	CHREA RADA
Date :	**31/8/2005**

characteristic of the test		T180
normal A B C D	modified	
56	blows/layer	
5	Layers	
	Hammer (g)	4535
	Drop height (mm)	457
	mould volume (cm³)	2123.00

Specific gravity G :	2.7
% retain on 20 mm :	0
% retain on 5mm :	33.46



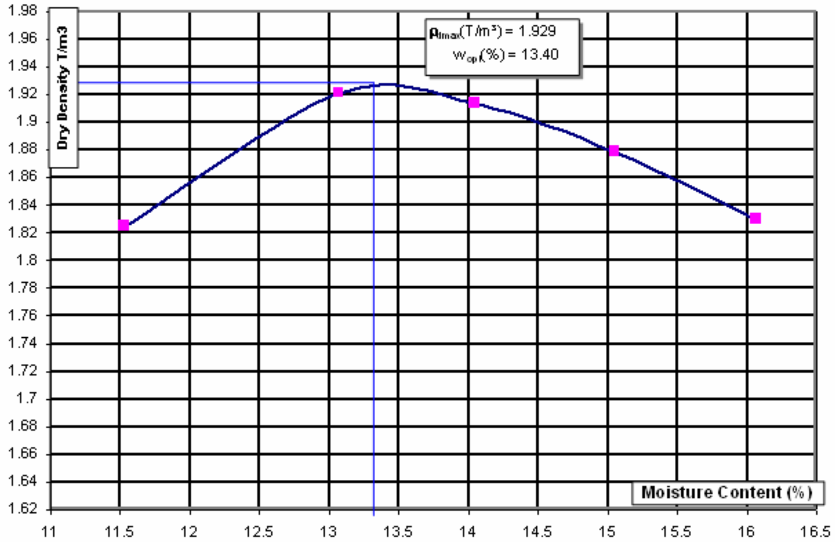
Assumed water content (%)	10.0		12.0		13.0		14.0		15.0	
Wt. of mould W (g)	7792		7792		7792		7792		7792	
Wt. of moule + wet soil W_w (g)	12451		12765		12788		12740		12654	
Wt. of wet soil (g)	4659		4973		4996		4948		4862	
Volume of mould V (cm³)	2289.71		2289.71		2289.71		2289.71		2289.71	
Wet density (g/cm³)	2.035		2.172		2.182		2.161		2.123	
Container n°	O	I	R1	Z1	T2	T3	Z3	Z4	T11	T12
Wt. of container (g)	22.9	28.2	28.2	24.2	92.9	93.5	25.8	25.8	110.4	100.4
Wt. of container + wet soil (g)	144.7	132.1	159.7	151.4	249.15	228.3	160.1	193.1	245	256.2
Wt. of container + dry soil (g)	132.3	121.2	144.6	136.6	229.9	211.7	142.3	171.5	226.4	234.6
Wt. of water (g)	12.4	10.9	15.1	14.8	19.25	16.6	17.8	21.6	18.6	21.6
Wt. of dry soil (g)	109.4	93	116.4	112.4	137	118.2	116.5	145.7	116	134.2
Water content (%)	11.33	11.72	12.97	13.17	14.05	14.04	15.28	14.82	16.03	16.10
Average water content (%)	11.53		13.07		14.05		15.05		16.06	
Dry density (g/cm³)	1.824		1.921		1.913		1.878		1.830	

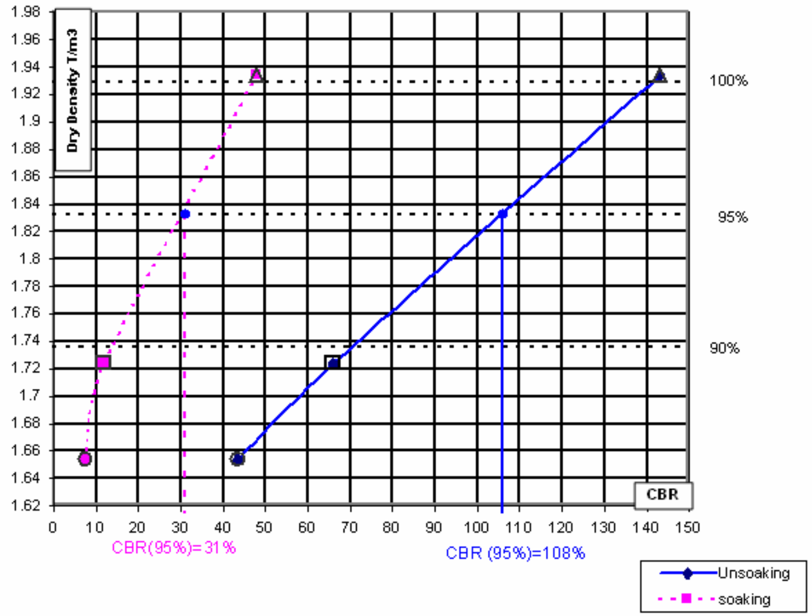
Project :	SEACAP-8	
Subject :	TEST OF PROCTOR AND CBR	
Location : **Phnom Dey, SRSNo1**	Description : Laterite	Sampling date : 30-Jul-2005
Client : **IC**	Made by : **KHEM Ratha**	Date : 9-Jan-2005
	Checked By : **CHREA Rada**	Date : 12-Sep-2005

CBR	Dry Density T/m³	%M.C. at Compaction	% M.C after 96h Soaking	Swelling (%)
△ 65 Blows	1.934	13.373	15.288	0.535
□ 30 Blows	1.724	13.373	19.384	0.921
○ 10 Blows	1.654	13.447	19.838	0.441

MAX DRY DENSITY : 1.929 T/m³

OPTIMUM MOISTURE CONTENT: 13.4 %





A-4 Laboratory tests of Sand Samples from Daun Keo

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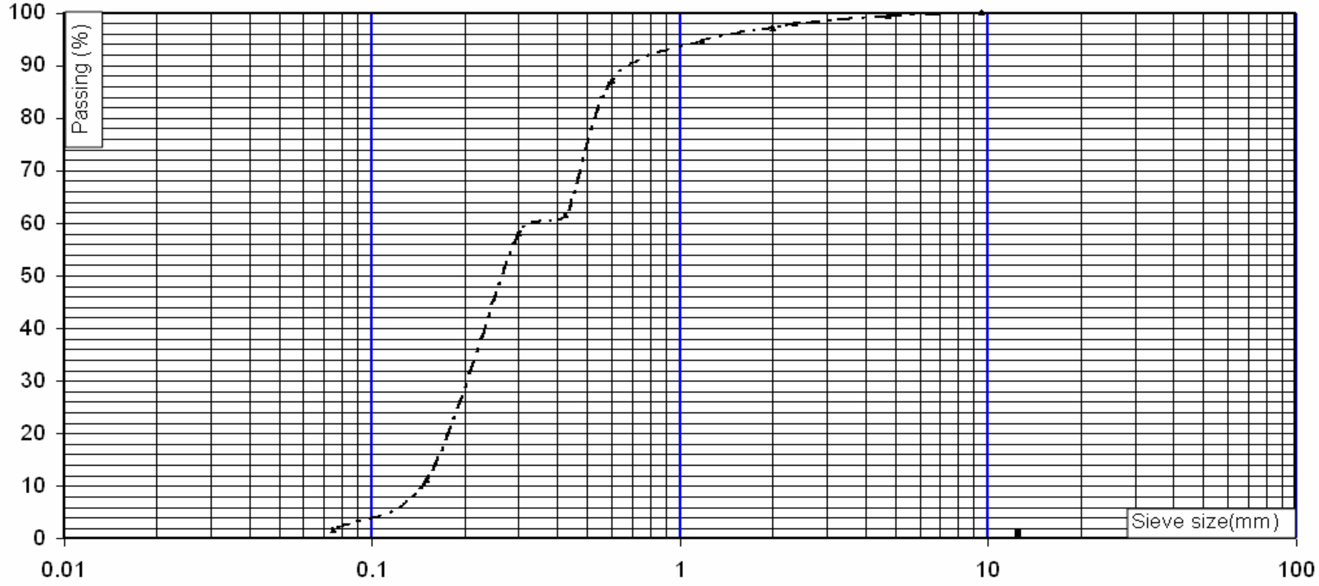
NATION RELIGION KING

Graphic Representtive		Specification Limit	Source of Material	Date Sampling	Date Testing	LABNº
— · — · — · —	Actual test	AASHTO T-11 T - 27/ T-88	Fine Sand	19-Feb-05	23-Feb-05	0265
	Upper limit					
	Lower limit					

INTECH CAMBODIA COSULTING ENGINEERS
Fine sand from Pouk SIEM REAP

Granular

Sieve size (mm)	Actual test (%)
12.5	
9.5	100
4.75	99.4
2.36	97.9
2.00	97.1
1.18	94.7
0.600	87.1
0.425	61.6
0.300	58.0
0.150	11.1
0.075	1.7



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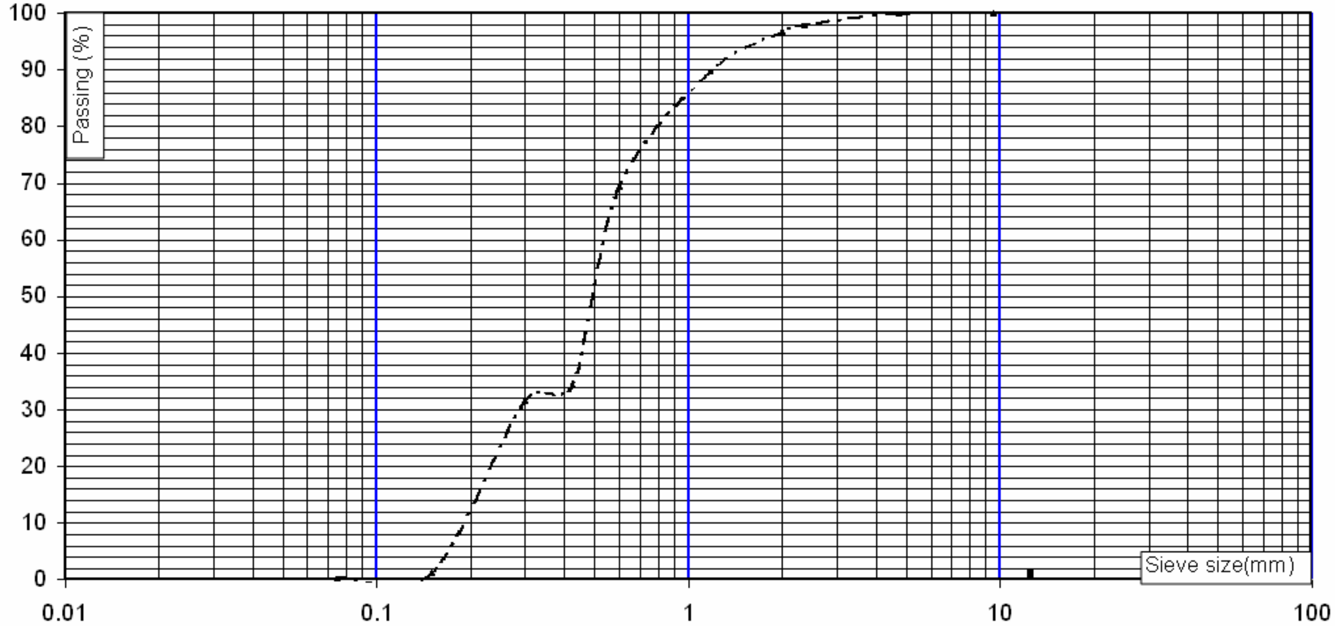
KINGDOM OF CAMBODIA
NATION RELIGION KING

Graphic Representtive		Specification Limit	Source of Material	Date Sampling	Date Testing	LABNº
— · — · — · —	Actual test	AASHTO T-11	Course Sand	19-Feb-05	23-Feb-05	0265
	Upper limit	T - 27/ T-88				
	Lower limit					

INTECH CAMBODIA COSULTING ENGINEERS
Course sand from Pouk SIEM REAP

Granular

Sieve size (mm)	Actual test (%)
12.5	
9.5	100
4.75	99.9
2.36	97.9
2.00	96.6
1.18	89.7
0.600	69.3
0.425	34.3
0.300	31.6
0.150	1.1
0.075	0.3



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INTECH CAMBODIA

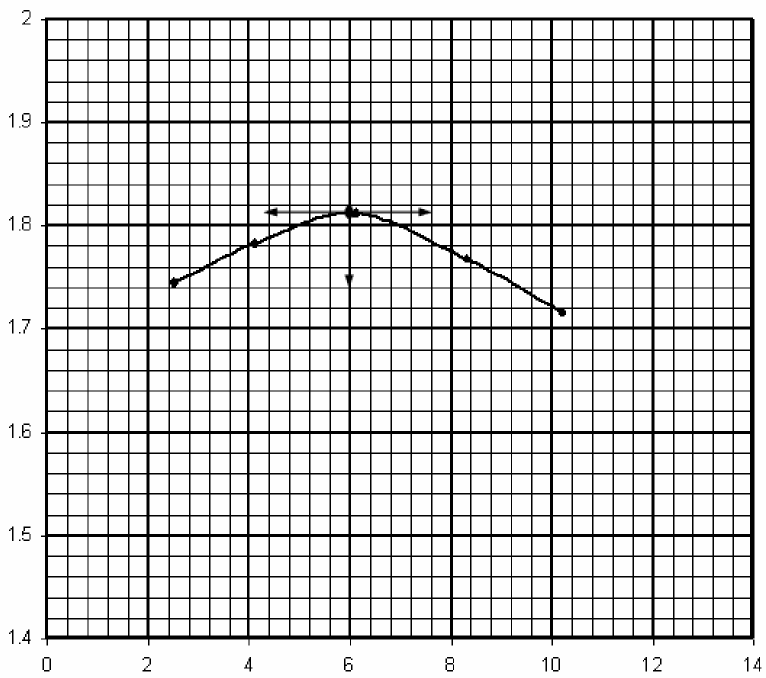
Fine Sand from Pouk Siem Reap Province

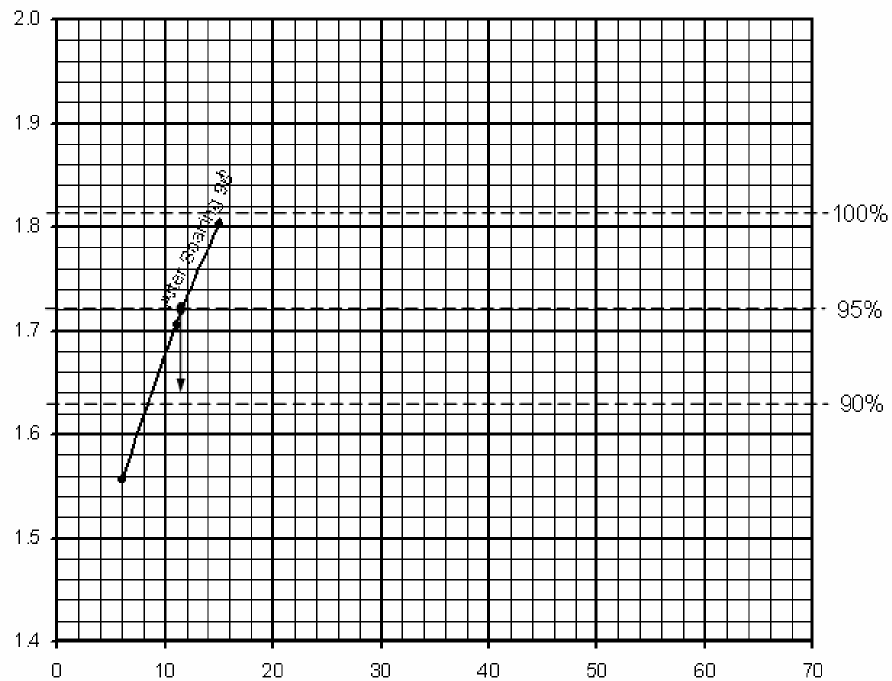
CBR for Fine Sand After Soaking 96^{H},at Point 95% CBR = 11

Lab: 265

MDD = 1.812g/cm³
OMC = 6.0 %

CBR	DRY DENSITY (g/cm^3)	Moisture Content at Compaction (%)	Moisture Content after 96^h Soaking (%)	SWELLING (%)	REMARKS
56 Blows	1.803	6.400	15.80	0.701	AASTHO T-193
25 Blows	1.706	6.200	17.00	0.685	
10 Blows	1.557	6.000	17.40	0.677	





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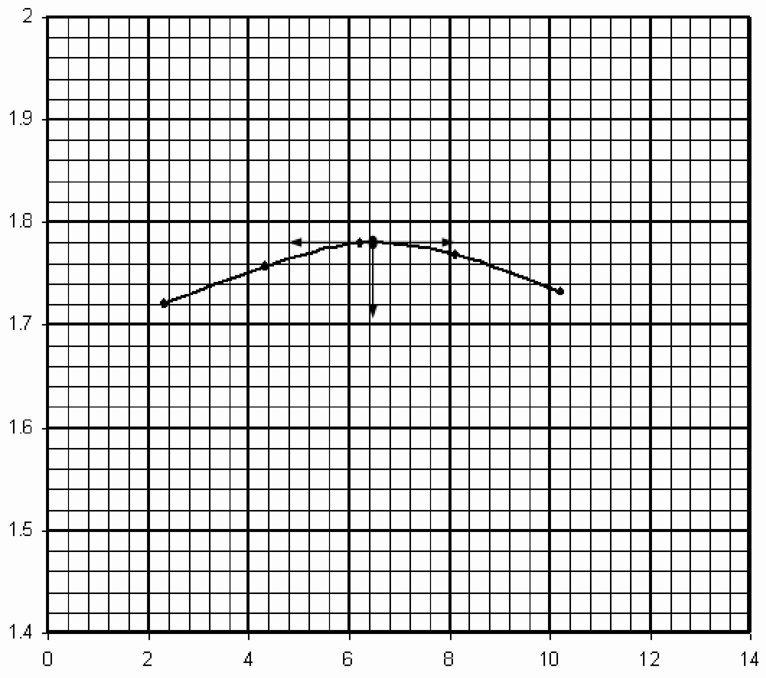
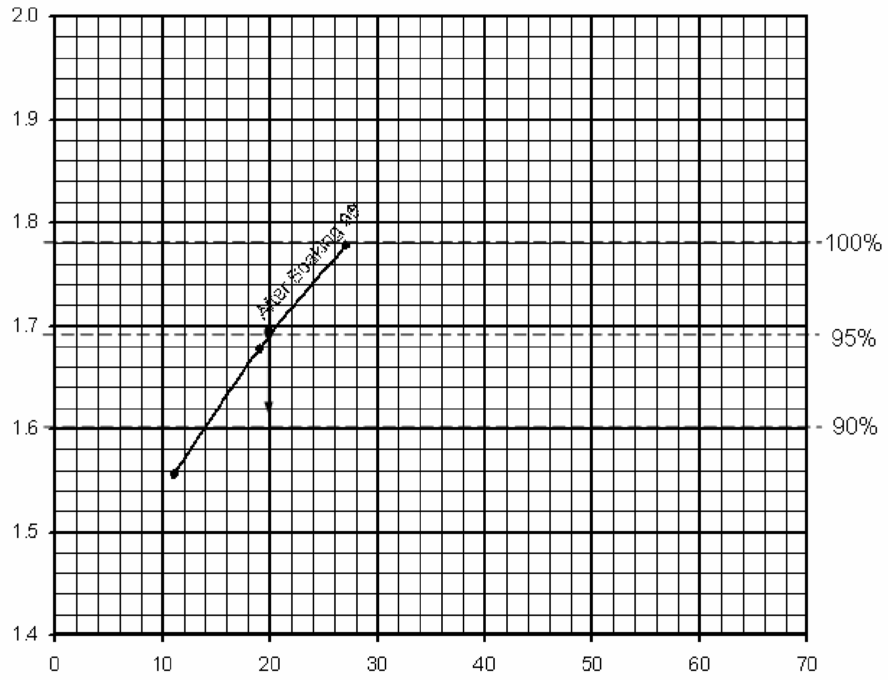
INTECH CAMBODIA
Coarse Sand from Pouk Siem Reap Province
CBR for Coarse Sand After Soaking 96H,at Point 95% CBR = 20

Lab: 266

MDD = 1.780g/cm³
OMC = 6.5 %

CBR	DRY DENSITY (g/cm^3)	Moisture Content at Compaction (%)	Moisture Content after 96^h Soaking (%)	SWELLING (%)	REMARKS
56 Blows	1.778	5.700	15.70	0.779	AASTHO T-193
25 Blows	1.678	5.800	16.60	0.779	
10 Blows	1.556	5.800	17.00	0.771	





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BUILDING AND PUBLIC WORKS LABORATORY

LBTP OF CAMBODIA
Pochentong Boulevard B. P 2380 Phnom Penh
Fax/Phone office: (855) 23 880 415
H/P: 012 810 803 & 012 504 969

REPORT OF TESTING FOR UNCONFINED COMPRESSIVE STRENGHT FAA-P304

Customer name : **INTECH CAMBODIA CONSULTING ENGINEERS**
File number : 2005/M/1605
Date of testing : March/02/2005
Site location : Pouk Siem Reap
Ordered by : Mr. Heng Kackada (012 767 653)
Subject : Fine sand Mix cement 4% (PTI Brand)

NUMBER AND TYPE OF SPECIMEN: 3 SAMPLES OF CYLINDERS

Lab. N°097	Moisture content (%)	Casting Date	Date of Test	Age (Day)	Area (cm^2)	Masse (Kg)	Density (T/m^3)	Loads KN	Compression (N/mm^2)	Average	Remarks
1	6.2	23/02/05	29/02/05	7	81.03	1765.0	**1.878**	22.5	2.777	**2.53**	**Fine Sand Mix Cement 4% PTI Brand**
2	6.3	23/02/05	29/02/05	7	81.03	1760.0	**1.872**	21.0	**2.592**		
3	6.2	23/02/05	29/02/05	7	81.03	1762.0	**1.874**	18.0	**2.221**		

Lab. N°098	Moisture content (%)	Casting Date	Date of Test	Age (Day)	Area (cm^2)	Masse (Kg)	Density (T/m^3)	Loads KN	Compression (N/mm^2)	Average	Remarks
1	6.3	23/02/05	14/03/05	21	81.03	1762.4	**1.875**	24.7	**3.048**	**3.06**	**Fine Sand Mix Cement 4% PTI Brand**
2	6.2	23/02/05	14/03/05	21	81.03	1763.5	**1.876**	25.8	**3.184**		
3	6.3	23/02/05	14/03/05	21	81.03	1764.7	**1.877**	24.0	**2.962**		

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NUMBER AND TYPE OF SPECIMEN: 3 SAMPLES OF CYLINDERS

Lab. N°095	Moisture content (%)	Casting Date	Date of Test	Age (Day)	Area (cm^2)	Masse (Kg)	Density (T/m^3)	Loads KN	Compression (N/mm^2)	Average	Remarks
1	6.1	24/02/05	01/03/05	7	81.03	1764.8	**1.877**	32.2	**3.974**	**3.99**	**Fine Sand Mix Cement 6% PTI Brand**
2	6.1	24/02/05	01/03/05	7	81.03	1769.3	**1.882**	32.6	**4.023**		
3	6.2	24/02/05	01/03/05	7	81.03	1773.0	**1.886**	32.1	**3.961**		

Lab. N°096	Moisture content (%)	Casting Date	Date of Test	Age (Day)	Area (cm^2)	Masse (Kg)	Density (T/m^3)	Loads KN	Compression (N/mm^2)	Average	Remarks
1	6.1	24/02/05	15/03/05	21	81.03	1772.6	**1.886**	44.6	**5.504**	**4.94**	**Fine Sand Mix Cement 6% PTI Brand**
2	6.0	24/02/05	15/03/05	21	81.03	1763.6	**1.876**	39.2	**4.838**		
3	6.1	24/02/05	15/03/05	21	81.03	1765.8	**1.879**	36.2	**4.467**		

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Subject : Course sand Mix cement 4% (PTI Brand)

NUMBER AND TYPE OF SPECIMEN: 3 SAMPLES OF CYLINDERS

Lab. N°101	Moisture content (%)	Casting Date	Date of Test	Age (Day)	Area (cm^2)	Masse (Kg)	Density (T/m^3)	Loads KN	Compression (N/mm^2)	Average	Remarks
1	6.4	24/02/05	01/03/05	7	81.03	1735.8	**1.847**	20.8	**2.567**	**2.46**	**Course Sand Mix Cement 4% PTI Brand**
2	6.2	24/02/05	01/03/05	7	81.03	1735.9	**1.847**	19.4	**2.394**		
3	6.4	24/02/05	01/03/05	7	81.03	1740.0	**1.851**	19.6	**2.419**		

Lab. N°102	Moisture content (%)	Casting Date	Date of Test	Age (Day)	Area (cm^2)	Masse (Kg)	Density (T/m^3)	Loads KN	Compression (N/mm^2)	Average	Remarks
1	6.3	24/02/05	15/03/05	21	81.03	1734.3	**1.845**	25.6	**3.159**	**3.12**	**Course Sand Mix Cement 4% PTI Brand**
2	6.3	24/02/05	15/03/05	21	81.03	1732.9	**1.844**	24.9	**3.073**		
3	6.4	24/02/05	15/03/05	21	81.03	1740.0	**1.851**	25.4	**3.135**		

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Subject : Course sand Mix cement 6% (PTI Brand)

NUMBER AND TYPE OF SPECIMEN: 3 SAMPLES OF CYLINDERS

Lab. N°099	Moisture content (%)	Casting Date	Date of Test	Age (Day)	Area (cm^2)	Masse (Kg)	Density (T/m^3)	Loads KN	Compression (N/mm^2)	Average	Remarks
1	6.2	24/02/05	01/03/05	7	81.03	1747.8	**1.859**	32.5	**4.011**	**3.73**	**Course Sand Mix Cement 6% PTI Brand**
2	6.4	24/02/05	01/03/05	7	81.03	1750.7	**1.862**	27.0	**3.332**		
3	6.3	24/02/05	01/03/05	7	81.03	1750.0	**1.862**	31.1	**3.838**		

Lab. N°100	Moisture content (%)	Casting Date	Date of Test	Age (Day)	Area (cm^2)	Masse (Kg)	Density (T/m^3)	Loads KN	Compression (N/mm^2)	Average	Remarks
1	6.4	24/02/05	15/03/05	21	81.03	1749.3	**1.861**	35.1	**4.332**	**4.40**	**Course Sand Mix Cement 6% PTI Brand**
2	6.3	24/02/05	15/03/05	21	81.03	1747.4	**1.859**	36.5	**4.505**		
3	6.3	24/02/05	15/03/05	21	81.03	1747.3	**1.859**	35.3	**4.356**		

VOLUME 2

APPENDIX B – Recommended Specifications

1. **EARTH WORKS AND SUBGRADE**
2. **GRAVEL SHOULDER**
3. **GRAVEL SUB-BASE**
4. **SAND-AGGREGATE ROADBASE**
5. **WATER-BOUND MACADAM ROADBASE**
6. **ARMOURED GRAVEL ROADBASE**
7. **HAND-PACKED STONE ROADBASE**
8. **DRESSED STONE SURFACING WITH/WITHOUT SEALED JOINTS**
9. **BAMBOO REINFORCED CONCRETE PAVEMENT**