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Lao People's Democratic Republic

Peace Independence Democracy Unity Prosperity

Ministry of Ministry of Public Works and Transport

Department of Roads

Local Resource Solutions to Problematic Rural Road Access in Lao (PDR)

SEACAP 17 Rural Access Roads on Route No.3

Module 2 – Completion of Construction Report

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Local Resource Solutions to Problematic Rural Road Access in Lao (PDR)
SEACAP 17 Rural Access Roads on Route No.3
Module 2 – Completion of Construction and Representative Data Capture

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Local Resource Solutions to Problematic Rural Road Access in Lao (PDR)

EXECUTIVE SUMMARY

The Lao People's Democratic Republic in the centre of the Mekong region of South East Asia is an agrarian economy with more than three-quarters of the population living in rural areas, dependent on agriculture. It is estimated that some 90% of the poverty in Lao PDR is rural-based showing a strong correlation with access to basic infrastructure services.

SEACAP's goal is to promote low cost, sustainable solutions for rural access. Improving the sustainability and affordability of rural access will lead to improved access to economic opportunities, and health and education services; thereby creating opportunities for pro-poor growth and poverty alleviation. SEACAP 17 aims at identifying low-cost, locally resource based methods of improving problematic lengths of road to provide sustainable rural access.

The SEACAP-17 results are being reported in 4 modules:

- Module 1: Project Planning and Initiation
- Module 2: Construction and Base Data Phase
- Module 3: Data Capture and Interpretation
- Module 4: Information Dissemination and Training

This report covers Module 2.

The project has been implemented in conjunction with the ADB Northern Economic Corridor Project (NEC) to carry out research on a group of rural access roads in Houay Xai district. The approach adopted is to replace the standard NEC gravel pavement with SEACAP trial pavements at specific locations along the access roads. The pavement types selected for the trials were taken from those presented at the Knowledge Exchange Workshop in Vientiane December 2004 and cover 8 different forms of construction ranging from Concrete Slab to Engineered Natural Materials.

In order to monitor the pavement trials, various base data have been collected and stored in a database (developed in Microsoft Access) which will be used and owned by Ministry of Public Works and Transport. Data records have been collected in a similar method to that of other SEACAP projects so that comparisons with other trial sections in other countries can be made.

The construction of the trial sections and collection of base data is now complete and this report includes a description of the pavement construction and of the base data and the techniques used for collection.

It is concluded that all weather access can be provided using techniques which are suitable for local procurement and local supervision but during the design phase it is important that detailed investigations of all successful construction techniques within the project area be investigated and applied or adapted as appropriate to prevent the use of pavement construction methodologies which are not suited to local resources and skills.

The contract documents should encourage, or require, Contractors to use local labour. This has economic benefits for the local community, provides some feeling of ownership and helps create a pool of experienced labour in the area which will be of value in future construction and in maintenance of the existing roads.

Maintenance considerations should be taken into account when selecting pavement types, for example, gravel surfaces and bituminous seals require significantly more routine and periodic maintenance than concrete roads. The designer must consider not only the maintenance requirements of each surface type but also whether maintenance will actually be carried out and the effects of non performance, if this seems likely. Within this project area it must be recognised

that maintenance is likely to depend largely on the willingness of the communities to contribute their labour with the DPWT providing only technical and minimal budgetary support when necessary.

On the basis of the work to date it is concluded that the advantages and disadvantages for each pavement structure depend on the particular circumstances to which the design is being applied. In order to design rural access roads effectively on a limited budget, it is necessary for experienced engineers to spend time in the field understanding the particular problems and exploring the various solutions. In general it is expected that the preferred design solution will involve a 'spot improvement' approach where, for example, substantial and relatively expensive, pavement structures for short, difficult lengths combine with simple and cheap structures in the longer and more forgiving stretches to provide the minimum cost, sustainable, robust solution.

Implementation of the construction phase has highlighted problems which occur when research work is carried out under a more or less conventional construction contract. There is a lack of flexibility which makes changes and adjustments either too expensive or impossible whilst the nature of the contract makes it very difficult to force the contractor to rectify small areas of poor work. These problems are likely to be magnified when, as in this case, the research element is simply a part of a larger, conventional contract which must reflect the realities of the commercial world and an over-riding desire to complete the Contract.

It is necessary that a long term monitoring regime follows through on the base line data capture conducted during this work. This will involve monitoring the performance and deterioration of the trial pavements and the NEC standard gravel, taking into consideration the environments to which they are subjected, the standard of construction, the traffic and the maintenance required and actually carried out.

1 INTRODUCTION

1.1 Background

The Lao People's Democratic Republic is in the centre of the Mekong region of South East Asia. It has an agrarian economy with more than three-quarters of the population living in rural areas and dependent on agriculture. It is estimated that some 90% of the poverty in Lao PDR is rural-based and there is a strong correlation between access to basic infrastructure services and the incidence of poverty.

The goal of the South East Asia Community Access Programme (SEACAP) is to support the uptake of low cost, sustainable solutions for rural access. Improving the sustainability and affordability of rural access will lead to improved access to economic opportunities and to health and education services, thereby creating opportunities for pro-poor growth and poverty alleviation. SEACAP 17 aims at identifying cost-effective methods of improving all-year access to the rural poor through low-cost locally resource based improvement of problematic lengths of road resulting in effective and sustainable rural access roads.

The project has been implemented in conjunction with the Asian Development Bank (ADB) funded Northern Economic Corridor Project (NEC) to carry out research on a group of rural access roads in Houay Xai district of the Lao PDR. The project has required close collaboration between Ministry of Public Works and Transport ADB, SEACAP and the Consultant.

The research has been implemented in four modules as follows:

- Module 1: Project Planning and Initiation Report Submitted June 2005[1]
- Module 2: The Construction Phase and Base Data Capture- This Report
- Module 3: Operational Data Capture and Interpretation
- Module 4: Information Dissemination and Training

A breakdown of the requirements of each of these modules is shown in Appendix A.

The approach adopted has been to identify key sections at specific locations along the access roads and to replace the standard NEC gravel pavement proposed for these sections with a SEACAP trial pavement. The NEC design method is contained in Appendix B. The pavement types selected for the trials were taken from those presented at the Knowledge Exchange Workshop in December 2004 (set out in the Module 1 report) and the specifications for each of the trial pavements has been developed from similar projects in the region and worldwide as follows:

1. **Standard NEC Gravel**, this construction comprises 200 mm of gravel wearing course with a bearing capacity of CBR≥25% constructed on an in-situ subgrade which, after mechanical modification, should have a bearing capacity of CBR≥8% in fill and CBR≥5% in cut. Alternatively, where the in-situ subgrade does not meet these standards a 300 mm thick selected subgrade layer should be imported having a bearing capacity of CBR≥8%.
2. **Bamboo Reinforced Concrete**, a bamboo reinforced surface consists of a layer of concrete, reinforced with strips of bamboo, and laid upon a compacted base.
3. **Geocell**, manufactured plastic formwork is used to construct in-situ concrete paving. The plastic formwork is sacrificial and remains embedded in the concrete creating a form of block paving.
4. **Mortared Stone**, this surface consists of a layer of large stones, placed closely together to form a tight surface. The voids are filled with mortar to form an impervious layer.

[1] ***Local Resource Solutions to Problematic Rural Roads Access in Lao PDR**, SEACAP Access Roads on Route 3. SEACAP 17, Module 1 Report, July 2005*

5. **Hand Packed Stone**, this surface consists of a layer of large stones into which smaller chips are packed. Remaining voids are filled with sand or gravel to form a strong and semi-impervious matrix.
6. **Concrete Paving Blocks**, the blocks are precast in moulds and then laid side by side on a prepared subbase. Gaps between blocks are filled with fine material to form a strong and semi-impervious layer.
7. **Sand Seal**, this seal consisting of a machine applied film of bitumen followed by the application of excess sand which is lightly rolled into the bitumen.
8. **Otta Seal**, this surface comprises a layer of binder followed by a layer of aggregate that is rolled into the binder using a roller or loaded trucks. It is different to surface dressing in that an 'all in' graded gravel or crushed aggregate is used instead of single sized chippings. The layer is thicker and more bitumen is used.
9. **Engineered Natural Surface**, this construction is used where the existing subgrade material comprises natural gravel with the same engineering characteristics as the pavement layer.

In order to monitor the pavement trials, various preliminary data have been collected, specifically; the bearing capacity of the road foundations, the gradients and alignment, predicted traffic loading and climatic data. This data is stored in a database (developed in Microsoft Access) which is owned by the Ministry of Public Works and Transport (MPWT).

On completion of the trial sections, base condition monitoring was conducted as follows:

- Visual Inspection and surface condition logging;
- Photographic logging;
- Surface deformation recording (dipped levels and rut measurement);
- Surface roughness using a MERLIN apparatus;
- Surface Texture (sand patch test);
- Classified traffic counts, and;
- Structural integrity using a Dynatest 3031 LWD Light Weight Deflectometer.

The records have been collected in a similar method to that of other SEACAP projects and stored in a similar format (an MS Excel based database) so that comparisons with trial sections on other projects can be made.

Having examined the performance of various pavement types, one of the main objectives of the project is to disseminate the findings to regional and international agencies. Workshops and seminars will allow all practitioners to share experiences from projects within Lao PDR, the SE Asia region and worldwide.

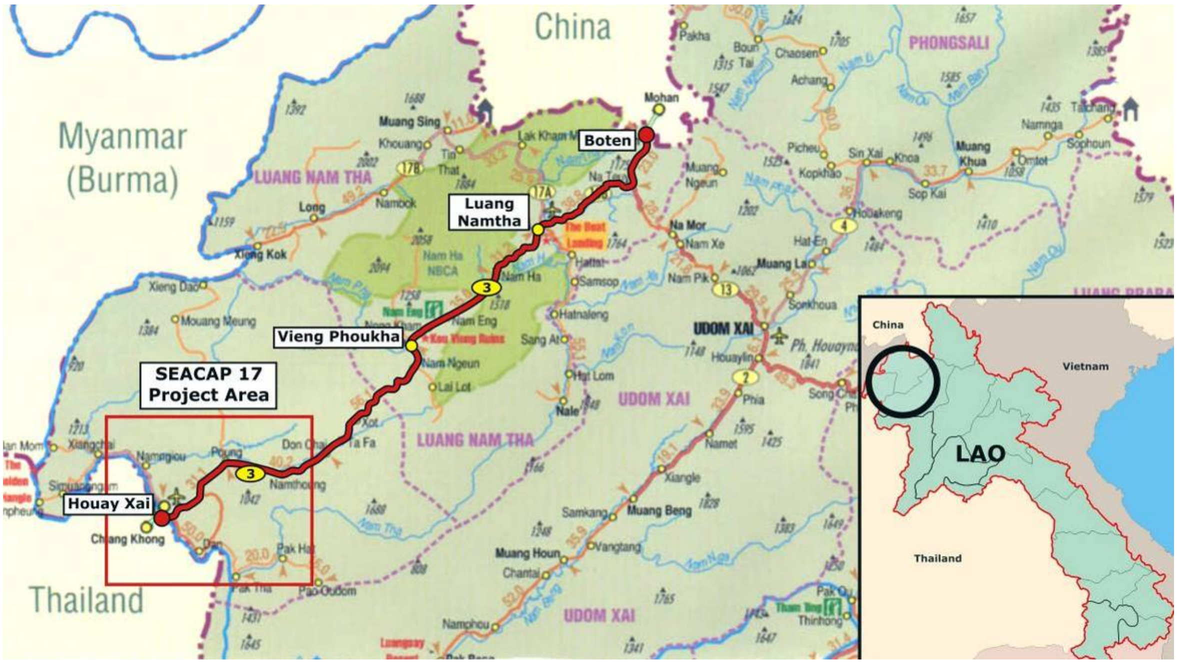
1.2 Northern Economic Corridor Project

The NEC project aims to improve the Route No.3 (R3) road from Houay Xai on the Thai border with Lao PDR to Boten on the Chinese border. This will create an international north - south corridor linking Thailand and the People’s Republic of China (PRC). The location of Route 3 is shown in Figure 1, also shown in this Figure is the SEACAP 17 Project area.

The 228 km long NEC Route 3 has been upgraded from the existing poor quality gravel road which has been known to become impassable during the wet season, to a combination of Class II and Class III of the Lao PDR design standards. This will result in a 7 m wide paved carriageway with surface dressed shoulders of between 1.5 and 2.5 m wide.

This upgrading of R3, to which the project access roads connect, places additional emphasis on the need to upgrade the access roads so that the benefits of the R3 improvement are spread as widely as possible. To this end, as well as the main contracts for R3 improvement, a set of 3 contracts were let, each covering a package of access roads.

Figure 1 Location of Road No.3 and the NEC Project



1.3 The SEACAP 17 Project

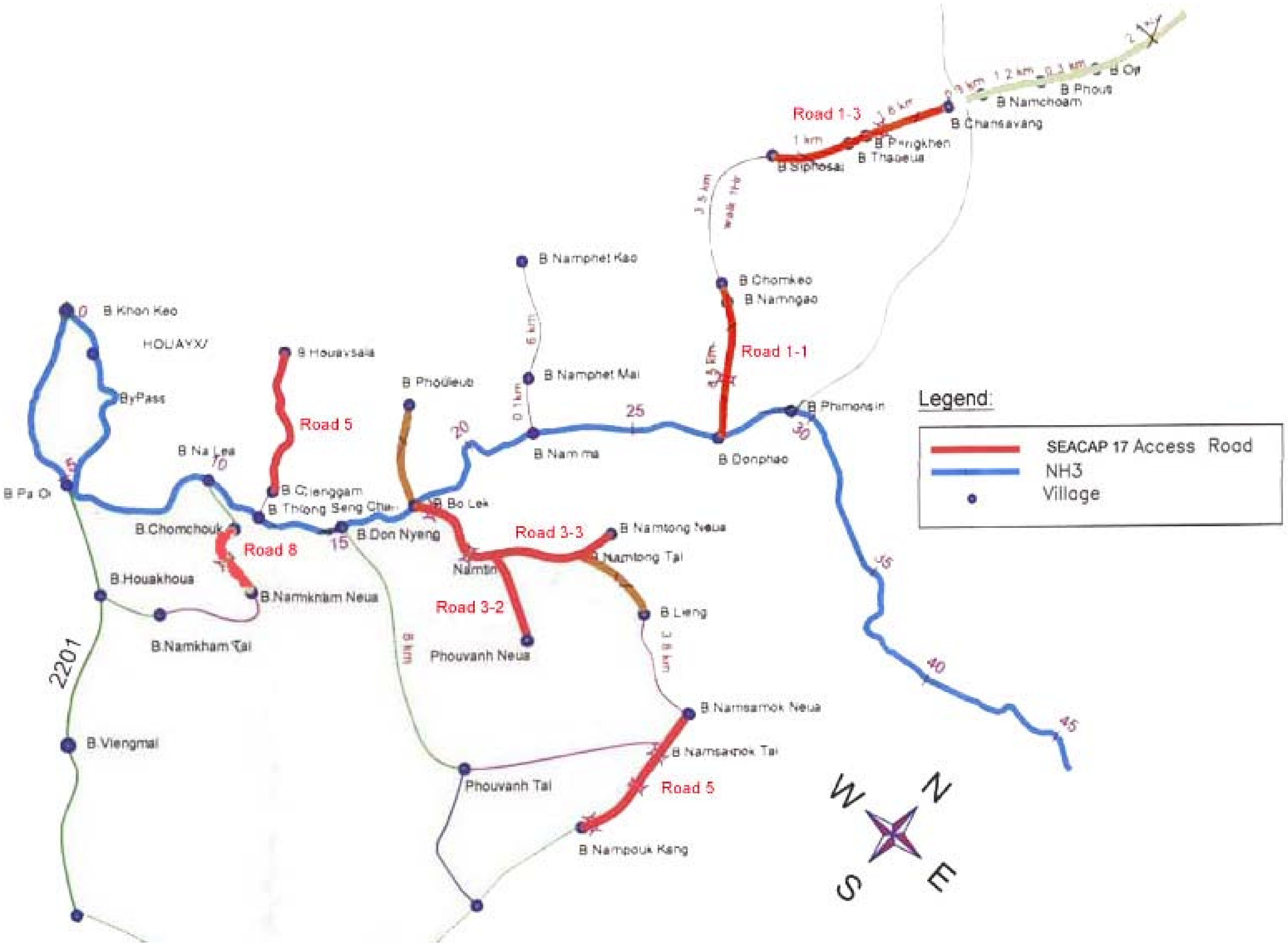
The overall goals of SEACAP 17 are to investigate and to promote suitable methods of sustainable technology for the construction of low volume roads. The practicalities of gravel surfacing over the long term have been described (SEACAP 1) and alternative surfacing options and strategies for more sustainable pavement structures recommended. Over time it is envisaged that a detailed technology based selection methodology will be developed by investigating the deterioration and performance of the pavements constructed under this project.

The approach taken to setting up the project was that trial sections should not be isolated on different parts of a road but should be assembled together on complete roads as shown in Figure 2. The selected roads were solely in Package 1 of the three construction package format used to construct the access roads along the R3 project. Any road that contains a trial section became a SEACAP Access Road in its entirety. The access roads selected, totalling 28.2 km, are those listed in Table 1 and shown graphically in Figure 2. Also shown in Table 1 is an approximate terrain classification.

Table 1 SEACAP 17 Rural Access Roads

Road No.	From	To	Length (km)	Terrain Classification
1-1	B.Phimonsine	B.Chomkeo	2.183	Hilly
1-3	B.Chansavang	B.Siphosai	2.887	Rolling
2	B Namphoukang	B.Namsamokneua	5.350	Flat
3-2	B.Bolek	B.Namtong Nuea	6.880	Rolling
3-3	B.Namtin	B.Phouvanekao	2.000	Rolling
5	B Gam Mining	B.Houaysala	6.093	Hilly
8	B.Chomchouk	B.Namkhamneua	2.770	Rolling

Figure 2 Location of the Selected SEACAP 17 Access Roads



1.4 The Access Road Construction Contract

The details of the construction contract have been described under Module 1. The contract started on 15 January 2006 with a contract period of 20 months ending on 14 September 2007; actual completion of the works was achieved on 23 August 2007.

➢ Employer	Ministry of Public Works and Transport (MPWT)
➢ Design Consultant	Oriental Consultants (OC) in association with AEC and LTEC
➢ Construction Supervision Consultant and Trial Section Designer	Roughton International (UK) in association with Lao Transport Engineering Consult (LTEC)
➢ Contractor	Guangdong No.3 Water Conservancy and Hydroelectric Engineering Board (People's Republic of China)
➢ Number of Access Roads	Seven
➢ Total length	28.164 km
➢ Carriageway width	3.50 m
➢ Shoulder width	2 x 0.50 m
➢ Formation width	4.50 m
➢ Number and length of SEACAP Trial Pavements	Nine, 4.100 km
➢ Number and length of Standard Gravel Control Sections	Seven, 1.400 km
➢ Total Construction Cost	USD 1.082 million (LAK 9,558 million)
➢ Estimated Cost of the NEC Standard Gravel Roads (24.0 kilometres)	USD 0.892 million (LAK 7,879 million) USD 34,000/km (LAK 0.296 million/km)
➢ Estimated Cost of the SEACAP Trial Pavement Sections (4.1 kilometres)	USD 0.268 million (LAK 2,365 million) USD 65,000/km (LAK 0.577 million/km)

The increase in overall cost of the SEACAP Trial Pavement Sections relative to the NEC Standard Gravel Roads is about 95% on the basis that the costs of other works, drainage, earthworks, etc., are evenly distributed along the length of the project; this is obviously incorrect in practice but gives a fair indication of the cost increase per kilometre resulting from the use of the trial pavements.

1.4.1 The Challenges

To undertake meaningful research within the context of a commercial construction contract was found to be difficult as the contractor had little interest in research and was largely concerned with completing the works quickly and within his budget.

The normal Works Contract used for SEACAP 17 works is not designed to facilitate research and the Consultant was limited in ability to change aspects of the contract to suit research needs. An example of this was an attempt to change a surface type from dressed stone to clay bricks. When requested for a price for this change the contractor, who clearly did not wish to undertake the change despite the bricks being locally available, offered a wholly unacceptable high price for the variation.

Particular problems related to this work arose from the contract being won by a Chinese contractor leading to language and communication difficulties. The Contract did not require the contractor to use local staff and the supervisory consultant faced difficulties communicating with and training the contractor's staff. The Contractor was slow to mobilise and his initial progress missed many deadlines. In general the Contractor had insufficient equipment and qualified professional staff to undertake the works efficiently.

The construction of the access roads and SEACAP trial sections were a small part of the NEC contract and consequently the contractor concentrated his efforts on the large contract with the result that materials and plant for the access roads were sometimes delayed resulting in poor and inefficient working.

The contractor generally performed poorly and had little interest in the trial pavements. It was necessary to redo some work due to poor workmanship and in other areas substandard work had to be accepted. These are less than ideal circumstances from the point of view of research.

The contractor underestimated the problems posed by the hilly nature of the project area which resulted in poor location of temporary detours during construction and consequent complaints from users.

1.4.2 The Outcomes

Despite the contractual problems, the access roads and the planned trial sections were all constructed, substantially to the required standard, within the construction budget and completed within the allotted time.

1.4.3 Local Involvement

MPWT and PMU were involved and offered valuable advice throughout the project. The local authorities, especially DPWT of Bokeo Province, provided sound cooperation and helped throughout the contract.

2 THE DESIGN OF THE ACCESS ROADS

2.1 Topographic Survey and Road Alignment

Apart from some small changes that were executed during construction, the SEACAP 17 consultant had no input into the design of the alignment of these access roads. The consultant did, however, conduct a detailed topographic survey (X,Y,Z) along the original tracks and then again along the finished access roads. Both the horizontal and vertical alignments can be seen in Appendix C and it was on the basis of the consultant's visual inspections that the locations for the pavement trial sections were selected.

2.2 The Geometric Design

Over recent years the specifications for the design of local roads in the Lao PDR have undergone modification and updating. However, despite the NEC geometric design having been done in 2004, the 1990 standard was used rather than the current 2003 standard for the design of Local Roads[2] in Part II: Basic Technical Specification for Low Traffic Volume Roads. These 2003 specifications have now been updated in the, yet to be approved, Low Volume Rural Roads Standards and Specifications (Parts I, II, III)[3]. It is recommended that in future designs the most recent available standards are used.

The parameters used for the design as contained in Appendix B are shown in Table 2 together with values taken from the 2003 standards for Local Roads.

Table 2 NEC Geometric Design Criteria

No.	Parameter	NEC Geometric Design		2003 Standards
I	Terrain	Flat and Mountainous		Mountainous Class VIII
II	Design Speed	Desirable	Minimum	
1	Design Speed (km/h)	30	10	20
III	Formation Width (m)	4.5		3.5
1	Number of Lanes (No.)	1		1
2	Carriageway Width (m)	3.5		2.5
3	Shoulder Width (m)	2 x 0.5		0.5
IV	Maximum Gradient (%)	12 (14)		15
V	Minimum Horizontal Curve Radius (m)	15 (10)		15
VI	Minimum Vertical Curve Radius (m)			
1	Crest (m)	150		50
2	Sag (m)	100		50
VII	Crossfall (%)	4		8

The note beneath this table states that: *'The numbers as shown in the parenthesis as used for the minimize value or reduce of gradient and horizontal curve.'* and is taken to mean that the numbers in brackets should be used in extreme cases.

2 ***Specification for Local Roads (for District and Rural Roads)**, Volume 1/04, Editor – Mr.O.Siriamphone, Ministry of Communication, Transport, Post and Construction, Department of Roads, Lao (PDR), 2003.*

3 ***Low Volume Rural Roads Standards and Specifications (Parts I, II, III)**, SEACAP 03, Mainstreaming Appropriate Local Road Standards and Developing a Strategy for the MPWT Research Capacity, DfID; South East Asia Community Access Programme (SEACAP) for Department of Roads, Ministry of Public Works and Transportation, Lao PDR*

Clearly the geometric alignment values used were in excess of the current standards. While the NEC Design Consultant may have complied with the parameters of the 1990 standard, the result has been a design which is not always sympathetic with the terrain and is unnecessarily costly, for example the large cutting on Road 3-2, in the photographs below would have been avoided using the current standards.

Steep section with some erosion due to rain water running down the road.

The section at the start of the construction showing bush clearance.

The excavation of very large cutting to keep within the geometric specification.

The final road showing the large cutting.

In this case, a steep section of road, while difficult during the wet season, had been used for many years. Using the relaxed gradients of the latest standards, the problem could have been solved with minimum earthworks using an all-weather surface and improved, properly engineered drainage to provide year round accessibility.

An alternative would have been to use a different alignment but this is always likely to introduce problems associated with land acquisition.

Although design using a computer based, topographic modelling system has probably become the norm and offers considerable advantages over traditional systems, especially in terms of reviewing alternatives and computing quantities, care must be taken that the opportunities offered by such systems do not overwhelm the basic requirement to keep design as simple as possible and make maximum possible use of existing alignments.

2.3 Extent of Earthworks

The terrain in which each road was located was initially classified using the customary three grades of Flat, Rolling and Hilly based on road gradients. The earthworks for the seven roads are related to this classification in Table 3; it can be seen that the classification broadly correlates with the earthworks; length of road in cut increases with terrain severity whilst length on fill decreases. It is suggested that the earthworks could have been reduced significantly with the adoption of the more recent standards and with use of a 'spot improvement' philosophy to ensure viability of the resulting steeper gradients.

Table 3 Earthworks Statistics for the Access Roads

Road No.	Terrain Class.	Percentage of the length greater than:	
		Cut -0.3 (m)	Fill 0.3 (m)
Access Road No.: 1-1	Hilly	21%	43%
Access Road No.: 1-3	Rolling	11%	40%
Access Road No.: 2	Flat	3%	74%
Access Road No.: 3-2	Rolling	19%	35%
Access Road No.: 3-3	Rolling	4%	61%
Access Road No.: 5	Hilly	30%	26%
Access Road No.: 8	Rolling	15%	38%

It must be noted, however, that, in the context of this project, excavation is relatively cheap at just over USD 1/m³, embankment relatively expensive at USD 2/m³ using excavated material and USD 3/m³ when borrow must be provided and that a reduction in excavation would not necessarily yield any great saving. More important is the question of whether the small improvements in gradient, achieved at considerable cost to the landscape can result in year round vehicular access without the additional expenditure for improved pavements.

2.4 Terrain Categories and Design Solutions

In order that specific engineering solutions can more easily be related to alignment, a more detailed division of terrain types by gradient is proposed as shown in Table 4. It is generally accepted that gradients of greater than 15% are undesirable; however, along short sections, if designed and constructed properly, steep gradients may both be practical and offer significant construction cost savings.

Table 4 Terrain Type as Defined by Gradient

Terrain	From	Up To
Flat	0.0%	3.0%
Slight	3.0%	5.0%
Moderate	5.0%	10.0%
Steep	10.0%	15.0%
Very Steep	15.0%	25.0%

Based on this categorisation the total length of each terrain type within the access roads has been considered in three ways, shown in Table 5, namely:

- Existing Length — This is based on the pre-construction alignment, generally along the centreline of the existing track;
- Design Length — This is based on the exact alignment between the various surveyed points along the constructed centreline;
- Terrain Type (TT) Length — This is similar to the design length but has been assessed on a practical rather than a theoretical basis. Very short sections within a length will have gradients outside the particular range for the type, which is why the design and TT lengths for each type are slightly different.

Table 5 Length of the Access Roads falling into Various Terrain Categories

Terrain	Existing		Design		Terrain Type	
	Length (km)	Length (%)	Length (km)	Length (%)	Length (km)	Length (%)
Flat	17.280	61.5%	18.462	66%	18.502	66%
Slight	4.023	14.5%	4.065	14%	3.190	11%
Moderate	4.430	16%	4.303	15%	4.898	17%
Steep	1.745	6%	1.333	5%	1.573	6%
Very Steep	0.605	2%	0.000	0%	0.000	0%
		Total	**28.164**	**100%**	**28.164**	**100%**

Table 5 shows that despite these roads being in a landscape which is considered rolling to hilly, for most of their length they are actually in ‘flat’ terrain as classified by gradient. Also demonstrated, is the fact that the design tends to reduce the overall gradient of the roads, although this effect is not huge; in general a small percentage of the length is moved down a notch in each category resulting in the elimination of the 2% categorised as ‘steep’ and an ultimate rise of 4.5% in the length categorised as ‘flat’. This is also shown graphically in Figure 3, below.

It is important to remember that road sections may be on ‘flat’ or ‘slight’’ gradients in what is actually a hilly or even mountainous landscape. This can happen, for example, if the route follows a river valley bottom or because the road is in sidelong ground on the flank of a hill. However, climate and traffic being similar, it is the road gradient which is generally the key factor governing wear and damage to the surface and hence the most suitable pavement type. Where the road is clearly subject to landslide risk, as it may be in mountainous, sidelong ground, the key factor affecting pavement choice may become the need to cater for this risk and the associated clearance operations. Where the desire to achieve low gradients results in increased bend severity and frequency this can have adverse effects on gravel roads as material is regularly thrown off to the outside of the bends.

In the context of the SEACAP 17 trial pavements the questions to be answered are:

- Do the least expensive pavements perform adequately in road sections with low gradients?
- Bearing in mind the underlying soils, at what gradient does it become necessary to turn to a more expensive pavement to ensure year round availability?

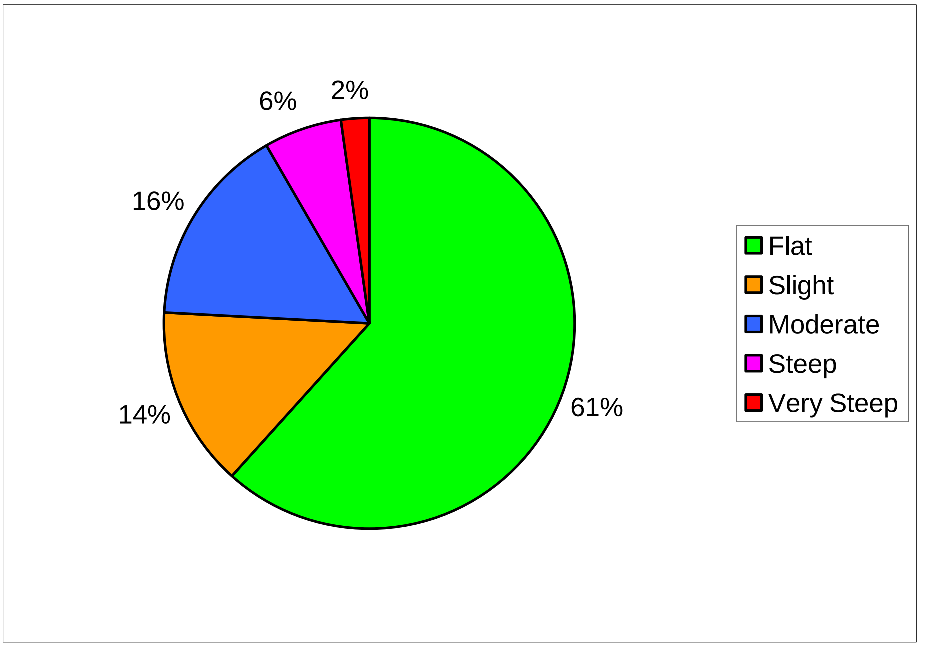
- Of the pavements tested, do any particular types offer any special performance advantages in specific gradient ranges?

In the case of a specific road there are other questions which must be considered, primarily

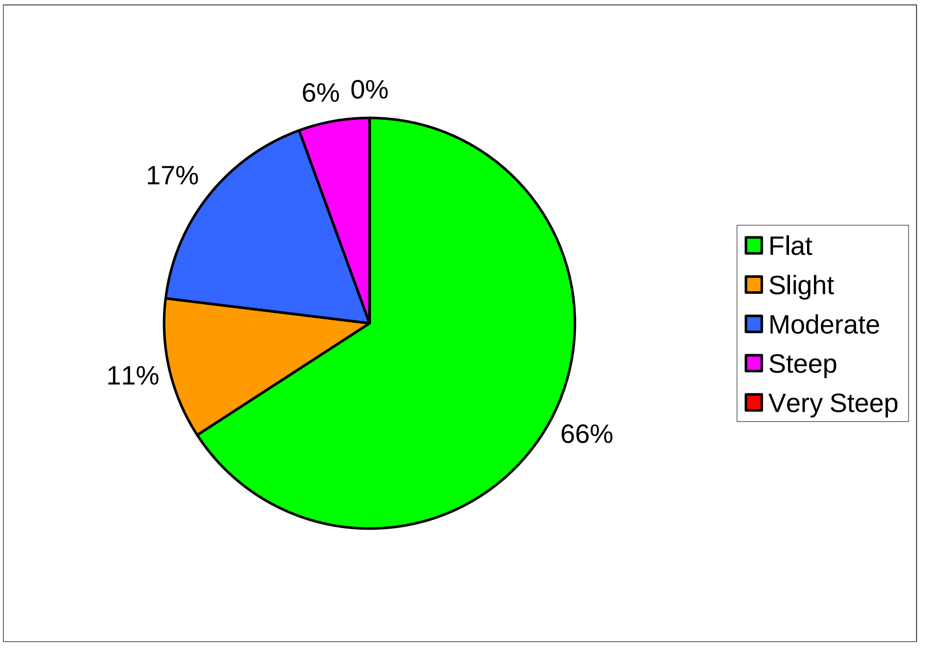
- Can the increased construction cost of reducing gradients be covered by the savings in pavement construction cost?

Figure 3 Comparison of the Terrain Types

Pre-Construction Terrain Classification



Post-Construction Terrain Classification



2.5 The Pavement Design

The NEC design method is contained in Appendix B but can be summarised as 200 mm of natural gravel wearing course complying with the requirements in Table 6 placed on a prepared subgrade. having a 4-day soaked CBR ≥8%.

Table 6 NEC Wearing Course Requirements

Item No.	Description	Test Method	Requirements
1	**Atterberg Limits**		
1.1	Liquid limits	AASHTO T89	≤35%
1.2	Plasticity Index	AASHTO T90	≥8% and ≤20%
2	**Strength Test (Bearing Capacity)**		
2.1	California Bearing Ratio (CBR) (4 days soaked at 95% MDD)	AASHTO T193	≥25%

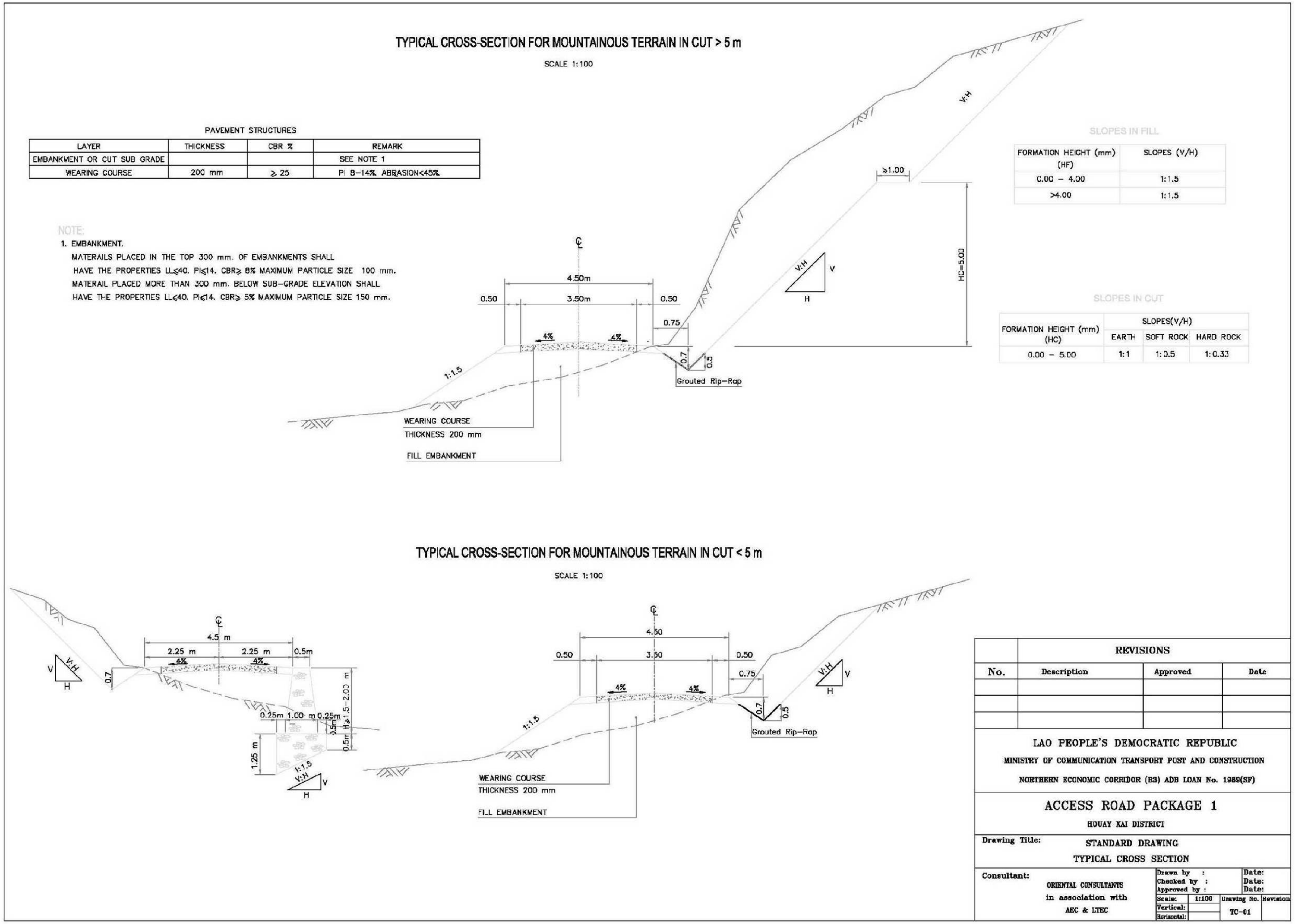
The typical cross-section is shown in Figure 4 which is a standard drawing from the NEC Contract. The typical cross section drawings as contained in the specification are given in Appendix D.

The top 300 mm of the embankment was required to have a Liquid Limit LL ≤40, a Plasticity Index PI ≤14, a bearing capacity (4 day soaked CBR) ≥8% and a maximum particle size of 100 mm. The material placed below this layer was required to have a Liquid Limit LL ≤40, a Plasticity Index PI ≤14, a bearing capacity CBR ≥5% and a maximum particle size of 150 mm. It does not state how thick this layer should be but it is assumed to be 300 mm.

Where the road is constructed at or below natural ground level (NGL) and subgrade CBR <8%, the top 300 mm is removed and replaced with imported SSG material with a CBR ≥8%. To implement this, the specification required that the contractor excavate test pits at 200 m intervals in all cut sections, after the earthworks had been excavated to full depth. A sample of the top of the subgrade was taken and the soaked CBR established in the laboratory.

This level of CBR testing was really only possible because the contractor for the access roads was also the contractor for one of the main R3 road sections. In normal access road construction/improvement works it is doubtful if CBR testing would be practical. Accordingly, the consultants supplemented this CBR testing using Dynamic Cone Penetrometer (DCP) tests. These were conducted on all fill sections at 100 m spacing in order to rapidly determine the CBR value and on a closely spaced grid in all trial sections. While this test is not as accurate as a laboratory test and only gives an indication of the CBR at the field moisture content rather than the soaked laboratory values, it is possible to undertake a correlation with laboratory CBRs and the test will always provide a clear indication of possible weak areas; the DCP will very seldom overestimate the CBR although it may easily underestimate. For long term use, the test is of enormous value in that it provides a cheap and simple means of controlling compaction and checking subgrade strengths. It is expected that future monitoring will relate any areas of failure to the DCP records from the trial pavement areas and so assess the role of subgrade strength in such failures.

Figure 4 Typical NEC Gravel Road Cross Section



3 SEACAP TRIAL PAVEMENTS

Essentially, three specific wet-season problems were identified that cause sections of rural access roads to become impassable, namely:

- Rapid and serious pavement deterioration particularly in flat, flood prone areas;
- Rapid and serious pavement deterioration particularly on steep gradients due to erosion, and;
- Road blockages or collapse through landslips in hilly and mountainous terrain.

The basic approach to the SEACAP research was to replace the standard NEC gravel pavement with a particular SEACAP trial pavement at specific locations. These locations were selected in areas where problems were envisaged in the future based on inspections prior to construction. No change to the existing design alignment was made.

3.1 Subgrade Design Bearing Capacity

Since no investigation into the subgrade quality had been conducted during the design stage the consultant required that the subgrade quality be investigated during construction. Consequently the consultant undertook a subgrade survey which required the contractor to excavate trial pits and conduct a DCP survey as stated in the specifications and shown in Table 7.

Table 7 Testing Requirements Prior to Construction

Test	Number	Method
Field testing.		
Dynamic Cone Penetrometer Tests along the proposed Centreline	1 test per 100 m	ORN31 and as instructed by the Engineer
Dynamic Cone Penetrometer Tests within the proposed Trial Lengths	33 tests per 100 m	ORN31 and as instructed by the Engineer
Trial Pits excavation, logging of the profile and removal of two 100 kg material samples along the proposed Centreline	1 test per 1,000 m	ORN31 and as instructed by the Engineer
Trial Pits excavation, logging of the profile and removal of two 100 kg material samples within the proposed Trial Lengths	2 tests per 100 m	ORN31 and as instructed by the Engineer
Laboratory testing of the samples obtained during the trial pit excavation, above.		
Compaction characteristics and bearing capacity determination	20 tests	
Particle Size Distribution	30 tests	
Atterberg Limits including Linear Shrinkage	60 tests	

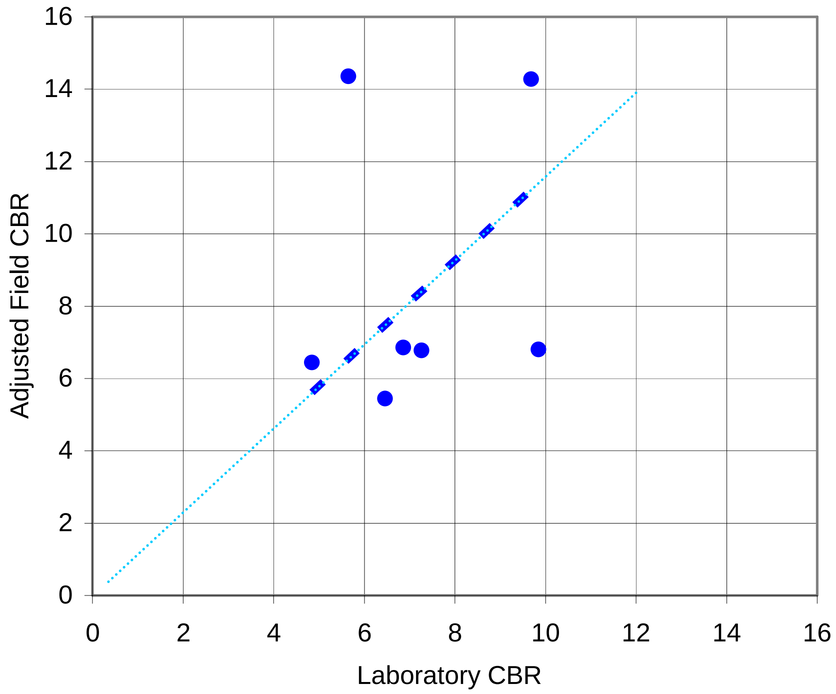
The consultant has introduced the DCP apparatus into the Contract in order to provide a rapid method of determining the 'in-situ' subgrade bearing capacity (CBR) by applying the equations documented in ORN31[4] and using the UKDCP software which was developed under a DFID

[4] ***A Guide to the Structural Design of Bitumen-Surfaced Roads in Tropical and Sub-Tropical Countries***, *Overseas Road Note 31, Transport Research Laboratory, Crowthorne, United Kingdom, 1993.*

project and is freely available[5]. The results of the subgrade trial pit survey are contained in Appendix E and summarised in Table 8. The DCP data was correlated against the laboratory CBR test data and the correlation is shown Table 8.

Table 8 Summary of the Design Subgrade Bearing Capacity

Access Road No.:	Adjusted Bearing Capacity	Laboratory Tests (Trial Pits on CL)			
		CBR (%)	MDD (g/cm³)	PI (%)	OMC (%)
1-1	5	6	2	16	18
1-3	10	14	2	16	12
2-2	7	7	2	13	13
3-2	6	14	2	17	17
3-3	6	5	2	16	21
5	7	7	2	17	20
8	10	7	2	17	16



The SEACAP 17 Module 1 Report set out a final list of the trial pavements that were to be tested based on a likely spread of matrix variables and provided a rationale for selecting a specific trial method for each trial section. Each access road comprised a variation of conditions which enabled the categorisation of good, standard and problematic lengths.

The location and type of each of the trial sections is listed in Table 9. A detailed design was undertaken for each of the trial pavements as described in the Module 1 Report. Specifications were drafted and the NEC Contract Documents amended to include the construction of the trial sections. The trial pavement specifications, as included in the contract documents, were presented in the Module 1 Report (Appendix 6). During the construction of each of these trial sections a number of issues were raised by the Contractor and the Consultant, and these points have been incorporated into revised specifications. The revised specifications reflecting the experience

5 ***Dynamic Cone Penetrometer Tests and Analysis***, *Technical Information Note, Colin Jones, Improved Measurement of Pavement Strength by Dynamic, R8157, http://www.transport-links.org/transport_links/index.asp, May, 2004.*

gained during construction are contained in Appendix F of this Report. A summary of the pavement structures applied is shown in Table 10 and in detail in Appendix G. An approximate cost estimate based on reasonable unit prices for the materials as constructed in Lao PDR is also shown in Appendix G.

3.2 Pavement Types

The trial pavements can be classified loosely into four pavement categories as listed below. Some of these categories, however, merge into one another such as the Geocells which are similar in many ways to a concrete pavement during construction but result in a segmental block pavement on completion.

3.2.1 Concrete (Rigid) Pavements

This relatively expensive pavement structure is very suitable for high rainfall and flood prone regions and is well understood by local small contractors. The pavement requires minimal maintenance if properly constructed. Joints may require steel dowels particularly if heavy loading is expected.

3.2.2 Block (Segmental) Pavements

In general this construction is well suited to labour-based and local small contractor construction. The good load spreading properties of the blocks allow the surface to be constructed on relatively weak lower pavement layers. The pavement is simple to maintain by relatively unskilled labour as most of the blocks on a failed area can be reused once the lower layers are strengthened. These pavements make good use of local materials, local labour and thus the local economy. Block paving is usually laid on a bed of loose sand or fine aggregate of thickness 20 to 50 mm.

3.2.3 Bituminous (Flexible) Pavements

These construction methods are generally suitable for labour based methods and are generally well known by contractors in SE Asia and worldwide. Care is required to ensure that spray and application rates are applied to specification, and therefore require good site control. Suitable for low to medium volume light traffic, but maintenance is necessary in order to ensure longevity of the pavement.

3.2.4 Gravel Pavements

This traditional low cost option is suitable where adequate supplies of suitable material are available within reasonable haul distances, assuming that certain criteria are satisfied and an adequate maintenance regime is in place. Gravel surfaces are unsuitable in locations that experience high rainfall; long materials haul distances, steep gradients and in floodable areas.

Each of the trial pavements is described in detail within the context of Lao (PDR) and the various advantages and disadvantages discussed in the following sections.

Table 9 List of the SEACAP Trial Sections

Access Road						Trial Section Pavement Type		Lengths		
No.	From	To	Start (km)	End (km)	Length (m)			Start (km)	End (km)	Length (m)
1-1	B.Phimonsine	B.Chomkeo	0.000	2.183	2,183	*Control Section*	*NEC Standard Gravel*	0.500	0.700	200
						Training Section	*None*			
						Pavement Trial	None			
1-3	B.Chansavang	B.Siphosai	0.600	3.487	2,887	*Control Section*	*NEC Standard Gravel*	1.220	1.420	200
						Training Section	*None*			
						Pavement Trial	None			
2	B Namphoukang	B.Namsamokneua	0.000	5.350	5,350	*Control Section*	*NEC Standard Gravel*	0.400	0.600	200
						Pavement Trial	Hand Packed Stone	0.600	1.080	480
						Training Section	Hand Packed Stone	1.080	1.100	20
3-2	B.Bolek	B.Namtong Nuea	0.000	6.880	6,880	*Training Section*	Single Otta Seal	0.020	0.120	100
						Pavement Trial	Single Otta Seal	0.120	0.320	200
						Pavement Trial	Double Otta Seal	0.320	0.520	200
						Training Section	Eng' Nat. Surface	0.520	0.620	100
						Pavement Trial	Eng' Nat. Surface	0.620	0.920	300
						Training Section	Mortared Stone	0.920	1.020	100
						Pavement Trial	Mortared Stone	1.020	1.520	500
						Control Section	*NEC Standard Gravel*	1.520	1.720	200

Access Road						Trial Section Pavement Type		Lengths		
No.	From	To	Start (km)	End (km)	Length (m)			Start (km)	End (km)	Length (m)
3-3	B.Namtin	B.Phouvanekao	0.000	2.000	2,000	*Control Section*	*NEC Standard Gravel*	1.600	1.800	200
						Training Section	*None*			
						Pavement Trial	None			
5	B Gam Mining	B.Houaysala	0.000	6.093	6,093	*Training Section*	Concrete Paving Blocks	0.900	0.920	20
						Pavement Trial	Concrete Paving Blocks	0.920	1.400	480
						Pavement Trial	Bamboo Concrete	1.950	2.325	375
						Pavement Trial	Bamboo Concrete	2.325	2.500	175
						Training Section	Bamboo Concrete	2.500	2.525	25
						Pavement Trial	Geocells	2.750	2.950	200
						Pavement Trial	Geocells	2.950	3.050	100
						Pavement Trial	Geocells	3.050	3.125	75
						Training Section	Geocells	3.125	3.150	25
						Control Section	*NEC Standard Gravel*	4.500	4.700	200
8	B.Chomchouk	B.Namkhamneua	0.000	2.770	2,770	*Training Section*	Sand Seal	1.500	1.630	130
						Pavement Trial	Sand Seal	1.670	2.200	495
						Causeway	35.400			
						Control Section	*NEC Standard Gravel*	2.200	2.400	200
				Total:	**28,164**				**Total:**	**5,500**

Table 10 Pavement Structures for the SEACAP Trial Sections

Pavement Types		1 Standard NEC Gravel	2 Bamboo Reinforced Concrete	3 Geocell	4 Mortared Stone	5 Hand Packed Stone	6 Concrete Paving Blocks	7 Sand Seal	8 Otta Seal	9 Engineered Natural Surface
Surface Layer	Type	Nat. Gravel CBR ≥ 25%	Concrete	Concrete	Stone	Stone	Blocks	Sand Seal	S.Seal + Otta Seal / Double Otta Seal	Nat.Gravel CBR ≥ 25%
	Thickness	200 mm	125 mm 150 mm	75 mm 100 mm 150 mm	65 mm	100 mm	65 mm	10 mm	20 mm 30 mm	
Sub-surface Cushion	Type		Sand	Sand	Sand	Sand	Sand			
	Thickness		20 mm	20 mm	50 mm	50 mm	20 mm			
Base	Type							C.Rock CBR≥80%	C.Rock CBR≥80%	
	Thickness							150 mm	150 mm	
Subbase	Type		Nat.Gravel CBR≥25%	Nat.Gravel CBR≥25%	Nat.Gravel CBR≥25%	Nat.Gravel CBR≥25%	Nat.Gravel CBR≥25%	Nat.Gravel CBR≥25%	Nat.Gravel CBR≥25%	Nat.Gravel CBR≥25%
	Thickness		125 mm	125 mm	125 mm	125 mm	125 mm	120 mm	120 mm	Levelling only
Selected Subgrade	Type	Nat.Gravel CBR≥8%	Nat.Gravel CBR≥7%					Nat.Gravel CBR≥7%		
	Thickness	300 mm	150 mm					150 mm		
Subgrade	Type	CBR≥5%	CBR≥5%	CBR≥5%	CBR≥5%	CBR≥5%	CBR≥5%	CBR≥5%	CBR≥5%	CBR≥5%
	Thickness	Varies	Varies	Varies	Varies	Varies	Varies	Varies	Varies	Natural ground

3.3 The Constructed Trial Pavements

The following pavement types were designed. The designs were based on a nominal subgrade strength of CBR=5% and low predicted traffic volumes as defined in the NEC design report.

3.3.1 Standard NEC Gravel

Gravel surfacing is not always the best solution for rural roads in many circumstances. Work undertaken in neighbouring Vietnam[6] reported that although gravel has been the commonly recommended surfacing in recent rural road rehabilitation programmes, there was little available data on its engineering performance and deterioration and that this knowledge gap required urgent attention.

The subsequent SEACAP 4[7] investigations at a significant number of road sites in Vietnam, found serious shortcomings with the use of gravel due to factors relating to material quality, material availability, climate, terrain, drainage provision and maintenance. Overall gravel loss figures indicate that around 58% of the surveyed sites were suffering unsustainable deterioration, while 28% were losing material at twice the sustainable rate.

Care needs to be exercised when considering these figures as any gravel road is affected by a range of parameters. For example a gravel road in mountainous terrain may have steep gradients, but it is unlikely that the steep gradients extend for the length of the entire road. It is much more likely that the steep gradients comprise, say, just 5% of the length. Therefore, while the gravel surfaced pavement may not be suitable for those steep sections, it may be perfectly suitable for the remaining 95% of the road. It often happens that the design does not provide for additional improvement to the steep sections of the road, the access is broken in the wet season and the entire road is said to be impassable when, in reality, it is only a short section that is impassable. The consultant's suggested concentration of effort and funds on the problematic lengths is termed the 'spot improvement design philosophy' and will be discussed further in this report. This work aims to trial more sustainable, robust pavement structures.

3.3.2 Bamboo Reinforced Concrete

The construction method is the same as ordinary steel mesh reinforced concrete pavements with the exception that a bamboo mesh replaces the steel mesh. The slab widths were 3.5 m wide (the carriageway width) with a length of 5 m. No dowels were used between the slabs. The specification recommends that the bamboo, which comprises strips cut from large bamboo stems, shall have a minimum thickness of 5 mm and a minimum age of 4 growing years and be dried for a season.

Subsequent to the work under this project, an investigation has been undertaken to establish exactly what contribution to the overall strength of the pavement the bamboo contributes. It was concluded that while this form of construction is quite common in South East Asia, the bamboo does not contribute at all to the structural integrity of the pavement and in fact may have a detrimental effect[8], therefore, bamboo as reinforcement is not recommended for concrete roads.

In consequence, the bamboo reinforced pavement should be treated as a mass concrete pavement without the use of any steel, and should be monitored as such.

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[6] ***Rural Road Surfacing Research**, SEACAP 1, Final Report, Ministry of Transport Vietnam, December 2006.*

[7] ***Rural Road Gravel Assessment Programme**, SEACAP 4, Final Report, Ministry of Transport Vietnam, July 2005.*

[8] ***Bamboo Reinforced Concrete Pavements**, J Rolt (TRL Limited), Technical Paper No 1, SEACAP 19. Development of Local Resource Based Standards., South East Asia Community Access Programme Development of Local Resource Based Standards, Royal Government of Cambodia, February 2008.*

Advantages

- Besides the cement, a large amount of the materials needed to construct this pavement can be sourced locally. Aggregates need not be crushed and river gravel and sand can be successfully used.
- Little sophisticated equipment is required - two smallish concrete mixers can produce a reasonable amount of concrete continually. The construction is well suited to labour based construction and thus to the small scale contractor.
- The resulting pavement is strong and offers long serviceability with little maintenance if constructed properly.

Disadvantages

- Care is needed during the curing period. Loading slabs prematurely may cause failure - ideally the slabs should not be loaded for at least 14 days after concreting.
- Commonly the slabs are 150 mm thick and, even on the 125 mm thick trials conducted here, the cost of the concrete is high.
- While this pavement offers a relatively maintenance free pavement, when repairs are necessary they are difficult to undertake and consequently expensive.

3.3.3 Geocells

This entails the use of plastic cells as a sacrificial formwork into which concrete is poured and compacted lightly by hand. Rather than a concrete or rigid pavement this construction should be considered more like a flexible block paving surface where the blocks are cast in-situ. The thicknesses trialled varies from the thickness of a paving brick (75 mm) to the thickness of the concrete slabs (150 mm).

Advantages

- This pavement has all of the advantages of the concrete slabs such as the use of locally sourced materials and the fact that little sophisticated equipment is required. Construction is well suited to labour based work.
- The resulting pavement is of a high strength and therefore offers long serviceability with little maintenance. Because it is a flexible pavement it does not crack in the presence of subsurface deficiencies but will deform and, providing the deformation is not too great, should always offer an all weather surface similar to that of block paving.
- It is hoped that thinner pavements will perform as well as thicker pavements and therefore the cost should be lower. Construction time was found to be faster than the concrete slabs as the formwork (cells) were quickly set out and filled with concrete.
- Repairs to this pavement will be much easier and cheaper than that of concrete slabs.

Disadvantages

- Care is needed during the curing period. Loading slabs prematurely may cause failure - ideally the slabs should not be loaded for at least 14 days after concreting.
- It was found that the cost of the Geocell was high as this needed to be imported, however further investigation may source cheaper, local products; especially if a clear requirement is demonstrated.

3.3.4 Mortared Stone

These pavements are constructed using stone sourced from a quarry. It is necessary to create rectangular dressed blocks of stone which are placed close to one another. The void between the stones is then filled with a cement mortar similar to grouted stone riprap for protection.

Advantages

- The method of construction is almost entirely labour based and needs very little equipment. Only locally sourced natural materials are used except a small quantity of cement for the mortar.
- While skilled labour is required to create the blocks, less skilled labour is required to lay them. Consequently, the pavement can easily be repaired by limited skilled labour.

Disadvantages

- Suitable rock sources must be locally available.
- Requires a high level of expertise and a significant amount of labour and therefore was found not to be suitable for this contractor. It is surmised that unless the contractor has specific masonry expertise, or is able to resource the expertise locally, these highly skilled 'traditional' methods are unsuitable. It is noted, however, that while this contractor proved unable to knap the stone to an acceptable standard there have been major programmes in China, the country of the contractor, using this technology effectively and successfully.
- Slow laborious construction requiring neatness and care.
- The mortar joint is likely to crack under traffic loading, the significance of this is not fully known yet.
- The construction resulted in a very rough surface in this case which is not suited to bicycles.

3.3.5 Hand Packed Stone

Similar to the mortared stone above except that the voids are filled with sand or crusher dust mixed with smaller chips. The fine material is watered and brushed into the voids while the pavement is compacted with a light roller.

Advantages

- The method of construction is almost entirely labour based and needs very little equipment. Only locally sourced natural materials are used.
- While skilled labour is required to create the blocks, less skilled labour is required to lay them. Consequently, the pavement can easily be repaired by limited skilled labour.

Disadvantages

- Suitable rock sources must be locally available.
- Requires a high level of expertise and a significant amount of labour and therefore was found not to be suitable for a general contractor.
- Slow laborious construction requiring neatness and care.
- The construction resulted in a very rough surface in this case which is not suited to bicycles.

3.3.6 Concrete Paving Blocks

The contractor cast concrete blocks in his yard, he was able to do this during the earthworks operation on site thus ensuring that the blocks were ready as scheduled. This simple pavement construction results in an attractive flexible pavement.

The joints between the blocks are filled with sand or crusher dust. While it has been suggested that the joints can be sealed with mortar or bitumen this is rarely done worldwide.

Advantages

- Suitable for labour based construction requiring minimal plant and minimal skilled labour.
- Results in a flexibly pavement that will not fail rapidly but will deform in weak areas resulting in a pavement that will remain trafficable under most circumstances.
- The pavement can be easily repaired with minimal skilled labour reusing the displaced blocks.
- Can sustain heavy traffic loads soon after construction.
- Different laying patterns result in an attractive road surface.
- As the blocks remain largely intact during the life of the road there is a high residual value.

Disadvantages

- Requires a significant amount of labour and up front work to construct the blocks.
- Slow laborious construction requiring neatness and care.
- Resulted in a somewhat rough surface.

3.3.7 Sand Seal

This pavement comprised a crushed rock base of 150 mm primed with MC-70 bitumen at a rate 0.85 l/m². The sand seal was successfully constructed quickly by the contractor using a MC-3000 bitumen applied at a rate 0.80 l/m² followed by a sand cover applied at a rate 0.012 m³/m² and rolled with a 12 t steel wheel roller.

Advantages

- This low cost pavement was easy and rapid to construct.
- Although this pavement as constructed utilises a crushed rock base it might be possible to sand seal a standard gravel road resulting in a more stable non erodible dust free surface.

Disadvantages

- Specialist equipment and plant is required and material (bitumen) needs to be imported, although it should be noted that this equipment is commonly used by contractors.
- Successful construction requires skilled technicians with experience in the construction of bituminous surface dressed pavements. Again, this is fairly common amongst contractors.
- This surface is very susceptible to damage through relatively mild abuse such as dragging of loads, passage of agricultural equipment, vehicle accident damage, etc.
- This is considered a high maintenance option and will need to be resealed every few years, although this activity is fairly easy to perform.

3.3.8 Single Otta Seal and a Sand Seal

This pavement comprised a crushed rock base of 150 mm primed with MC-70 bitumen at a rate 0.85 l/m². The Otta seal was successfully constructed quickly by the contractor using a MC-3000 bitumen applied at a rate 1.6-1.8 l/m² followed by a sand cover applied at a rate 0.015 m³/m² and rolled with a 12 t steel wheel roller. While it is recommended to use a pneumatic tyred roller in order that the aggregate is kneaded into the surface the steel wheeled roller was allowed due to availability. The overlying sand seal was constructed using a MC-3000 bitumen applied at a rate 0.80 l/m² followed by a sand cover applied at a rate 0.012 m³/m² and rolled with a 12 t steel wheel roller.

Advantages

- This pavement was easy and rapid to construct.
- The pavement structure trialled in this work comprises a crushed rock base, however for low volume rural roads a natural gravel base should be considered. Expanding on this it might be possible to apply an Otta seal to a standard gravel road resulting in a more stable non erodible dust free surface.
- Aggregate specifications are not onerous and natural gravel can be used.
- Results in a thick durable surface with a design life of up to 10 years.

Disadvantages

- Specialist equipment and plant is required and material (bitumen) needs to be imported, although it should be noted that this equipment is commonly used by contractors.
- Successful construction requires skilled technicians with experience in the construction of bituminous surface dressed pavements. Again, this is fairly common amongst contractors.
- This type of surface is a relatively heavy user of bitumen. Whilst this is likely to promote longevity it also increases cost.

3.3.9 Double Otta Seal

This pavement comprised a crushed rock base of 150 mm primed with MC-70 bitumen at a rate 0.85 l/m². The Otta seal was successfully constructed quickly by the contractor using a MC-3000 bitumen applied at a rate 1.6-1.8 l/m² followed by a sand cover applied at a rate 0.015 m³/m² and rolled with a 12 t steel wheel roller. The second Otta seal was a repeat of the first.

Advantages

- This low cost pavement was easy and rapid to construct.
- The pavement structure trialled in this work comprises a crushed rock base, however for low volume rural roads a natural gravel base should be considered. Expanding on this it might be possible to apply an Otta seal to a standard gravel road resulting in a more stable non erodible dust free surface.
- Aggregate specifications are non-onerous and natural gravel can be used.
- Results in a thick durable surface with a design life of up to 10 years.

Disadvantages

- Specialist equipment and plant is required and material (bitumen) needs to be imported. Although it should be noted that this equipment is commonly used by contractors.
- Successful construction requires skilled technicians with experience in the construction of bituminous surface dressed pavements. Again, this is fairly common amongst contractors.
- Even more so than the single Otta seal, his type of surface is a heavy user of bitumen. Whilst this is likely to promote longevity it also increases cost.

3.3.10 Engineered Natural Surface

These pavements are gravel surfaces but comprise shaped and compacted existing in-situ soil material to form carriageway with a crossfall of about 5% to disperse rainwater into side drainage in order to ensure that rain water flows away from the road. In general the in-situ soil should have a bearing strength of CBR≥15%.

Advantages

- Very low cost suitable for low and light traffic volumes.
- No imported materials required suitable for labour intensive construction with inexpensive equipment and plant.
- Easy to maintain using labour or simple, low cost, grading equipment.

Disadvantages

- Can only be considered when there are high quality in-situ materials.
- High maintenance requirements.
- May fail in wet weather; however with careful maintenance, specifically of the drainage, this can be avoided in future years.
- Dust pollution in dry weather.

3.4 Construction Costs

The basic construction costs for project access roads are largely common to all types of pavement construction. Only the actual costs of providing the various pavement types are variables within the project context.

Total planned construction costs for the project roads based on the Contractor's tender offer are shown in Table 11.

Table 11 Tender Price

Bill	Description	Amount (LAK)	Amount (USD)	Composition
100	General provisions	506,970.24	57,383.98	6.05%
200	Earthworks	2,842,531.07	321,746.19	33.93%
300	Pavement	1,472,111.14	166,628.31	17.57%
400	Drainage	1,645,225.41	186,223.12	19.64%
500	Structures	54,886.40	6,212.59	0.66%
600	Miscellaneous	98,656.16	11,166.89	1.18%
	Subtotal	6,620,380.42	749,361.09	79.02%
900	Trial Pavements			
	Pavement	1,528,577.90	173,019.79	18.24%
	Monitoring (Cost of beacons and equipment)	229,204.00	25,943.61	2.74%
	Subtotal	8,378,162.32	948,324.48	100.00%
	Contingencies	837,816.23	94,832.45	
	Dayworks	61,872.00	7,003.29	
	Total Tender Price	**9,277,850.10**	1,050,160.18	

For comparison purposes, costs in this table, originally tendered in LAKs, are shown in US dollars at the July 2008 exchange rate of USD 1 = LAK 8,835

The construction costs for each of the trial pavement types based on the area constructed and using the Contractor's unit rates are shown in Table 12.

Table 12 Costs of Trial Pavement Types

Pavement Description		Length (m)	Cost (USD)	Cost/m² (USD)
1	Hand Packed stone	500	11,073	6.328
2	Mortared Stone	600	13,288	6.328
3	Sand Seal	625	13,720	6.272
4	Single Otta Seal and Sand Cover	300	8,070	8.070
5	Double Otta Seal	200	6,370	9.100
6	Bamboo Reinforced Concrete			
	125mm	375	19,978	15.222
	150mm	200	12,417	17.739
7	Concrete Paving Block	500	51,793	29.596
8	Geocell Concrete Pavement			
	75mm	200	13,180	18.829
	100mm	100	8,212	23.464
	150mm	100	11,457	32.734
9	Engineered Natural Surface	400		
	Total	**4,100**	**169,560**	
	NEC Standard Gravel Control	1,400	11,891	2.427

July 2008: USD 1 = LAK 8,835

In each case the cost per square metre is the cost of the designated pavement construction above the prepared subgrade. On this basis the cost of Engineered Natural Surface is nil since this is, effectively, the prepared subgrade in an area where the in situ material is of a high enough quality to act as the road pavement/surface.

Examination of the construction costs for each pavement type indicates two obvious irregularities:

- The cost of a 150 mm Geocell concrete pavement is almost double that of a 150 mm Reinforced Bamboo concrete pavement although the cost of 150 mm Geocell form material is only USD 6/m² against which must be set the cost of providing the bamboo reinforcement and the edge formwork required for the Bamboo Reinforced pavement; and,
- The cost of plain Concrete Block paving is also remarkably high, particularly when compared with the costs of Hand Packed or Mortared Stone pavement (USD 6.328/m²). Even allowing for the cost of concrete it would appear that concrete block paving, which is simpler to lay than the Stone pavements, should have cost no more than USD 14.15/m² (LAK 125,000/m²) at the very most.

Unfortunately, because the project was constructed by a single contractor under a single contract there are no comparative prices available to allow us to refine these rates by reference to other commercially based costing, however, for the purpose of any further analysis the cost of concrete block paving will be considered USD 14.15/m².

The costs of all the proposed trial pavements are substantially higher than for a simple gravel pavement; a 200 mm layer of good quality gravel at this contractor's rates amounts to USD 2.427/m².

Because this trial was superimposed on an existing road project there was no opportunity to investigate, in detail, the possibility of making savings in earthworks costs through the use of more extreme alignments which the greater durability of the improved pavements should make possible. However, the road cutting at the start Road 3-2 as discussed earlier, which was undertaken as a part of the original project design in order to reduce a steep gradient, clearly illustrates the possibility for savings of this nature.

3.5 Maintenance Requirements, Capacity and Cost

3.5.1 General

No road pavement can be expected to perform well in the long term without receiving appropriate maintenance.

The road as a whole requires regular maintenance which may vary somewhat depending on climate and terrain but which will consist essentially of cleaning drains and drainage systems, vegetation control, shoulder maintenance and general upkeep and repairs to the road infrastructure, guard rails, signs, etc. These items are independent of pavement type. However, on paved roads where water cannot soak into the surface, it is particularly important that the shoulders be carefully maintained so that water can run across the shoulders and into the side drains.

The maintenance requirements for the road pavement will vary considerably depending on the pavement construction and the traffic to which it is subjected. There is, in general, a trade-off between pavement first cost and subsequent maintenance costs. This trade-off, however, is not constant but will vary with conditions of use. A gravel pavement used on a stretch of straight and level embankment will require very substantially less maintenance than the same pavement employed on a steep gradient with severe curves.

The most cost effective choice of pavement can be assessed on the basis of the estimated whole life cost of the pavement, that is the initial construction cost plus the amortised costs of future pavement maintenance.

In the case of roads carrying substantial traffic this estimation can be complicated by the need to consider the cost implications for that traffic, Vehicle Operating Costs (VOC), of varying road conditions resulting from alternative maintenance scenarios together with variations in the maintenance requirements generated by different traffic levels.

In the case of the project roads, traffic is extremely light and maintenance requirements will be the result more of environmental effects (primarily, if not wholly, rainfall) than of traffic, particularly in the cases of natural and gravel surfaces. Bituminous bound surfaces can be expected to resist environmental effects for some time but they will eventually require repair and renewal. The plain sand seal, in particular, is likely to succumb fairly rapidly as it will be susceptible to damage from even the light traffic on these roads, opening the way to subsequent erosion damage in the wet season. The hard surfaces of the stone, block and concrete pavements can be expected to last much longer.

During construction, the contractor provided stockpiles of gravel along the access roads to be used by the communities for maintaining the gravel surfaces.

If sufficient stocks are available from the contractor, it is also possible and straightforward to replace broken concrete blocks. Again, these are relatively cheap to produce and could be made available by DPWT. It has been recommended that DPWT purchase the remaining blocks from the contractor and identifies a local manufacturer. Alternatively it should be possible for village groups to manufacture replacement blocks if DPWT will provide cement and some basic supervision.

Maintenance tasks relating to the bamboo reinforced concrete and bituminous surfaces require more expertise as well as specialised equipment and materials. When any substantial maintenance to these surfaces is required, these tasks will have to be carried out by contractors through the DPWT.

All pavements will require maintenance to preserve them. Failure to maintain will lead to accelerating deterioration as ruts become gullies and surfacing faults turn into ever larger potholes. Basic maintenance activities for the SEACAP pavements are summarised in Table 13.

Table 13 Specific Maintenance Activities for SEACAP 17 Pavements

Pavement Type	Maintenance Activity
Gravel	Grade the surface to maintain an acceptable cross section shape; Patch potholes; Fill ruts and depressions; Regravel as required to maintain overall thickness.
Bamboo Reinforced Concrete	Seal cracks in concrete; Cut out and replace failed sections; Reseal construction joints if required.
Geocells	Replace damaged concrete blocks.
Mortared Stone	Repair damaged sections.
Hand Packed Stone	Replace damaged stones.
Concrete Paving Blocks	Replace damaged blocks.
Sand Seal	Seal cracks in bitumen; Patch potholes and reseal surface.
Otta Seal	Seal cracks in bitumen; Patch potholes and reseal surface.
Engineered Natural Surface	Patch potholes; Fill ruts and depressions; Regravel as required to maintain overall thickness.

The measurement of deterioration rates and the cost of the corresponding maintenance requirements are key elements of the data required for the whole life cost analysis of the project pavements. The other key element is the ability of the roads authority and the communities to carry out the maintenance.

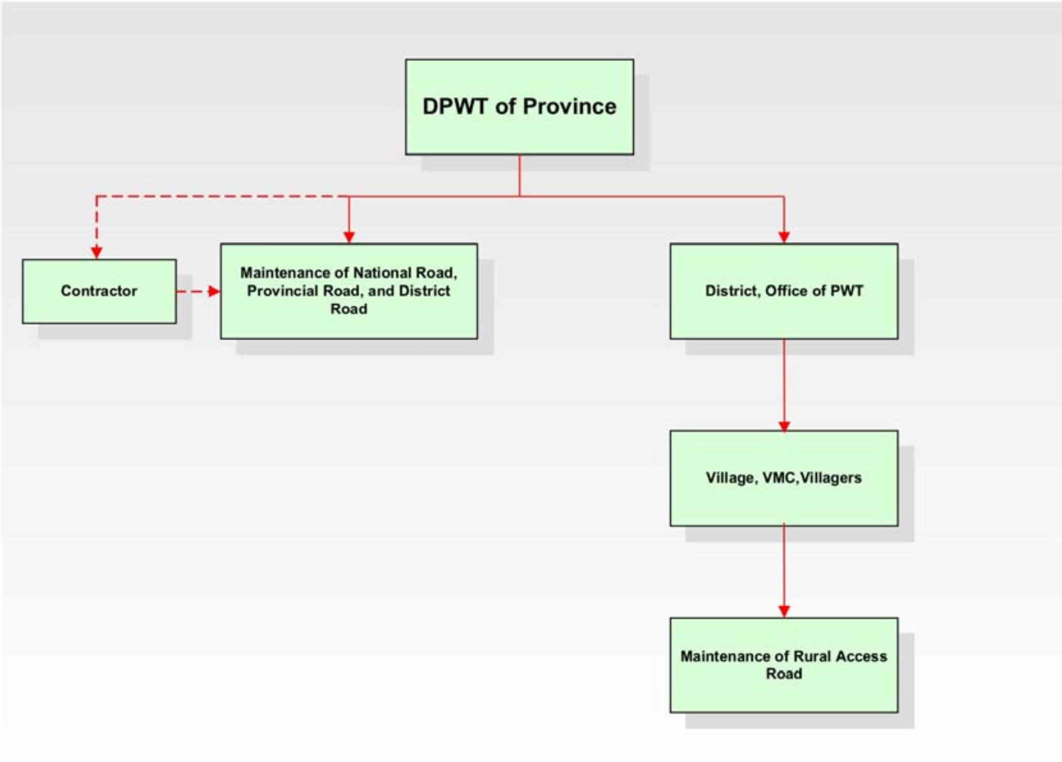
3.5.2 Organisation of Maintenance

<u>Institutional Capacity</u>

The structure of the DPWT is similar to MPWT, under the Director there are a number of divisions taking care of housing, roads, transport etc. Each division has a chief and his deputies and may have a staff of five to eight technical persons. DPWT is under MPWT for technical matters and under the province for administration. For road maintenance works, the road division is responsible for inspecting the roads, planning the maintenance and repairs and supervision of the implementation.

In Lao (PDR), the maintenance of National, Provincial and District roads is carried out by contractors under maintenance contracts (generally for three years) covering routine maintenance with heavy or periodic maintenance being done through separate short-term contracts. However, rural access road routine maintenance is entirely a provincial matter and is carried out on a community basis using Village Maintenance Committees (VMC) organised by the District Officer of the District's Public Works and Transport department. In principle the VMC's organise the manpower for maintenance on the basis of each 25 households having responsibility for one kilometre of road. The provincial DPWT monitors these maintenance activities. Heavy maintenance is funded through the central, MPWT, maintenance budget via the Local Roads Division of the Department of Roads and a carrot and stick approach appears to be used whereby rural access roads which the community has not maintained to a reasonable standard will only get low priority for heavy maintenance requirements. The simple structure of Rural Roads maintenance organisation is shown in Figure 5.

Figure 5 Rural Roads Maintenance - Organisation Structure



The costs of rural access road maintenance to the Province are therefore limited to the costs of organisation and monitoring and to the provision of essential tools. Whilst it appears that this system is working and that access road maintenance has improved under it, there are apparently problems in many areas in that the community cannot supply 25 households per kilometre of road. The level of 25 households per kilometre, in fact, seems rather high. In other countries where 'lengthman' maintenance operations have been inaugurated it has normally been found that one lengthman, working full time, can cover at least 2 km or more. With 25 household per kilometre this would suggest that each household has to supply the equivalent of no more than half of one man-day per month.

Bokeo province has already organised VMC's for all five districts as follows:

- Houayxai 9 groups
- Tonepheung 13 groups
- Paktha 6 groups
- Meung 6 groups
- Pha Oudom 8 groups

MPWT provides a budget allocation to Bokeo province for all maintenance works as shown in Table 14. Although it is probable that this funding will be utilised on Route 3, which has a higher profile than the feeder roads, it might be possible to obtain some assistance in areas where the communities do not have the capability to carry out the maintenance works unaided, for example in repairing bituminous surfaces, grading gravel roads and the supply of cement for cement based surface repairs.

Table 14 Summary of Budget for Road Maintenance in Bokeo Province

Road Maintenance		Donor	Budget (USD x 1,000)			
			2005 - 2006	2006 - 2007	2007 - 2008	2008 - 2009
1	**Routine Maintenance**					
1.1	Road Kontune - Chiengtong	SIDA		23.4		
1.2	Road Pak Ngao - Nam Sen	SIDA			27.6	
1.3	Road Pha Ngam - Phadam	SIDA			101.3	
1.4	Road Namkeung Mai - Ban Mai Phathana - Ban Donkeo	SIDA	50.4			
2	**Periodic Maintenance**					
2.1	Road Ban Pa-Oy - Ban Nampuk	RMP2		380		
2.2	Ban Namkeung - Ban Donkeo	RMP2		440		
2.3	Contract: BOK01-0506-RH-PR28	RMP2			289	
2.4	Contract: BOK02-0506-RH-PR29	RMP2			350	
2.5	Contract: BOK01-0708-RM-PR03	RMP2			90	
2.6	Ban Pa-Oy - Tin Doi Houaythou	Lao Govt			47	
2.7	Houay Param - Hadsa	Lao Govt			11.8	
3	**Rural Road Maintenance**	**Lao Govt**				**106**
		Total:	**50.4**	**843.4**	**916.7**	**106**

July 2008: USD 1 = LAK 8,835

As can be seen, most of the Bokeo maintenance budget is donor related and the total allocated for all rural road maintenance in 2008-9 is just USD 106,000 or LAK 936 million.

3.5.3 Routine Maintenance Activities

Routine maintenance must be carried out on the project roads to ensure sustainable access. This concept is well understood in MPWT; however, there are constraints in that the funding available is insufficient to meet the needs of the rural road network. Maintenance works ongoing in Lao PDR are mainly project driven, although some government funding is available for these activities. It is unlikely that an adequate allocation of the scarce maintenance funds will be made available for the access roads in Houay Xai. Sustainable access must therefore rely on the contributions of the local communities with technical support from the DPWT.

All of the general tasks such as vegetation clearance and drain and culvert cleaning are simple to implement and are within the technical capabilities of the local villagers to implement with monitoring from the local DPWT. Pothole patching and some elementary surface regulating on gravel roads is also within the abilities of the community as are repairs and patching to hand packed stone surfaces. Additional maintenance to gravel surfaces will require at least the use of a grader and frequently the use of transport as well to supply additional material. All other surfaces will require additional outside inputs, even though this may only be nominal quantities of cement for patching mortared stone surfaces. Care will be needed in monitoring repair of cement based surfaces to ensure that adequate quantities are supplied and used. Attempts at excessive economy in cement usage are likely to lead to useless repairs.

3.5.4 Execution of maintenance

The Engineered Natural Surface and the NEC Standard Gravel pavements are simple candidates for community maintenance since they are already similar to the bulk of access roads throughout Lao (PDR). However, for optimal maintenance a gravel pavement really requires periodic grading and the import of suitable gravel material for patching (except, presumably for the Natural Surface) and these pavements may not, therefore, be the optimal candidates.

With training, the Hand Packed Stone pavement is perhaps the best candidate. The surface should not deteriorate significantly over the medium term and maintenance should be limited to repairs to isolated failed areas. These repairs require no imported materials or equipment and, if they are well executed, the maintenance load may well reduce over time as weak areas are identified, remedied and eliminated.

The same logic applies to the various other block type pavements – Mortared Stone, Block Paving and the Geocell types. They can all be repaired by hand with simple tools and local materials except that they will require the provision of small amounts of cement.

Plain concrete pavements (Bamboo Reinforced in this case) are likely to present more problems, requiring, for proper repairs, the breaking out of substantial sections of concrete and the mixing of larger volumes of replacement material needing more cement and, possibly, mixing equipment.

Bituminous based surfaces are the most problematic. The only way to avoid the use of equipment for heating and spraying the bitumen to give good quality repairs is to use Emulsion. Unless this is in common use it will be difficult to supply in small quantities for local repairs. The alternative is to use crudely heated, hand poured bitumen and accept a (much) lower quality of routine maintenance repair work.

On all roads and pavement types, the execution of routine drainage and shoulder maintenance is important to the life of the pavement itself. Without this routine maintenance, pavement preservation is difficult or impossible. It is good that the Lao authorities acknowledge this and have tried to establish a self perpetuating system of low cost maintenance for their lowest tier of roads.

3.5.5 Maintenance Training

During the project, training was provided for DPWT staff and selected representatives from the local communities along the project roads. The number of participants was:

Organisation	No of Participants
Villagers (village head and assistant)	26
DPWT Bokeo	6
District Office	3
Provincial Governor's Office	1

Topics included in the workshops included:

- The need for maintenance
- Routine maintenance techniques
- Planning maintenance interventions

Additionally, the DPWT of Bokeo Province in cooperation with SIDA and KFW has previously organized a three day training course on road maintenance by community participation, and then provided tools for the village groups.

As the SEACAP 17 roads are handed over to the Province at the end of the one year Defects Liability Period in September 2008, additional VMCs will need to be set up to handle the associated maintenance. It would seem appropriate that some outside assistance be given to promote this process, involving further training sessions and the donation of essential tools. Additional training related to the various pavement types constructed under the project would also be appropriate.

3.5.6 Whole Life Costs

The use of community labour for routine maintenance confuses the issue of whole life costs, since it adds in a substantial element which is free of charge from the Government's budgetary viewpoint. However, the bulk of routine maintenance (Vegetation control, drainage maintenance, etc.) is common to all roads, regardless of pavement type, and need not be considered in any comparison. Instead, all that is required is to assess the maintenance requirements of the various pavement types including both regular detail surface maintenance and heavy or periodic maintenance.

Without further monitoring of the performance and maintenance costs of the trial pavements, any evaluation of whole life costs is strictly a provisional estimate and it would be unwise to place too much reliance on it. However, an initial estimate of whole life costs has been prepared and is presented overleaf. This estimate is made using the assumptions tabulated below.

➢ Gravel pavement: (Flat)	Grade twice yearly; Replace 25 mm of Gravel each year.
➢ Gravel Pavement (Hilly):	Grade thrice yearly, Replace 35 mm of Gravel each year.
➢ Engineered Natural Surface:	As for Gravel pavements
➢ Bamboo RC:	Replace 2% and 2.5% of the pavement after each 5 years for 150 mm and 125 mm thicknesses respectively
➢ Geocells:	Replace 2%, 3% and 4% of the pavement each 5 years for 150 mm, 100 mm and 75 mm thicknesses respectively
➢ Mortared Stone:	Replace 4% of the pavement each 5 years
➢ Hand Packed Stone:	Replace 6% of the pavement each 5 years
➢ Concrete Paving Blocks:	Replace 3% of the pavement each 5 years
➢ Sand Seal:	Replace 20% of the Seal every 2 years and 100% every 10 years
➢ Single Otta Seal with Sand Seal:	Replace 50% every 5 years and 100% after 15 years
➢ Double Otta Seal:	Replace 50% every 10 years

Table 15 Comparison of the Whole Life Costs for the Pavements

Working Life	Standard NEC Gravel - Straight and Level		1 Standard NEC Gravel - Hilly		2.1 Bamboo Reinforced Concrete 125mm		2.2 Bamboo Reinforced Concrete 150mm		3.1 Geocells 75mm		3.2 Geocells 100mm		3.3 Geocells 150mm		4 Mortared Stone		5 Handpacked Stone		6 Concrete Paving Blocks		7 Sand Seal		8.1 Single Otta Seal with Sand Seal		8.2 Double Otta Seal		9 Engineered Natural Material - Level		9 Engineered Natural Material - Hilly	
Year 0	Constr.	-2.43	Constr.	-2.43	Constr.	-15.22	Constr.	-17.74	Constr.	-18.83	Constr.	-23.46	Constr.	-32.73	Constr.	-6.33	Constr.	-6.33	Constr.	-14.15	Constr.	-6.27	Constr.	-7.69	Constr.	-9.10	Constr.	-0.23	Constr.	-0.23
Year 1	13%	-0.76	18%	-1.10		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		-0.76		-1.10
Year 2	13%	-0.76	18%	-1.10		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	20%	-1.25		0.00		0.00		-0.76		-1.10
Year 3	13%	-0.76	18%	-1.10		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		-0.76		-1.10
Year 4	13%	-0.76	18%	-1.10		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	20%	-1.25		0.00		0.00		-0.76		-1.10
Year 5	13%	-0.76	18%	-1.10	3%	-0.38	2%	-0.35	4%	-0.75	3%	-0.70	2%	-0.65	4%	-0.25	6%	-0.38	3%	-0.42		0.00	50%	-3.84		0.00		-0.76		-1.10
Year 6	13%	-0.76	18%	-1.10		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	20%	-1.25		0.00		0.00		-0.76		-1.10
Year 7	13%	-0.76	18%	-1.10		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		-0.76		-1.10
Year 8	13%	-0.76	18%	-1.10		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	20%	-1.25		0.00		0.00		-0.76		-1.10
Year 9	13%	-0.76	18%	-1.10		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		-0.76		-1.10
Year 10	13%	-0.76	18%	-1.10	3%	-0.38	2%	-0.35	4%	-0.75	3%	-0.70	2%	-0.65	4%	-0.25	6%	-0.38	3%	-0.42	100%	-6.27	100%	-7.69	50%	-4.55		-0.76		-1.10
Year 11	13%	-0.76	18%	-1.10		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		-0.76		-1.10
Year 12	13%	-0.76	18%	-1.10		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	20%	-1.25		0.00		0.00		-0.76		-1.10
Year 13	13%	-0.76	18%	-1.10		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		-0.76		-1.10
Year 14	13%	-0.76	18%	-1.10		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	20%	-1.25		0.00		0.00		-0.76		-1.10
Year 15	13%	-0.76	18%	-1.10	3%	-0.38	2%	-0.35	4%	-0.75	3%	-0.70	2%	-0.65	4%	-0.25	6%	-0.38	3%	-0.42		0.00	50%	-3.84		0.00		-0.76		-1.10
Year 16	13%	-0.76	18%	-1.10		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	20%	-1.25		0.00		0.00		-0.76		-1.10
Year 17	13%	-0.76	18%	-1.10		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		-0.76		-1.10
Year 18	13%	-0.76	18%	-1.10		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	20%	-1.25		0.00		0.00		-0.76		-1.10
Year 19	13%	-0.76	18%	-1.10		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		-0.76		-1.10
Year 20	13%	-0.76	18%	-1.10	3%	-0.38	2%	-0.35	4%	-0.75	3%	-0.70	2%	-0.65	4%	-0.25	6%	-0.38	3%	-0.42	100%	-6.27	100%	-7.69	50%	-4.55		-0.76		-1.10
Salvage	-50%	1.21	-50%	1.21	-50%	7.61	-60%	10.64	-40%	7.53	-50%	11.73	-60%	19.64	-50%	3.16	-30%	1.90	-50%	7.07	-50%	3.14	-60%	4.61	-60%	5.46	-50%	1.21		1.21
NPV	**6%**	**-10.14**		**-13.90**		**-12.98**		**-14.46**		**-17.12**		**-20.23**		**-26.69**		**-5.58**		**-6.17**		**-12.20**		**-15.75**		**-16.50**		**-10.81**		**-8.06**		**-11.82**
NPV	**10%**	**-7.91**		**-10.60**		**-13.39**		**-15.27**		**-17.15**		**-20.78**		**-28.18**		**-5.68**		**-6.00**		**-12.53**		**-12.38**		**-13.16**		**-9.81**		**-5.91**		**-8.60**

Note: Estimated Maintenance Scenarios

Costs in LAK - July 2008: USD 1 = LAK 8,835

SEACAP work in Vietnam[9] on the use of various pavement types has provided some insights into possible gravel pavement maintenance requirements within the region but has not yet produced data relevant to other pavement types. The SEACAP data for gravel roads has been used in an approximate form only since it is not clear that conditions between the different areas are wholly comparable and because the SEACAP gravel loss prediction mechanism for Vietnam is still in a preliminary state.

The Contract rates include no separate Figure for subgrade shaping and compaction, there is therefore no contract rate available to represent the costs of grading and reshaping gravel road surfaces. For the purposes of this illustrative analysis, shown in Table 15, a rate of USD 0.23/m² (LAK 2,000/m²) has been assumed as the cost of a single grading and shaping maintenance operation.

Although initial construction of the engineered natural material is low (corresponding to the USD 0.23/m² assumed above) subsequent maintenance has been assumed to use imported gravel and to be equal to that for the NEC gravel pavement since reliance on the in situ material implies that the road level will become progressively lower and lower as material is not replaced; this is considered unacceptable. Costs have been reviewed using 6% and 10% discount rates.

When the Net Present Value (NPV) or whole life costs of these pavement types are summarised and considered in order of NPV they can be ranked as shown in Table 16. This Table shows 6% rankings to the left and 10% to the right.

Table 16 Pavement Type in Order of NPV

Pavement Type Ordered using 6% Discount Rate	Cost USD/m²	NPV 6%	NPV 10%	Cost USD/m²	Pavement Type Ordered using 10% Discount Rate
Mortared Stone	6.33	-5.58	-5.68	6.33	Mortared Stone
Handpacked Stone	6.33	-6.17	-5.91	0.23	Engineered Natural Material - Level
Engineered Natural Material - Level	0.23	-8.06	-6.00	6.33	Handpacked Stone
Standard NEC Gravel - Straight and Level	2.43	-10.14	-7.91	2.43	Standard NEC Gravel - Straight and Level
Double Otta Seal	9.10	-10.81	-8.60	0.23	Engineered Natural Material - Hilly
Engineered Natural Material - Hilly	0.23	-11.82	-9.81	9.10	Double Otta Seal
Concrete Paving Blocks	14.15	-12.20	-10.60	2.43	Standard NEC Gravel - Hilly
Bamboo Reinforced Concrete 125mm	15.22	-12.98	-12.38	6.27	Sand Seal
Standard NEC Gravel - Hilly	2.43	-13.90	-12.53	14.15	Concrete Paving Blocks
Bamboo Reinforced Concrete 150mm	17.74	-14.46	-13.16	7.69	Single Otta Seal with Sand Seal
Sand Seal	6.27	-15.75	-13.39	15.22	Bamboo Reinforced Concrete 125mm
Single Otta Seal with Sand Seal	7.69	-16.50	-15.27	17.74	Bamboo Reinforced Concrete 150mm
Geocells 75mm	18.83	-17.12	-17.15	18.83	Geocells 75mm
Geocells 100mm	23.46	-20.23	-20.78	23.46	Geocells 100mm
Geocells 150mm	32.73	-26.69	-28.18	32.73	Geocells 150mm

July 2008: USD 1 = LAK 8,835

As noted above these results must be viewed with caution since they are based on just one Contractor's view of the costs. Although the rankings change somewhat depending on whether a 6% or 10% discount rate is adopted the overall pattern is much the same with only minor differences.

9 ***Rural Road Surfacing Research**, SEACAP 1, Final Report, (Vol 1 and App A) Ministry of Transport Vietnam, December 2006.*

The position of the Engineered Natural Material in this table has little meaning since this is a special case, possible only in highly specific local circumstances, although, in those circumstances, it will obviously be the surfacing of choice for roads with low gradients.

More significant is the consistently low value of the Mortared and Hand Packed Stone Pavements. Apart from the low cost, these pavements are likely to be successful once the basic skills have been acquired as they are highly suited to community maintenance requiring no equipment other than hammers, some basic transport and a source of stone.

The NEC gravel pavement (Hilly) also comes out fairly well, however, it must be remembered that the low whole life cost in this table includes only regular maintenance and does not reflect the cost of emergency maintenance for wash-outs; it offers no certainty that such a road will be kept open at all times during the rainy seasons. In addition, the regular grading maintenance that such a pavement requires, implies substantial regular inputs at the DPWT level, not just community based work. It should be noted that regular grading is an essential maintenance element since it is this which keeps gravel loss within acceptable limits.

The Double Otta Seal is apparently the best of the various bitumen based pavements. This double seal offers a potentially robust pavement without the fragility of the sand seal topping. It suffers, of course, from the inevitable requirement for outside assistance and equipment where bitumen distribution is required for maintenance purposes.

Concrete block paving is a reasonably direct alternative to the handpacked stone surfaces and merits further attention. As noted previously there is considerable doubt about the validity of the pricing of this material and if the price can be brought down to USD 8.49/m² (LAK 75,000/m²) then NPVs at 6% and 10% become USD 7.3 (LAK 64,500) and USD 7.53 (LAK 66,500) respectively; although this remains above the handpacked stone surfaces it is clearly competitive when one considers the ease with which a much superior finished surface can be constructed.

4 MONITORING THE TRIAL SECTIONS

Monitoring will take place in two phases. Initially a complete set of base data must be gathered and subsequently regular monitoring is required to evaluate pavement performance by comparing pavement condition with this base data. This section of the report covers the collection of the base data; performance monitoring is for the future.

4.1 Monitoring Beacons

During the course of the project a series of beacons was constructed along both sides of the trial sections at 10 m spacing as shown in Photo 1. These beacons were to serve two purposes:

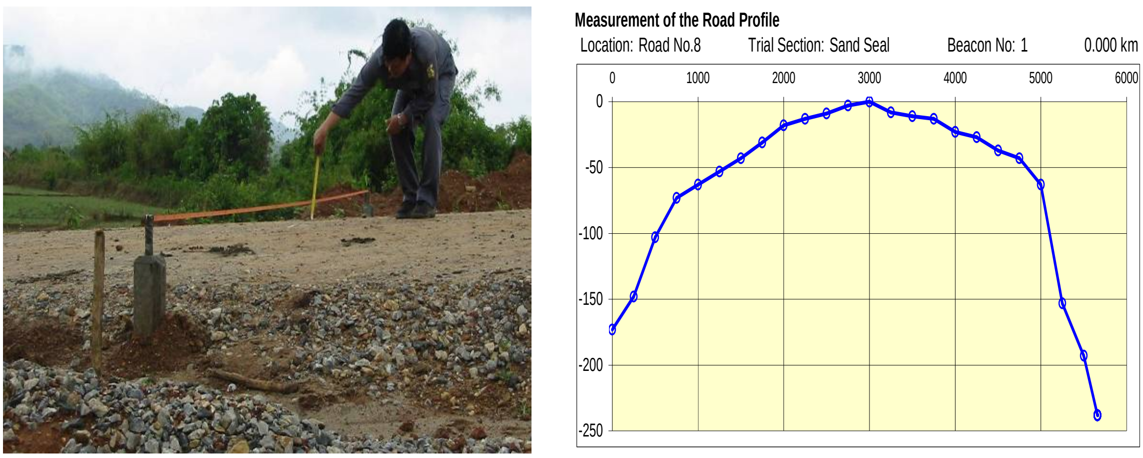
- To divide up the trial length into sections to allow easy identification of the various areas, or segments, and.
- To allow easy cross section measurement in order to measure the surface deformation as shown in the photograph and diagram below (Figure 6).

The beacons have been surveyed and their position fixed with the intent that damaged or missing beacons can be reinstated as necessary during the monitoring period.

The 10 m length of road between two adjacent beacons is referred to as a segment in the following discussion.

Photo 1 Monitoring Beacons

Figure 6 Measuring the Road Surface Profile



During the site visit at the recent Knowledge Exchange Workshop (7 November 2007) it was noticed that many of the monitoring beacons had been smashed. While some concern as to the safety of a road user, such as a cyclist, colliding with the beacons was raised it is the consultant's opinion that the damage to the beacons was due to the theft of the rebar reference marker in the head of each beacon. Since that visit further beacons have been vandalised and it must be accepted that this method of preparing for future monitoring will not work. Monitoring will have to be carried out using survey equipment and minimal in situ reference markers which do not represent a target for theft or vandalism.

4.2 The Base-Line Data

During the planning and design of an access road it is important to determine a number of characteristics of each road, or part thereof, so that the road can be optimally designed. The three main parameters that should be determined are:

- The alignment (terrain, gradients and horizontal alignment);
- The design strength (bearing capacity) of the subgrade, and;
- The predicted traffic volume over the design life of the pavement.

The first two parameters were measured and analysed and are stored in the database, the third parameter was estimated during the design.

Once the roads were constructed and the trial sections defined (Table 9) a series of base-line measurements were conducted as follows:

- Visual Inspection and surface condition logging;
- Photographic logging;
- Surface deformation recording (dipped levels and rut measurement);
- Surface roughness using a MERLIN apparatus;
- Surface Texture (sand patch test);
- Classified traffic counts, and;
- Structural integrity using a Dynatest 3031 LWD Light Weight Deflectometer.

4.2.1 Pre Construction Surveys

Alignment

The alignment has been categorised in accordance with values set out earlier in this report and the percentages of each of the access roads that fall with these categories identified. The details of alignment, gradient and curvature, for each trial section have been recorded.

Subgrade Strength

Since no investigation into the subgrade quality was conducted during the design stage the consultant undertook a subgrade survey which required the contractor to excavate trial pits and conduct a DCP survey as stated in the specifications.

Before and during the construction of the roads, trial pits were excavated along the alignments at a frequency of 200 m, samples were taken and tested in the laboratory in order to determine the 4-day soaked bearing capacity of the natural subgrade.

A correlation was undertaken between the laboratory CBR results and the DCP results which enabled an estimation of the design CBR along each of the access roads.

Design Traffic Loading

Since the access roads in general were merely tracks with little or no motorised traffic prior to the project, the design consultant had to make a prediction of the likely traffic volumes expected on these roads.

4.2.2 SEACAP – Monitoring Programme

A SEACAP programme (No.27) entitled the Pavement Condition Monitoring of the Rural Road Surfaces Research (RRSR) in Vietnam was started in late 2007. This programme is monitoring pavements, similar to those constructed during this project, over the long term. It is therefore envisaged that, in order to allow data to be compared throughout the SEACAP work, these pavements in Lao will be monitored using the same methods as those used in SEACAP 27.

4.2.3 Post Construction Surveys

Visual Inspection and Surface Condition Logging

The consultant suggests that the long term visual condition surveys will be conducted in two distinct activities:

- Visual condition surveys that assess the extent and degree of each of the particular modes of distress numerically in accordance with the guideline that result from SEACAP 27, and;
- Graphic representations of the surface of the trial sections.

Visual Condition Surveys

These require the inspector to inspect each segment, identify the mode of distress and assess what degree and percentage of the segment is affected by this distress and where within the cross section the distress occurs. For example in a segment of surface dressed pavement there might be pumping crocodile cracking, the inspector would record the percentage of the area of the segment that is cracked, 30% say. The inspector would record the spacing between the cracks, 200 mm say, and note that this form of distress is severe and that 50% was found to be pumping under the action of traffic loading. This range of data would be recorded for each pavement segment on a paper form in the field and subsequently transferred into spreadsheets or a database, unless the inspection team is equipped with a laptop in which case data might be entered directly into the final spreadsheet or database.

Graphic Representations

Forms have been produced that show each of the segments (areas between beacons) schematically allowing the inspector to sketch the distress exactly as it is seen. An example of a form used for these surveys is shown in Figure 7. The completed forms can then be scanned and stored in the database. A complete set of these forms are contained on the compact disk bound into this report for future use.

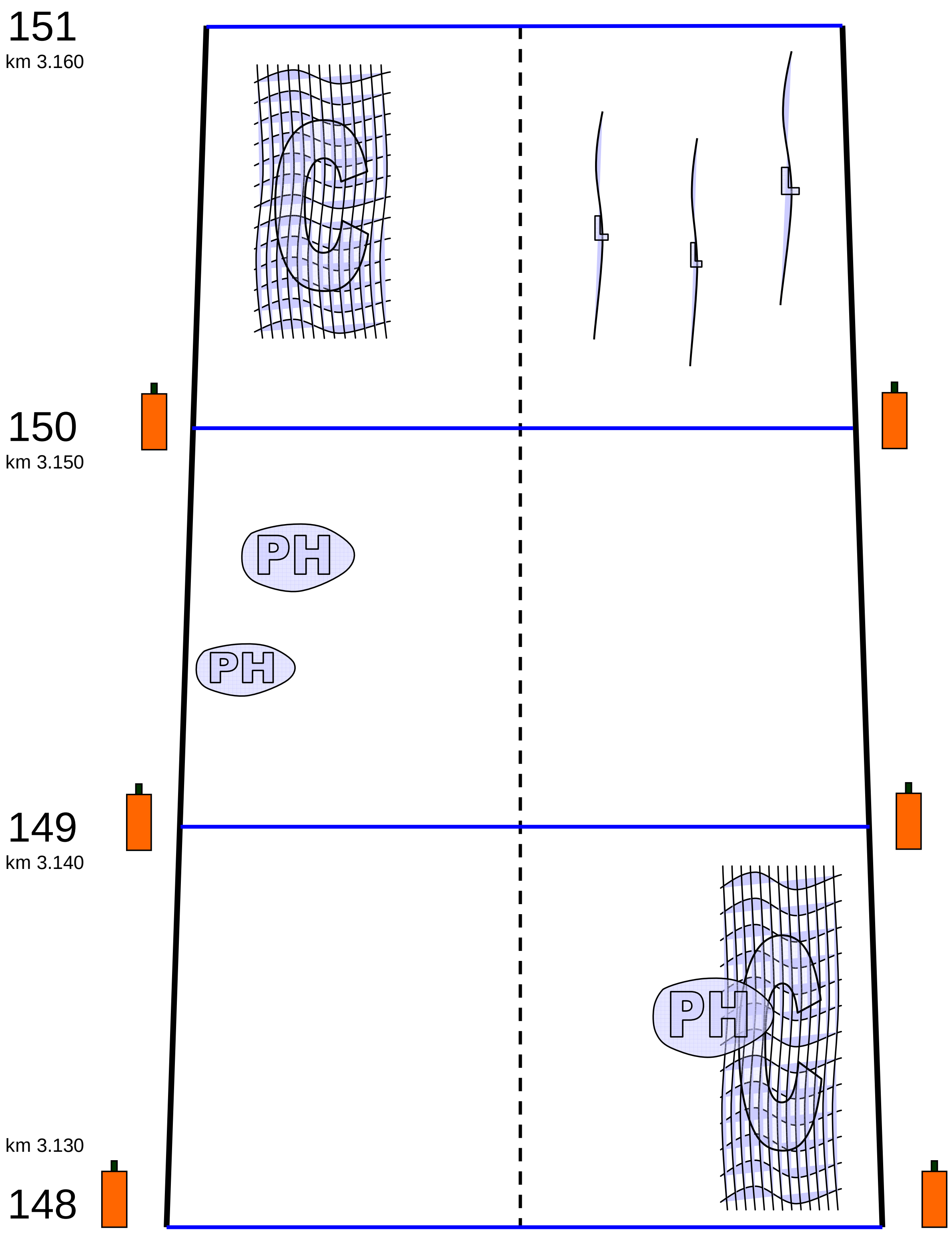
Both of these visual surveys should be backed up by means of a photographic record of the condition of the road surface as described below.

Photographic Logging

The consultant has set up a method of photographing the trial sections based on the beacons alongside the road. In summary, the surveyor photographs each segment of the trial section including the beacons ensuring that the beacons are in the centre of the photograph. This means that each segment is photographed from approximately the same position during each different survey and that photographs can be shown as a moving video or viewed individually. The photographs are stored in PowerPoint presentation files together with description pages for each road.

Figure 7 Graphic Representation Survey Form

SEACAP 27 **5/6** Date: 20/10/2007 Monitor: Roughton
Lao (PDR) Surface: Surface Dressing from km 3.125 to km 4.125
Section: Training Section Length: 1000 m



Surface Deformation Recording (Dipped Levels and Rut Measurement)

As discussed above the consultant devised a method of dipping across the road at 10 m intervals between the beacons. This method was used for this base line data collection but due to the vandalism of the beacons it appears that the method will have to be changed in subsequent surveys. The height from the tape is measured at predefined intervals, which can be measured on the tape, of 300 mm intervals. This method provides an easy way to measure the road cross section profile regularly without the need for any complex survey or calculations. Accurate gravel loss and surfaced pavement deterioration would have been easily calculated allowing deterioration models for the various pavements to be determined rapidly and with little effort.

4.2.4 Rut Depth Measurement using a Straight Edge

Rut Measurements by the more traditional method using a 3 m straight edge have been conducted. The methodology for this is shown graphically in Figure 8. The relationship between rutting and deflection is well documented and a comprehensive sequence of rut depth measurements will allow realistic models of deterioration against traffic loading to be produced in the future.

4.2.5 Surface Roughness Using a MERLIN Apparatus

The consultant has measured the roughness along each trial section using the well tried and tested MERLIN apparatus. The consultant has constructed a MERLIN apparatus under the project as shown in Photo 2, and handed this over to the MPWT. The consultant measured the roughness along predefined lines, approximately along the wheel-paths, along each trial section in both directions. Where trial sections were short, <200 m, the consultant has measured each line twice in each direction in order to capture a statically correct number of measurements. The International Roughness Index (IRI) (m/km) has been determined for each trial section.

Figure 8 Rut Depth Measurement using a Straight Edge

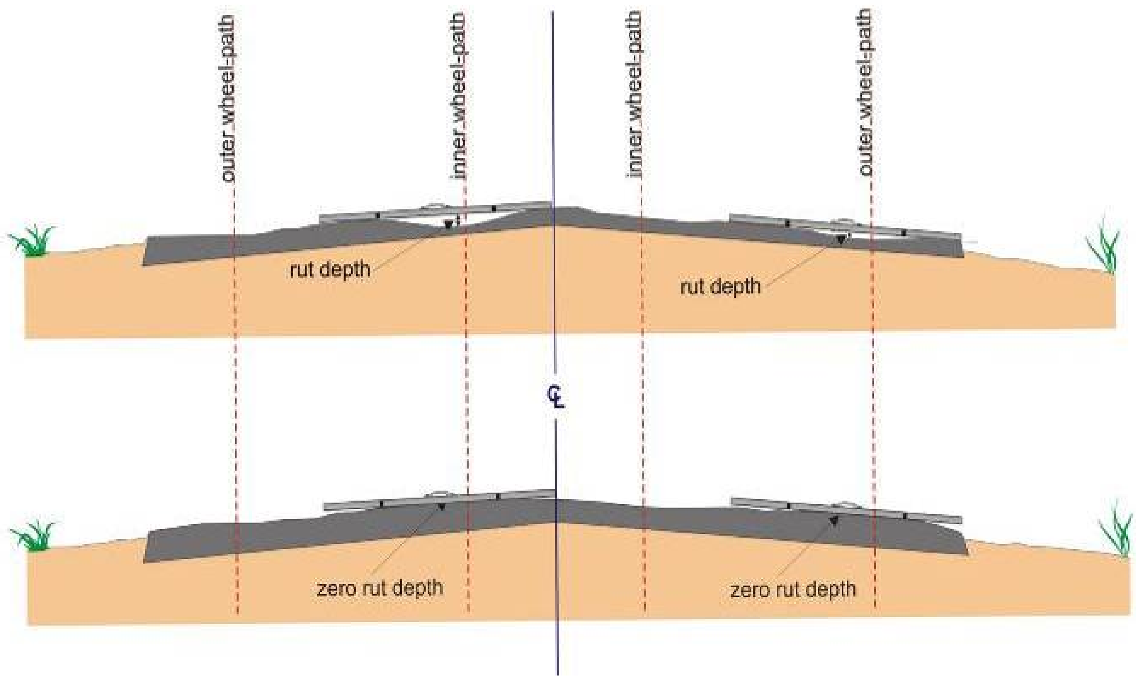


Photo 2 The MERLIN Apparatus measuring Roughness in Lao PDR

4.2.6 Surface Texture (Sand Patch Test)

This test has been used to determine the surface texture for bituminous surfaced roads at predefined locations on each surfaced trial section. This test is simple to perform using only simple equipment. The basic method by which this test is conducted is shown Figure 9. In essence, a measured volume of sand is placed on the road and rubbed into a circular shape using the standard circular paddle. The area of road surface covered is inversely related to surface texture depth.

Figure 9 The Sand Patch Test for Surface Texture

4.2.7 Classified Traffic Counts

Following completion of construction the Consultant carried out traffic counts on each of the project roads with the results given in Table 17, below. These counts were 12 hour counts covering daylight hours and averaged over three days. It is estimated that total, uncounted, night-time traffic would amount to no more than 20% of the daytime traffic.

The traffic volumes counted on these roads are low in terms of vehicles likely to create significant pavement wear; however, it must be remembered that these are new roads, serving communities previously without acceptable vehicular access. It will take time for outside operators to develop services to serve these communities and for the communities themselves to start taking advantage of the improved access.

Table 17 Traffic Counts on the Project Roads

Road	Location	Bicycle;	M/Cycle;	Car/4WD/P/up;	Cong Nog, Tok Tok, Tractor;	Light Trucks <5t;	Heavy Trucks >5t;	Mini Bus, Bus;	Pedestrian; Walkers, and;	Animal/Hand Cart.
1.1	0.940	48	17	2	3	3	0	0	41	0
1.3	0.650	28	43	5	5	0	0	0	114	0
2.2	0.650	134	64	6	60	2	0	0	98	6
3.2	3.400	63	20	2	2	2	0	0	94	0
3.2	0.920	41	71	4	24	2	0	0	108	0
3.3	0.650	72	37	0	6	2	0	0	170	0
5	0.650	9	15	7	20	0	0	0	31	0
8	0.650	32	49	3	13	2	0	0	362	0

A corollary of these very low traffic volumes is that when an axle loading estimation is conducted, as shown in the data files, it is concluded that the predicted pavement loading over a 10 year design life is negligible when categorised in accordance with common worldwide pavement design guidelines such as the ESA concept.

It is highly desirable that future monitoring includes records of traffic and estimated ESA levels in order that these may be correlated with pavement performance. Additional counts should also be performed as necessary to determine seasonal variations, if any.

4.2.8 Structural Integrity using a Dynatest 3031 LWD Light Weight Deflectometer

During the project a LWD Deflectometer was purchased and the consultant has conducted a survey comprising a single or a double test in each segment of each trial pavement (i.e., tests at 10 m intervals) in order to determine the structural integrity of the pavement at the point of the test. Tests have always been made at the centre of the segment measured longitudinally and transversely at the centreline for single tests or at the quarter points for Left and Right tests (further details of the locations are given in the field data). This apparatus is designed to determine the Resilient Modulus for the various pavement layers and pavement structure as a whole. Repeating these tests at the same points and recording this data over time will show the deterioration of the pavement trial sections under the specific climatic, alignment and loading conditions and can play a significant part in constructing, defining and calibrating deterioration models for the various pavement structures.

4.3 Data and Results

The consultant has written a database (Module 1) which contains information pertaining to each of the access roads and trial sections. The consultant has included the results of these surveys in the database as links to 'print outs' of the data in the form of pdf files and the database is contained on a Compact Disk bound into this report in Appendix H.

The analysis of results can only be conducted when a time series of data is available and will therefore have to form part of the Module 3 report.

5 CONCLUSIONS AND RECOMMENDATIONS FOLLOWING THE CONSTRUCTION

5.1 General Comment

Owing to the long term nature of this project there are only limited conclusions to be drawn at this intermediate stage.

The design process has shown the need for experienced engineers to spend some time in the field understanding the particular problems of the route(s) and exploring the various possible solutions. Solutions adopted should take account of both local materials and any available local skills.

The construction process has provided data regarding the cost of constructing various types of alternative pavement and the problems which may be found in their construction. It has also highlighted the problems which can be encountered when trying to implement a research operation on the back of a regular commercial construction contract.

The collection of baseline data has illustrated some problems likely to affect long term data collection systems.

Cost data shows, unsurprisingly, that improved pavements cost more. Accordingly it is recommended that a Spot Improvement philosophy be considered as the normal approach to basic access road provision whereby the simplest pavement structures be used for undemanding sections of road and the higher cost, improved structures be used on sections prone to failure, typically steep gradients. This same philosophy applied during alignment design may be used to limit construction costs by permitting the use of more extreme alignments and thus reducing earthworks and, sometimes, acquisition costs.

A review of the maintenance organisation and funding shows that local participation is essential to the maintenance of access roads in Lao (PDR). Measures already exist to provide for such local participation, however, it is highly desirable that construction contracts should be structured to require the maximum possible local employment. Apart from the immediate benefits of employment, this will give the local community a sense of ownership of the road and help equip them with the necessary skills and understanding required for its future maintenance.

At this stage, the advantages and disadvantages for each pavement structure, other than the construction costs, cannot be clearly defined and it would be difficult to compile a table, or indeed a design methodology, that made a definitive recommendation for a particular pavement structure in particular circumstances. This emphasises that in order to draw conclusions in respect of specific pavement types, the medium and long term monitoring of the trial sections is of critical importance.

5.2 Conclusions

The following points are the general conclusions regarding the pavement trials highlighting the advantages and disadvantages of each:

- Standard NEC Gravel Pavement, Engineered Natural Surface and Sand Seal should not be used on problematic areas as these surfaces will not withstand heavy traffic, steep gradient or high erosive conditions i.e., rainfall.
- Sand Seals and Single Otta Seals are ideally suited to urban conditions with low traffic where dust from gravel roads is unacceptable. However, both of these surfaces will require periodic maintenance which could, ideally, be undertaken by the communities through which they pass.
- Concrete block paving, concrete pavements and bituminous bound pavements can be undertaken successfully by small scale contractors using imported and local materials. These initially expensive pavements result in sustainable pavements with reduced maintenance needs.

- Hand Packed or Mortared Stone Surfaces appear likely to offer the best value for money and are suitable for community based maintenance. However, unless very experienced artisans are used for the block preparation, extremely rough surfaces will result. Rough surfaces will in general be unacceptable to road users except in cases where the road was extremely bad and mostly impassable previously. Improvement of these areas to year round accessibility, using roughly hewn stone blocks, will be a huge improvement despite resulting in a rough surface. The standard of surface will improve as the community gains experience and will be better with mortared rather than hand packed stone.
- All of the pavements, but in particular the Engineered Natural Surface will perform much better during the wet season if the drainage is functional. A detailed drainage investigation should be conducted at the design stage resulting in drainage designed to function 'with nature' ensuring that water is not routed incorrectly. Routine drainage maintenance before the wet season will be of great help in ensuring that the road remains open throughout the wet season.
- Double Otta seals can be constructed using natural gravel which is well out of specification for normal surface dressed pavements, resulting in a durable surface which can be applied to all but the most severe areas. This construction is ideal for small contractors as it requires little plant and expertise, providing a bitumen distributor is available, but does require labour intensive care during construction.
- Geocells and Non-Reinforced Concrete pavements are suited to small contractors as suitable concrete can be mixed in small mixers using local materials. The specified thickness of the Geocell pavement can be less than that of concrete slabs however, the cost of the plastic Geocell form may negate some of this saving.
- Double Otta Seals, Concrete Blocks and Concrete pavements are suited to high traffic volumes. Also these pavements can be applied to steep gradients and sharp corners where traffic action on the surface is most severe.
- Hand Packed or Mortared Stone Surfaces, Paving Block surfaces are easily repaired reusing much of the materials by unskilled labour.

Some of the chosen pavement methodologies were not as well suited to resources (human and/or material) available in Houay Xai as others. An example was the knapped stone based pavements. Since there seems to be no history of knapped stone in the area (although the stone is available) it was very difficult to find experienced artisans to construct roads using this technique, which has proven successful elsewhere. Detailed investigations of the project area should highlight potential successful construction techniques.

The construction cost of the all-weather surface types exceeds the construction cost of the standard gravel road significantly. It is concluded that these all-weather surface types should be applied at the problematic spots on a rural access road where they are needed to maintain all weather access or, possibly, for social reasons rather than along the entire length. This 'Spot Improvement' pavement design philosophy should be applied as widely as possible given a lack of funds to provide improved pavements throughout the road length.

The existing database of rural road surfacing knowledge has been expanded significantly by the work undertaken by SEACAP 17 in Lao PDR.

The DPWT and Governor's office as well as the communities have a good understanding of the need for maintenance of the access roads in order to provide continued sustainable access.

Maintenance of the roads will depend largely on the willingness of the communities to contribute their labour and on the DPWT providing technical support and budget support when necessary.

Maintenance considerations should be taken into account when selecting pavement types, for example gravel surfaces and bituminous seals require significantly more routine and periodic maintenance that concrete roads. Stone surfaces are potentially most suited for long term community maintenance without significant outside assistance or funding.

5.3 Recommendations

The SEACAP 17 contractor's staff had insufficient communication skills to benefit properly from the training given. Clear communication was found to be almost impossible (intentionally or unintentionally) due to the entire staff base being Chinese. It is recommended that future contracts clearly require local labourers, artisans and technicians to be employed. Not only does this have economic bearing on the local community, but also provides some feeling of ownership and ensures that the expertise created through training is not lost from the area. In the future these trained labourers will be able to construct other roads and to maintain existing roads.

When using contractors to undertake small scale but accurate work in which they have little or no expertise, it is vital that considerable training is provided in order that the non-standard or unfamiliar construction techniques are conducted properly. It is recommended that small scale local contractors are trained and given a tender advantage over large international contractors. This will empower local communities, provide a sense of ownership within communities and ensure that expertise and economic benefit remains in communities.

Problems were found when applying a research project to a commercial contractor, the contractor had little interest in the research and was primarily concerned with his costs and missed deadlines. An understanding must be shaped early in the project between client, funding agencies, consultant and the contractor such that research related contractual variations and requirements are defined, anticipated, allowable and enforceable. Care should be taken when compiling contract documents to ensure that they are adapted appropriately to the research aims; suitably weighted prequalification would be a significant advantage for research projects.

Some specifications were found to be inappropriate when applied in Lao PDR. For example the shape of hand knapped stone for Hand Packed or Mortared Stone Surfaces. These specifications have now been modified.

Some specifications were found to be inappropriate for labour based construction, for example high quality concrete and bituminous surfaces. These specifications have now been modified to ensure that suitable levels of quality are achieved.

5.4 Future Work

Clearly, further monitoring work is required to assess the long-term performance of the SEACAP 17 trial pavements against time in order that a detailed cost against longevity/deterioration model can be defined. Only when their success over the long term has been clearly demonstrated, will these techniques be accepted by general practitioners and the recommendations of this work become acceptable practice and mainstreamed.

Both soft and hard actions are required to make an impact of this work with practitioners. Soft action (Dissemination) will increase awareness and knowledge and will win hearts and minds leading to ownership by practitioners who will apply the concepts in their districts. Hard action (Mainstreaming) will result in the production of design guides, specifications and contract documents that allocate appropriate resources to the use of these techniques in the design and construction of rural access roads. This will again lead to the ownership by practitioners who will become confident in the success of these methods.

Long Term Monitoring

It has been agreed that in order for this work to be of value beyond that discussed in this report it is necessary for a long term monitoring regime to follow through on the base line data capture.

This will involve the monitoring of the performance and deterioration of the trial pavements and the NEC standard gravel control sections, taking into consideration the traffic environments to which they are subjected and the maintenance requirements, costs and arrangements.

This assignment is not part of the current SEACAP 17 scope. It is, however, essential that the monitoring work be planned and carried out in a systematic manner and conducted to acceptable standards.

Maintenance Considerations

During Phase 2 of SEACAP 17, the condition of the trial pavements on the access roads will be monitored on a regular basis. During these monitoring exercises, the deterioration and defects on the gravel sections will be highlighted as a comparison with the trial pavements. The consultant must also monitor and comment on the implementation and effectiveness of maintenance on the project roads. Where noticeable deterioration is occurring, this must be brought to the attention of the DPWT and MPWT.