Local Resource Solutions to Problematic Rural Road Access in Lao PDR SEACAP Access Roads on Route 3

Mr.Mike James BSc (Hons), MICE, CEng, Mr.Mike Taylor BSc (Eng), CEng, MICE and Dr.Simon Gillett, BSc (Eng), PhD, GMICE

The SEACAP 17 Project aimed to identify cost-effective community orientated approaches for improving all year access to remote rural areas through a low-cost and local resource based improvement of roads in Lao PDR. The trials were undertaken as part of the Asian Development Bank funded Northern Economic Corridor (NEC) Project, comprising the rehabilitation of Route 3 and a number of access roads. Alternative pavements and surfacing to the standard laterite pavement were tested by way of trials on short problematic sections of selected access roads linking Route 3 with the outlying villages. Several of these pavements were previously trialled in Vietnam and Cambodia through DfID research. The trials were carried out under a normal contract environment with local supervision. The research is divided into two phases, construction and monitoring. This paper presents the results of the construction phase.

1 INTRODUCTION

1.1 The Problem

Gravel surfacing is not always the best solution for rural roads in many circumstances. Work undertaken in neighbouring Vietnam[i] 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[ii] investigations, 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.

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 worst sections may only comprise a small percentage of the length of the road but can consume much of the cost of the construction of the road pavement.

1.2 Environmentally Optimised Design and Spot Improvement Design

Environmentally Optimised Design (EOD) has been defined as a system of road design that considers the variation of the different road environments along the length of the road such as steep gradients, wet and marshy areas as well as passage over easy terrain.

The Spot Improvement Design (SID) methodology is applied to the EOD philosophy and concentrates on ensuring that each section of a road is provided with the most suitable pavement type for the specific circumstances. The main factors likely to render a gravel road impassable are:

- Steep gradients;
- Soft wet areas;

- Severe erosion of the road and embankment due to water flowing across the road;
- Debris on the road due to material being washed from side slopes or landslides, and;
- Slope failures from poorly designed slopes above and below the road.

It is in these circumstances that the SID philosophy is likely to be of great value. In order to provide a substantial improvement in the utility of the road it is only necessary to carry out properly engineered 'Spot Improvements' on the sections of the road now known to be most unreliable to achieve the maximum return for a given expenditure.

The basic approach to the SEACAP 17 research was to replace the standard gravel pavement with a particular SEACAP trial pavement at specific locations where access problems were envisaged in the future. No change to the existing design alignment was made.

2 DESIGN ISSUES

2.1 NEC Design Standards

Over recent years the specifications for the design of local roads in the Lao PDR have undergone modification and updating. However, the 1990 standard[iii] was used for the geometric design rather than the current 2003 standard for the design of Local Roads. The new standard[iv] for mountainous terrain reduces the carriageway width and relaxes the maximum gradient from 12% to 15%.

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 in harmony with the terrain; for example a large cutting was introduced on one access road to provide a reduced gradient suitable for a gravel pavement and earth side drains. Using the relaxed gradients of the latest standards, the problem could have been solved with a reduced cut, using an all-weather surface and improved, properly engineered drainage to provide year round accessibility. Although potential problems with the braking and stability of the locally made vehicles were not specifically considered on steeper gradients care is recommended.

2.2 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 was used as shown in Table 1. 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 1 Terrain Type as Defined by Gradient

Gradient	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%

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. 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. In the context of the SEACAP 17 trial pavements the questions to be answered were

- Do the least expensive pavements perform adequately in road sections with low gradients?
- At what gradient does it become necessary to use 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?

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

2.3 Pavement Structures

The road pavement is intended to protect the subgrade by the provision of pavement layers and to achieve a chosen level of service over the design period as economically as possible.

For SEACAP 17 the consultant chose the TRH4[v] design methodology, which considers roads with low volumes. The bituminous surface in the TRH4 design was substituted with different surface types using the basic rules of pavement design. From the options presented at the project inception workshop[vi] the following pavements were selected to provide a suitable range of alternatives that could be tested under local conditions.

- **Bamboo Reinforced Concrete**: consists of a layer of concrete, reinforced with strips of bamboo, and laid upon a compacted base.
- **Otta Seal**: consists of a layer of binder followed by a layer of aggregate that is rolled into the binder using a roller or loaded trucks
- **Geocell**: a formwork fabricated from plastic sheeting that is used to cast interlocking concrete block paving in situ. The plastic formwork is sacrificial and remains embedded in the pavement.
- **Hand Packed Stone**: consists of a layer of large stones into which smaller chips are packed. Remaining voids are filled with a blinding of sand or lateritic gravel to form a strong and semi-impervious matrix.
- **Mortared Stone**: 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.
- **Concrete Paving Blocks**: consists of blocks arranged side by side. Gaps between blocks are then filled with fine material to form a strong and semi-impervious layer.
- **Engineered Natural Surface**: Where the existing subgrade material comprises natural gravel with the same characteristics as the designed gravel pavement, it can be considered as gravel pavement material. Depending on the depth of the existing material it can be used to reduce the thickness of added pavement materials or can be shaped and compacted without the addition of gravel.

The designs were based on a nominal subgrade strength of CBR=5%, based on the pre-construction subgrade investigation, and low predicted traffic volumes as defined in the NEC design report, the actual pavement structures are shown in Table 2.

3 RESULTS AND ANALYSIS

3.1 Pavement Costs

Table 3 details the costs for each trial pavement. In each case the cost per square metre is the cost of the designated pavement construction above the prepared subgrade. 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 150 mm Geocell concrete pavement is almost double that of 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,

Table 2 Trial Pavement Construction Details

Pavement Types		1 Standard NEC Gravel	2 Bamboo Reinforced Concrete	3 Geocell	4 Mortared Stone	5 Hand Packed Stone	5 Concrete Paving Blocks	7 Sand Seal	8 Otta Seal	8 Engineered Natural Surface
Surface Layer	Type	Natural Gravel CBR≥25%	Concrete	Concrete	Stone	Stone	Blocks	Sand Seal	Sand Seal + Otta Seal Double Otta Seal	Natural 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							Crushed Rock CBR≥80%	Crushed Rock CBR≥80%	
	Thickness							150 mm	150 mm	
Subbase	Type		Natural Gravel CBR≥25%	Natural Gravel CBR≥25%	Natural Gravel CBR≥25%	Natural Gravel CBR≥25%	Natural Gravel CBR≥25%	Natural Gravel CBR≥25%	Natural Gravel CBR≥25%	Natural Gravel CBR≥25%
	Thickness		125 mm	125 mm	125 mm	125 mm	125 mm	120 mm	120 mm	Levelling
Selected Subgrade	Type	Natural Gravel CBR≥8%	Natural Gravel CBR≥7%					Natural 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

Table 3 Trail Pavement Costs

Pavement Description		Length (m)	Cost (USD)	Cost/m (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	8.07
5	Double Otta Seal	200	6,370	9.1
6	Bamboo Reinforced Concrete			
	125 mm	375	19,978	15.222
	150 mm	200	12,417	17.739
7	Concrete Paving Block	500	51,793	29.596
8	Geocell Concrete Pavement			
	75 mm	200	13,180	18.829
	100 mm	100	8,212	23.464
	150 mm	100	11,457	32.734
9	Engineered Natural Surface	400		
10	NEC Standard Gravel Control	1,400	11,891	2.427

- 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.

Because the project was constructed by a single contractor under a single contract there are no comparative prices available to allow refinement of 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.

This trial was superimposed on an existing road project with no opportunity to investigate the possibility of making savings in earthworks costs through the use of steeper alignments. The greater durability of the improved pavements should make this possible. Future research should investigate such cost savings in earthworks to offset the high cost of the robust pavements.

3.2 Maintenance

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

The maintenance requirements for the road pavement will vary considerably depending on the pavement design, quality of 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 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. Whilst such analysis assumes maintenance will be carried out, it should also consider the case where little or no maintenance is provided due to lack of funds.

In the case of roads carrying substantial traffic this estimation is complicated by the need to consider the cost implications for that traffic, i.e. 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, the traffic is extremely light (average 22 motorised vpd with very few or no trucks greater than 5 tons or buses) and maintenance requirements will be the result more of environmental effects (primarily, if not wholly, rainfall) than of repetitive traffic loading, particularly in the cases of natural and gravel surfaces where wheel loading is also significant. Some discussion regarding tyre pressure and the effect on LVRR is made in SEACAP 19[vii] it is however largely irrelevant for the road studied in this project which are very lightly loaded.

Bituminous bound surfaces can be expected to resist environmental effects for some time but they will eventually require repair and renewal. The sand seal on gravel base, in particular, is likely to succumb fairly rapidly as it is 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.

The basic maintenance activities for the SEACAP pavements are summarised in Table 4.

3.3 Whole Life Costs

The bulk of routine maintenance (Vegetation control, drainage maintenance, etc.) is common to all roads regardless of pavement type. For this analysis assessment has been carried out of only 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 its precision. However, an initial estimate of whole life costs has been prepared and is presented below. This estimate is made using the assumptions in Table 5.

It should be noted that the maintenance assumptions shown in this table are the ideal case and it is probable that they will not be implemented due to the constrained government budget for rural access road maintenance.

SEACAP work in Vietnam[viii] 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 therefore been used in an approximate form since it is not clear that conditions between the different areas are wholly comparable.

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. Costs have been reviewed using 6% and 10% discount rates.

Table 4 Maintenance of Trial 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.

Table 5 Assumed Maintenance Strategy for Trial Pavements

Road Description	Maintenance Strategy
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 + Sand Seal:	Replace 50% every 5 years and 100% after 15 years
Double Otta Seal:	Replace 50% every 10 years

Table 6 Economic Evaluation of Trial Pavements

Pavement Type	Cost USD/ m²	Salvage Value	NPV	
			6%	10%
Mortared Stone	6.33	50%	5.58	5.68
Hand Packed Stone	6.33	30%	6.17	5.91
Engineered Natural Surface - level	0.23	50%	8.06	6.00
Standard NEC Gravel - level	2.43	50%	10.14	7.91
Double Otta Seal	9.10	60%	10.81	8.60
Engineered Natural Surface - hilly	0.23	50%	11.82	9.81
Concrete Paving Blocks	14.15	50%	12.20	10.60
Bamboo Reinforced Concrete 125mm	15.22	50%	12.98	12.38
Standard NEC Gravel - hilly	2.43	50%	13.90	12.53
Bamboo Reinforced Concrete 150mm	17.74	60%	14.46	13.16
Sand Seal	6.27	50%	15.75	13.39
Single Otta Seal with Sand Seal	7.69	60%	16.50	15.27
Geocells 75mm	18.83	40%	17.12	17.15
Geocells 100mm	23.46	50%	20.23	20.78
Geocells 150mm	32.37	60%	26.69	28.18

As noted above the results presented in Table 6 must be viewed with caution since they are based on the tendered prices from just one contractor from which to draw conclusions. . 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.

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 will only 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. As mentioned above, under the constrained maintenance funding, it is unlikely this will be implemented.

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 when 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 then NPVs at 6% and 10% become USD 7.30 and USD 7.53 respectively. Although the NPV remains higher than the hand packed stone surfaces it is clearly competitive when one considers the ease with which a much superior finished surface can be constructed.

3.4 Selection of Pavement Type

During the construction of the trial pavements it became apparent that some pavement structures or surface types are more appropriate in certain circumstances. For example, the sand sealed surfaces are only appropriate for low traffic volumes on flat undemanding terrain primarily providing a comfortable ride with little dust pollution. By contrast, the hand packed stone, which results in a rough but readily maintainable surface is likely to be more appropriate on very steep sections of road which would otherwise be impassable in the wet season. However, it has become clear that the EOD/SID design philosophy requires that substantial time in the field by experienced Engineers to select a suitable pavement structure each short length of problematic road in order to overcome the particular problems at that spot in the most appropriate and economic way. This can also be achieved by local engineers who have a good knowledge of the local road network and available materials, providing they receive training in the EOD/SID approach.

In order to allow some comparison with other work a simplistic table has been completed for the nine pavement structures trialled in SEACAP 17 as shown in Table 7.

Table 7 Trial Pavements Assessed Against some Key Markers

Pavement Type	Key Markers									
	Local Materials	Flat Terrain	Steep Terrain	Populated Areas	Marshy Areas	Weak Subgrades	Small Contractor Suitability	Labour Based	Likely Cost Advantages	Maintenance Reduction
Standard NEC Gravel Pavement	✓	✓	✗	✗	✗	✗	✓	✓	✗	✗
Bamboo Reinforced Concrete	✗	✓	✓	✓	✓	✓	✓	✓	✗	✓
Geocell	✗	✓	✓	✓	✓	✓	✓	✓	✗	✓
Mortared Stone	✓	✗	✓	✗	✓	✓	✓	✓	✓	✗
Hand Packed Stone	✓	✗	✓	✗	✓	✓	✓	✓	✓	✗
Concrete Paving Blocks	✗	✓	✓	✓	✓	✓	✓	✓	✗	✓
Sand Seal	✗	✓	✗	✓	✗	✗	✓	✓	✓	✗
Otta Seal	✗	✓	✓	✓	✓	✓	✓	✓	✓	✓
Engineered Natural Surface	✓	✓	✗	✗	✗	✗	✓	✓	✓	✗

Note: ✓ Positive advantage

✗ Probable disadvantage

The more expensive, robust pavements will require less maintenance than the cheaper options. The concrete pavements are advantageous in all situations, but may be found to be so expensive that they are never applied. The real conclusion, based on this work and the work in Vietnam, is that all practical construction options should be investigated and considered during the design and the most suitable for the particular area selected.

4 MONITORING

Monitoring is being undertaken in two phases. Initially a complete set of base data was gathered on completion of the road construction. This will be followed by regular monitoring to evaluate pavement performance against the base data. On completion of the trial sections a series of base-line measurements were conducted as follows:

Visual Inspection and Surface Condition Logging

- 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[ix]., and;
- Graphic representations of the surface of the trial sections.

Photographic Logging

- Photographic logging based on the beacons alongside the road. The surveyor photographs each segment of the trial section including the beacons ensuring that the beacons are in the centre of the photograph. Although this provides no data for analysis, it does allow visual comparison of the surface condition with future photos.

Surface Deformation Recording

- Surface deformation recording rut measurements using a 3 m straight edge. 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
- Surface roughness using a MERLIN apparatus. The roughness was measured approximately along the wheel-paths on each trial section in both directions. The International Roughness Index (IRI) has been determined for each trial section.
- 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 is a standard test to determine skid resistance, which is relevant on steep slopes when considering the breaking and stability of locally made vehicles.

Other

- Classified traffic counts, 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. 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.
- Structural integrity using a Dynatest 3031 LWD Light Weight Deflectometer.

It is envisaged that, in order to allow data to be compared throughout the SEACAP initiatives, the SEACAP 17 pavements will be monitored using the same methods as those used in SEACAP 27.

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 and the method will have to be changed in subsequent surveys.

5 CONCLUSIONS AND RECOMMENDATIONS

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 time in the field during the design stage 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 such as the destruction of the survey beacons used for profile measurement.

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.

The local government offices 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. However, maintenance of the roads will depend largely on the willingness of the communities to contribute their labour and on the government providing technical support and budget support when necessary. To date there is no history of such community participation in the project area. The LSRSP3[x] Basic Access Component has investigated the use of voluntary community participation in road construction and maintenance but it is not yet certain that this will provide a sustainable maintenance system.

5.2 Pavement Options

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 constant traffic on steep gradients or high erosive conditions.
- Concrete block paving, concrete pavements and bituminous bound pavement construction can be undertaken successfully by small scale contractors, as the technology required is common and does not require sophisticated equipment, using imported and local materials. These initially expensive pavements are expected to result in sustainable pavements with reduced maintenance needs.
- Hand Packed or Mortared Stone Surfaces appear to offer the best value for money and due to their labour intensive construction process are appropriate 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. The standard of surface should improve as the community gains experience and will

be better with mortared rather than hand packed stone.

- Otta seals can be constructed using natural gravel which is out of specification for normal surface dressed pavements. It produces 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, provided that a bitumen distributor is available, but does require labour intensive care during construction.
- The construction process for Geocells and Non-Reinforced Concrete pavements is suited to small scale operations as concrete can be prepared in small mixers using local materials. However, the success of Geocells will depend on the local availability of the geocell fabric or identifying sources for its importation. Three thicknesses of the Geocell pavement were used in the trials. These were less than that of concrete slabs however cost savings from the reduced pavement thickness could be negated by the cost of the plastic Geocell form. The success of the thin Geocell pavements will be determined during the monitoring phase.
- Double Otta Seals, Concrete Blocks (on light gradients) and Concrete pavements can be applied to steep gradients and sharp corners where traffic action on the surface is most severe. These pavements are also suited to high traffic volumes, which increases their potential use throughout the road network. Sand Seals and Single Otta Seals are ideally suited to urban conditions with low traffic where dust from gravel roads is unacceptable.

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. This 'Spot Improvement' pavement design philosophy should be applied as widely as possible given a shortage of funds to provide improved pavements throughout the road length.

All of the pavements and surfaces, 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.

5.3 Contractual Issues

The SEACAP 17 contractor's staff had insufficient communication skills to benefit properly from the training given. Clear communication was found to be extremely difficult due to the entire staff being Chinese

Problems were found when applying a research project to a commercial contractor. Understandably, the contractor had little interest in the research and was primarily concerned with his costs and 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.

Some specifications were found to be inappropriate when applied in Lao PDR, for example achieving the shape of hand knapped stone for Hand Packed or Mortared Stone Surfaces due to the available skills and level of supervision. The use of high quality concrete and bituminous surfaces was also inappropriate and these specifications have now been modified.

5.4 Long Term Performance

Section 2.2 of this paper raises four issues relating to the performance of the pavements which cannot be answered at this early stage as it must be seen how they deteriorate over time under the effects of the environment and traffic. The results will become apparent during the monitoring period.

5.5 Pavement Cost and Gradient

Regarding the increased cost of reducing gradients being covered by savings in pavement construction costs, this will depend on local conditions and costs. The monitoring stage should identify pavements that perform well on steep slopes. For future road projects, each case must be assessed independently and the costs of alternative pavements compared with the cost of earthworks.

5.6 Recommendations

During the course of this project the importance of incorporating local materials and expertise has become apparent. Substantial effort should be concentrated during the design phase to ensure that poor and good sections of the road are identified and the correct pavement solutions applied.

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.
- Future contracts clearly require local labourers, artisans and technicians to be employed. In the future these trained labourers will be able to construct other roads and to maintain existing roads.

Not only does this have positive economic bearing on the local community, but also provides a sense of ownership and ensures that the expertise created through training is not lost from the area.

In order to keep a road open throughout the year in is necessary to manage the water during the wet season, this can be done by:

- The hydrology of the project area should be studied properly to allow a detailed drainage design to be conducted. The proper management of water will prevent weakening of the pavement structure due to ingress of water and erosion of the surface due to poor side and cross drainage;
- Detailed assessments of slopes where they cannot be avoided will allow proper engineered solutions to be implemented reducing the chances of slope failures during the wet season.
- Optimal pavement structures should be selected which use local materials and expertise as much as is practicable. Robust pavement structures should be applied to problematic spots while more simple pavements are applied to the easy lengths;

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 are 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 possible land acquisition costs.

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.

6 REFERENCES

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

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

[iii] ***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*

[iv] ***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, 2008*

[v] ***Structural Design of Flexible Pavement for Interurban and Rural Road,*** *TRH 4, Committee of State Road Authorities, CSIR, Pretoria, South Africa, 1996*

[vi] ***SEACAP Knowledge Exchange Workshop,*** *Vientiane, December 2005*

[vii] **Behaviour of Engineered Natural Surfaced Roads**, Technical Paper No.1, SEACAP 19, Development of Local Resource Based Standards, November 2007

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

[ix] ***Pavement Condition Monitoring of the Rural Road Surfaces Research in Vietnam,*** *SEACAP 27, Ministry of Transport Vietnam, 2007*

[x] ***Lao Swedish Road Sector Project 3,*** *Sida funded project, Department of Roads, Ministry of Public Works and Transportation, Lao PDR, 2007*