LOW COST ROAD SURFACING (LCS) PROJECT

LCS WORKING PAPER No 13

REPORT ON PUOK TRIALS CONSTRUCTION

by

Fergus Gleeson, B Eng. M Eng.

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Intech Associates
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THE LOW COST ROAD SURFACING INITIATIVE

The Low Cost Road Surfacing (LCS) initiative aims to provide documentation and international guidelines on the provision and maintenance of low cost road surfaces and basic access for rural communities in economically emerging and developing countries (EDCs). It is based on a research project funded principally by the British Department For International Development (DFID) under its Knowledge and Research (KaR) programme. The initiative is led by UK-based specialist consultants Intech Associates. Collaboration is being established with a number of organisations with interests or experience in the sector, including CSIR, TRL Ltd, ILO/ASIST Africa and Asia-Pacific, the ILO-SIDA funded Upstream Project and Ministry of Rural Development Cambodia, WSP International, Ministry of Transport Vietnam, Greater Mekong Sub-region Academic Research Network, The Institute of Technology of Cambodia, Chieng Mai University Thailand, and the Committee C20 (Appropriate Development) of PIARC (World Road Association) and the International Focus Group (IFG). The LCS programme is being implemented over a 4 year period from 2001 to 2004.

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

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

INTERNATIONAL FOCUS GROUP

TRL is currently carrying out a number of research projects on low volume sealed and unsealed roads for DFID and other Donors. Intech Associates is carrying out research on low cost surfacing with a number of partners. As part of these projects, an International Focus Group (IFG) has been established. The main function of the IFG is to thoroughly examine technical, economic and social issues arising from the project work. The group will also provide a focus to improve opportunities for dissemination of project results. The IFG being developed will comprise technical experts and engineers from a number of African, Asian and other countries as well as other international experts. Participation in the IFG will provide opportunities to:

- *build regional and international partnerships*
- *exchange ideas, experiences, information and data*
- *strengthen local knowledge with new information*
- *build on existing local research*
- *promote wider acceptance of the projects themselves*

Four projects listed below, are of particular interest to the IFG. Projects 1, 2 and 4 are part of the DFID's Knowledge and Research programme, whilst Project 3, is a collaborative research project involving a number of different donors:-

Project 1: Reducing Whole Life Costs: Environmentally Optimised Design
Project 2: Minimising the Cost of Sustainable Basic Rural Road Access
Project 3: Engineering Standards for Labour-based Roads
Project 4: Low Cost Road Surfacing

This Working Paper is intended to inform and provoke discussion, contributions and dissemination. The LCS Project welcomes dialogue with engineers, managers, organizations, communities and individuals active or interested in the rural transport sector with the objective of the promotion of a sustainable rural access approach for EDCs.

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

The ILO Upstream Project, Cambodia

This ILO managed programme has been supporting Royal Government of Cambodia to develop capacity and systems for the efficient application of local resource based road works. The programme has been funded principally by SIDA. Initiatives have included policy development, systems development, capacity building in the road sector ministries, educational and professional bodies.

First Edition April 2003

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ACKLOWLEDGEMENTS

The Puok Market Trials have been a remarkable cooperation between the stakeholders and professionals interested in developing low cost sustainable solutions for rural access to poor rural communities in Cambodia. Special thanks are due to the organisations and individuals who have contributed to making the initiative a success. It is not possible to mention everybody, however substantial contributions have been made by Samer Al Fayadh, Mustafa Azam, Excellency Ngy Chanphal, Fergus Gleeson, Pol Hot, Heng Kackada, Taing Bun Kheang, Mour Kimsan, Excellency Sous Kong, Sok Nith, Robert Petts, David Salter, Minh Savath, Hun Savuth, Kim Sean, Lim Sidenine, Ms. Ham Sina, Pal Soun, Than Vuth, Doekle Wielinga.

Abbreviations

ASEAN – Association of South East Asian Nations
CAFEO – Conference of the ASEAN Federation of Engineering Organisations
CSIR – Council for Scientific & Industrial Research
DBST – Double Bituminous Surface Treatment
DFID – Department For International Development
EDC - economically Emerging and Developing Country
GMSARN – Greater Mekong Sub-region Academic and Research Network
IFG – International Focus Group
IFRTD - International Forum for Rural Transport and Development
ILO/ASIST - International Labour Office/Advisory Support Information Services & Training programme
IMT – Intermediate Means of Transport
ITC – Institute of Technology of Cambodia
ILO – International Labour Organisation
LCS - Low Cost (Road) Surfacing
PRIP – Provincial and Rural Infrastructure Project
SBST – Single Bituminous Surface Treatment
SEILA – a rural development programme named after the Khmer for foundation stone
SSC – Small Scale Contractor
TRL - Transport Research Laboratory
vpd - vehicles per day

Key Words: Rural Road Surface Trials

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REPORT ON PUOK MARKET TRIALS CONSTRUCTION, SIEM REAP, CAMBODIA; experiences and knowledge gained through the construction of the trial sections of paving techniques being investigated under the LCS Project.

By Fergus Gleeson, Research Engineer.

1. INTRODUCTION

The Puok Market paving trials have been constructed under a cooperation initiative between Intech Associates, ILO Upstream Project, Ministry of Public Works & Transport and Ministry of Rural Development, Cambodia. The trials were constructed in early 2002 by two local contractors: Minh Savath and Taing Bun Kheang using the minimum of equipment and the maximum input of local unskilled and skilled labour. The trials planning and construction was supervised by a team led by Fergus Gleeson. The trials were funded by DFID under the Knowledge and Research programme R7782 (Low-cost, labour-based Paved Roads for Poor Communities). Further information on this initiative may be found on the website www.transport-links.org.

The aim of the paving trials was to investigate and demonstrate the construction of a range of paving techniques as an alternative to gravel/laterite, suitable for secondary and minor roads using local-resource-based techniques wherever possible. The trials will also be the basis of assessing whole life costs of the various paving options. The rationale for investigating alternatives to gravel/laterite are contained in LCS Working Paper No 1[1].

The construction of the Puok Market trial sections was completed in July 2002, with the exception of sand seals for trial sections 2 and 4, and some minor finishing works. It is planned that the 'second seals' for sections 2 and 4 will be added as a 'stage construction strategy' at a later date. There have been minor modifications to the original designs throughout the construction phase and these have been documented in weekly site reports (Progress Reports 1-14, Fergus Gleeson). There have also been slight deviations from the original specifications that were deemed necessary by the site engineer in consultation with ILO engineers and Mr. Robert Petts, Principal, Intech Associates, the project manager. These are also detailed in the weekly progress reports. Details of knowledge gained from the construction phase are also documented here.

2. BACKGROUND

Gravel has been used as the usual form of surfacing for rural roads in many countries, including Cambodia. This indiscriminate application of gravel, due to its low initial investment cost, is an attempt to maximise the impact of limited available funds for the construction of rural roads. Unfortunately it has resulted in an unmanageable maintenance burden for the Government and people of Cambodia. Maintenance of gravel roads has been estimated to cost US$1,600 per kilometre per year by a recent study based on years of experience in the sector by the ILO Upstream Project in Cambodia[2]. With an estimated 28,000km of tertiary roads to be maintained and a limited maintenance budget, these roads rapidly fall into a state of chronic disrepair.

[1] Rationale for the Compilation of International Guidelines for Low-Cost Sustainable Road Surfacing (LCS) Working Paper No1, R C Petts, 2001.

[2] Cambodia MRD/ILO Upstream Project, Rural Road Investment, Maintenance and Sustainability, A case study on the experience in the Cambodian Province of Battambang, May 2001.

Gravel is a wasting material. It is worn away by traffic in the form of dust and washed away by high intensity rainfall. Road authorities in South East Asia expect a rural road regravelling cycle to be typically about 3 years for an initial gravel surface thickness of 200mm[3]. Hence up to US$15,000 per kilometre must be invested every three years depending of replacement materials availability. Furthermore natural gravels may often be of variable or dubious quality, which can render them even more susceptible to high intensity rainfall and traffic wear. Some natural gravels can pass normal construction quality tests, but break down in service under the action of weather and traffic. The problem, as such is compounded by the fact that natural gravels are a finite natural resource. Therefore the cost of gravel is rapidly increasing as supplies are depleted and haulage distances increase. Clearly the current situation is neither economically or environmentally sustainable. In addition there are dust and health issues related to the use of gravel as a road surface material.

It was against this background that the Low Cost Surface (LCS) Project was initiated to seek alternative solutions to gravel. The implementation of this project resulted in the construction of 10 trial paving sections designed with careful consideration of life cycle costs and to be constructed using local-resource-based methods and small scale contractors (SSC). The 10 trial sections constructed were as listed in Table 1.

Table 1: List of trial sections constructed under the LCS Project

Section No.	Section Type	Section Length
1.	Bamboo Reinforced Concrete Pavement	20m
2.	Sand-Aggregate Roadbase & SBST* & Sand Seal	100m
3.	Dressed Stone Pavement	50m
4.	Armoured Laterite Roadbase & SBST & Sand Seal	100m
5.	Dressed Stone Pavement & Bitumen-Sand Seal Joints	50m
6.	Sand-Aggregate Roadbase & SBST	100m
7.	Telford Pavement & SBST	100m
8.	Water Bound Macadam & DBST**	100m
9.	Armoured Laterite Roadbase & Sand Seal	50m
10.	Hand-Packed Stone & Laterite Wearing Coarse	50m

* SBST = Single Bituminous Surface Treatment (single chip seal), ** DBST = Double Bituminous Surface Treatment (double chip seal)

3. PREPARATION AND MANAGEMENT FOR THE TRIALS

The inception, preparation and management of the trials were carried out from the ILO Upstream Project office. This involved the initial planning, design and compilation of specifications and standards to be trialed, and preparation of the contract documents to be used to engage two local contractors. These contractors had previously been trained by the ILO Upstream Project in labour-based road construction and maintenance. The specifications and practices used in other countries was reviewed and adapted where necessary for application in Cambodia. Following this preparatory work, the construction phase of the project was initiated. The purpose of this research work was to gain and document knowledge of the various paving techniques in the local environment.

[3] Gravel surface wear rates depend on a range of factors.

The issue of introduction of new techniques was carefully planned. Consideration was given to the nature of the new approach; use of indigenous resources and labour-based appropriate technology in a developing country with serious human resources deficiencies (numbers of trained and experienced personnel), coupled with overall funding constraints. This led to the decision to orientate the learning process to be a predominantly an on-site process.

The benefits of this approach soon became apparent when the field work began and was reinforced with each passing day of work. Issues arose and had to be discussed and resolved on site. Many of these issues would have been difficult to foresee.

It was also important to document work as it was carried out rather than after the work had been completed. The goal of the trials necessitated a flexible approach to difficulties encountered in order to successfully overcome them in a financially and socially acceptable manner. Hence modifications were made to initial designs and deviations from initial standards and specifications agreed through scientific consideration of engineering problems and consultation with the various parties. These may be pointed to in veneration of the knowledge gained through the project rather than looked upon as compromising the goal of the project.

On initiation of work on site, solutions had to be found on a daily basis for problems posed. Such is the nature of engineering, particularly in developing countries and with the introduction of new techniques. A flexible approach was taken, relying on a pool of engineering knowledge, and allowing solutions to be found and agreed.

Supply of materials to site was regularly checked by the site engineer. However the long haulage distances (up to 130km for crushed stone aggregates and up to 50 km for laterite[4]), resulted in a some of the materials being supplied at night. These materials could only be checked by the site engineer after a large proportion of the required quantities had been delivered. This was not a satisfactory situation but could not be changed simply due to the haulage distance and lack of communications with the supply locations, and lack of testing facilities there. Samples could not be pre-delivered since the small scale contractors could not afford the time or expense of having their chief site technicians travel for 2 days. This would also lead to a 2 day delay of works on site. The quantities of specific materials being delivered were generally modest. Obviously this was difficult for the site engineer. For some materials, it was possible for samples to be supplied. Samples were obtained by contractor MS[5] and brought to site for inspection by the site engineer. Samples were obtained for dressed stone and aggregates for seals and concrete. However this was the exception rather than the rule and more often than not, material was delivered to site without prior inspection. Obviously the contractors had been given contract documents inclusive of detailed specifications and standards. These documents were in English, the official second language of Cambodia. The site technicians had been trained as engineering technicians by a previous ILO project. Hence they had a reasonable knowledge of the language and labour-based techniques. The contract documents were typical of the type used by the ILO Upstream project and so the technicians were familiar with the format. Thus it had been thought that adequate measures had been taken to ensure that the appropriate standards and specifications had been communicated to the contractors. It transpired at a later meeting

4 One of the aims of the local-resource-based approach is to utilise material resources close to the road site. However to enable demonstration of a range of techniques, materials were brought to a convenient location for the testing and demonstration function. The haulage component would be later taken into consideration in the costing processes.

5 Mihn Savath is referred to as contractor MS and Taing Bung Kheang is referred to as contractor TBK throughout this report and\also in previous weekly reports

with contractor TBK that the contract documents had not been read by the site technician because his English comprehension was not sufficient. Thus a situation existed where a vague understanding of the documents was coupled with night time delivery of materials without prior inspection of a sample in many cases. This inevitably led to delivery of materials above, below and in one case completely alien to the standard required. Steps were taken by the site engineer to alleviate the confusion of the site technicians representing the contractors. Since the site technicians had not constructed the type of roads being examined by the trials they had limited knowledge of the type of materials and quantities required. The site engineer calculated quantities, explaining compaction factors for each material and the type and standards for each particular material. This was done at the onset of the construction phase. It was inevitable that the site technicians would sometimes make mistakes. Indeed a goal of the trials was also to train two SSC while constructing the trials, developing knowledge and competence. Contractor TBK had materials delivered to site which did not meet the specified standards, as did contractor MS. With a haulage distance of 130km and the fact that these were trial contracts, the site engineer sought a solution that would utilise the delivered materials. In most cases this simply meant modifying materials (i.e. crushing aggregates on site or screening aggregates to force the grading) on site or mixing materials prior to use or during construction. Details of the processes employed are given in the proceeding paragraphs.

In some cases the initial design had to be modified for reasons which only came to light during the construction phase and could not be foreseen. These modifications were for the betterment of the trials and induced by an appreciation of country specific knowledge gained through consultation with stakeholders. The initial 9 sections planned for construction were thus increased to a total of 10 sections. The additional design was Telford pavement, a *pre-Macadam* technology. It was decided to construct this section a few weeks after the initiation of the works when difficulties were experienced in obtaining well graded aggregates required for standard water bound macadam. Other modifications to designs are detailed in the proceeding paragraphs.

4. RECORDING OF DATA

Recording of data on site during the construction phase of the trials was carried out on a daily basis through the site control sheets. These were filled in by the counterpart technicians from the Ministry of Public Works & Transport and the Ministry of Rural Development. The amount of labour, materials and tasks carried out per day were recorded on these site control sheets for every process of the construction of each section. As well as keeping these daily records, Dynamic Cone Pentrometer (DCP) readings were taken for the subbase layer after compaction. These were converted to California Bearing Ratios (CBR) using the regression equation provided by the manufacturer of the DCP apparatus. DCP readings will be taken for the subgrade as a follow-up activity and converted to soaked CBR values for the subgrade material. In addition to this levels were taken to record the thickness of each pavement layer as it was constructed. Thus drawings of the as constructed trial sections showing longitudinal gradient as well as cross sections may now be compiled.

Photographs of the construction processes were also taken at regular intervals and the operations on site were recorded on video at regular intervals during the week. This video footage shall be compiled into training material at a later date.

The socio-economic team visited the site on several occasions during the construction phase to interview workers in relation to social and environmental aspects of the trials. The road users and local residents will also be interviewed in the future. This information will be compiled in the form of a socio-economic report detailing social, economic and environmental aspects of each trial section.

There will be a programme of separate surveys and monitoring measurements which will be the subject of a separate report.

5. CONSTRUCTION OF THE TRIAL SECTIONS

Detailed descriptions of operations on site may be found in the weekly progress reports compiled by the site engineer during the construction of the trials. An overview of the construction of each section detailing difficulties encountered and overcome follows. The lessons learnt are in effect now being presented. A primary role of the trials was to determine the construction restraints when applying labour-based ("local-resource-based") methods to the various pavement types.

5.1 PREPARATION OF SUB-BASE LAYER

All trial sections were constructed on a 100mm thick sub-base layer of good quality well compacted laterite gravel. Prior to placement of the sub base layer the in situ laterite thickness was measured and the site was surveyed. The existing route had previously been gravelled, however most of the gravel had been worn away or contaminated by the in situ clay material. The laterite remaining on the road prior to construction was found to be very thin, 3cm in some places. Thus an additional layer of laterite was constructed for sub base. The contractor opted to use additional laterite rather than reshape the sub grade since the existing layer of laterite had hardened considerably and the labour cost would have been quite extensive. The contractor TBK was also behind schedule and wished to save time.

The source of the laterite was Phnum Dei, 50km from the trials site[6]. This laterite borrow pit was an approved source of laterite for road construction purposes used by the ILO Upstream Project at the time of construction. The laterite was spread, watered and compacted in a single layer of 100mm thickness. The contractor TBK used additional laterite under his own expense and with the agreement of the site engineer to fill any low points.

The soaked CBR for the subgrade could not be recorded accurately before the construction since it was the end of the dry season and the soil had hardened considerably. It was felt that soaking the soil on site would not produce accurate results and soaked CBR values will be recorded during the monitoring phase using DCP apparatus. Previously the site measured CBR for the subgrade soil in the area was recorded as 7. This value was recorded during the construction of the bamboo reinforced concrete pavement around Puok Market. With such a low CBR subgrade it was deemed necessary to construct a sub-base layer. The sub-base is an important load spreading layer in the completed pavement. It enables traffic stresses to be reduced to acceptable levels in the subgrade, it also acts as a platform for the construction of the upper pavement layers and it acts as a separation layer between the subgrade and roadbase (Reference 1).

5.2 SECTION 1: BAMBOO REINFORCED CONCRETE PAVEMENT

Section 1 was the shortest of the trial sections, being only 20m in length. Bamboo reinforced concrete pavement had been constructed in a successful trial at the site 2 years previous. The data gathered from this later trial is simply to document the method and as a demonstration project. A report detailing the experiences of the previous 2-3km trial at Puok market is published separately (Reference 2).

[6] The long haul distance (typical for Cambodia) illustrates the problems associated with this type of surface in Cambodia. Road builders are forced to haul typical construction materials for excessive distances with serious cost and haulage route damage implications.

5.3 SECTION 2: SAND-AGGREGATE BASE & SBST & SAND SEAL

The sand-aggregate roadbase of section 2 was the first completed base layer at the trials site. Although the aggregates were proportioned correctly using boxes of a specific volume, there was found to be an abundance of sand at the surface of the layer. This lead to difficulties in achieving adequate compaction. The layer was compacted using an 8 tonne roller but to no avail. The grading of the crushed stone aggregate used for the construction of this layer was rounded and contained very little larger (than 35mm) particle sizes. For this reason it was very difficult to attain aggregate interlock. Although less stringent grading is required for this type of road base than for water bound macadam, roughly downgraded aggregate with an angular particle shape, as was used for section 6, has been found to be preferable. It was also found for this section that correcting the fault when it was realised was quite time and labour intensive. However if the roadbase was constructed with adequate aggregates construction time is greatly reduced and very little work is required to prepare the surface for the application of a bituminous surface treatment.

Repairs to the upper portion of the roadbase were carried out using broken stone resulting from dressing the stone for section 3, dressed stone pavement. This demonstrates how relaxed the grading requirements actually are and that particle shape has a more pronounced effect. The stone resulting from the dressing processes was for the most part of large size and was also flat-faced and angular. The top 100mm of the roadbase was mixed with this stone and the voids on the surface were filled with crusher dust (6mm down). Crusher dust was used simply because the contractor MS had an excess on site at the time. The voids could easily have been filled with sand although the surface that resulted when using crusher dust was very dense and firm. Crusher dust is actually quite expensive in Siem Reap (US$12/m^3), its cost depending on haulage distance from Banteay Meanchey Province as per crushed stone aggregate. However it is unlikely that such a firm surface would result from the use of sand and the dense smooth surface was also beneficial to the application of primer and bitumen emulsion. The repairs to the roadbase of section 2 were carried out over a period of 2 weeks. This was simply because the contractor MS relied upon the progress of the dressed stone pavement for materials to be used, under the advice of the site engineer. While this saved money, it was quite time consuming. The exact repair work required could have been carried out in a much shorter period of time, possibly 1 or 2 days if the materials were readily available on site.

Once the surface was deemed to be firm enough by the site engineer, the contractor MS was instructed to apply the prime coat. When section 2 was sealed the rainy season had well and truly arrived. The weather was predictable however and it tended to be dry and hot during the morning with heavy rain storms occurring at approximately midday. Obviously the surfaces had to be sealed and so work was begun as early in the morning as possible. The surface was brushed to remove any loose material. Following this the bitumen emulsion prime coat (grade CSS1) was applied in the manner detailed in the weekly progress reports. As occurred for all sections, an unexpectedly long time was required for the prime coat to break or cure. This was not foreseen and the breaking time of not less than 2 days seemed excessive. The manufacturer was consulted. The addition of water apparently increased the breaking time. It was also possible that since the prime coat was being rained upon after application and prior to application of the main bitumen emulsion seal, that the curing time was increased by the constant exposure to moisture. The high humidity also probably retarded the emulsion evaporation and breaking speed. Application of the main seal bitumen emulsion at a spread rate of 1.6Kg/m^3 for the single bituminous surface treatment was carried out once the prime coat was deemed to be sufficiently cured by the site engineer. The contractor MS obtained very good quality cubical aggregate of 12-14mm nominal size and very little shape and gradation variation for use in the chip seal. The high quality aggregates has resulted in possibly one of the better surface treatments at the trials site. Uniform particle shape and size is essential in allowing the bitumen emulsion to work its way up through the aggregate and create a uniform seal. Bitumen spread rates are also determined under the assumption of uniform chip size and shape and as such the performance of the seal will be directly related to the quality of aggregates used. Furthermore uniformity of chips is important in producing a relatively smooth surface when a second seal is to be applied over the first. A sand seal was initially planned to be placed over the single chip seal of section 2.

It was decided after a number of trial areas had been carried out as well as the construction of a single sand seal on section 9 to delay the application of sand seal. A number of difficulties were encountered and it was thought to be prudent to reconsider the application of sand seal. The sand seal which was constructed on section 9 was found to be less than satisfactory after construction. The sand was applied directly after the bitumen emulsion and rolled immediately. There was a minimal delay between application of emulsion and application of sand and rolling. However a good bond did not develop between the emulsion and the sand. Coarse sharp river sand was used for the sand seal. The sand contained many larger particles and was quite rough in texture. It was thus deemed suitable by the site engineer. Attempts were made to rectify the situation after construction by allowing traffic to pass over the sand seal while constantly reapplying the sand. This yielded little improvement. Following this initial experience, a number of trial sections were carried out in an effort to overcome the difficulties encountered. The sand seal was constructed on a prime coat, not over a chip seal. Thus the sand seal was constructed on a perfectly smooth surface. The design specified spread rate of 1Kg/m^2 could not be achieved due to the high viscosity of the emulsion. The watering can and broom method used meant that a minimum spread rate of 1.5kg/m^2 had to be adopted. Many small areas were tested with different watering can nozzles, new brushes for screeding the emulsion and strict supervision but to no avail. Sections were also tested using sand with immediate rolling and crusher dust with immediate rolling. Neither of these sections proved to be successful. Neither the crusher dust nor the sand bonded with the emulsion. It is possible that the sand derived from sandstone of Siem Reap Province, which is a cationic rock since it is sedimentary in origin, would not bond easily with the cationic emulsion due to the chemistry of the materials. This was the reasoning behind testing the crusher dust as an alternative to coarse river sand. The crusher dust was obtained from Phnum Thom in Banteay Meanchey Province where the stone is igneous in origin and hence anionic. However the bond, while better initially, was not sufficient to keep the crusher dust on the surface of the seal. It is highly likely that the long breaking time of the emulsion, resulting in the emulsion remaining very soft for a long period, was the primary factor affecting the bond between the sand/crusher dust and the emulsion. The emulsion was simply too soft to prevent traffic wearing the sand or crusher dust layer from the emulsion. It was also found that when applying the sand seal over a single chip seal that an extremely high spread rate had to be used. This was due to the rough surface of the chip seal after construction. Thus it was decided to delay the application of a sand seal and reconsider its appropriateness with the materials being used at a later date.

5.4 SECTION 3: DRESSED STONE PAVEMENT

The construction of the dressed stone pavement of section 3 progressed very slowly and was a primary factor for the delay of the overall project. There is little or no stone available for the purposes of producing well dressed stone pavement blocks in Siem Reap. It would therefore not normally be a considered option for surfacing in Siem Reap. In a previous trial carried out by the ILO Upstream Project in Kampong Cham Province (Reference 3) basalt had been used since it was available in abundance in the local area. Basalt is a perfect stone for dressed stone pavement since it is relatively hard, yet relatively easy to dress or shape. The stone available in Siem Reap Province is sandstone. Samples of the varying types of stone available in Siem Reap Province were brought to site by the contractor MS. These included rheolites and sandstones, the majority of which were of very low quality. The rheolites very often contained iron ore as demonstrated by their red rusty constituency and were extremely weak and flaky. The sandstones were more often than not very soft and flaky. One sample of sandstone brought to site was available in larger boulders and appeared to be relatively strong. The site engineer suggested that the stone be tested for soaked CBR, crushing value and Los Angeles Abrasion value. However there were worries about using sandstone to construct dressed stone pavement and the tests were not carried out. However, with further investigations, the use of this stone could provide a viable low cost roadbase solution for Siem Reap Province in the future.

The stone used for the dressed stone pavement was granite from Phnum Thom. This stone was chosen because it broke in clean smooth sheaths, which allowed the contractor MS to dress only 4 faces. This was extremely advantageous since the stone was extremely hard and so very difficult and slow to dress. The stone supply was irregular due to difficulties of the quarry operators in understanding the contractor MSs' requirements, and wet season access problems. This included the failure of a Bailey bridge on the route. The site supervisor of contractor MS had to travel to the quarries on several occasions to clarify the situation by choosing the stone to be used himself. The stone blocks were placed on a 50mm compacted sand layer with pre-constructed continuous filter drains and restraining shoulders. They were then packed together by wedging stone pieces (resulting from the dressing process) between the joints using 5Kg hammers and steel pegs. The voids in the joints were then filled with coarse sand.

5.5 SECTION 4: ARMOURED LATERITE ROADBASE & SBST & SAND SEAL

The roadbase constructed for section 4 of the trials consisted of 180mm of laterite armoured with a dense roughly downgraded crushed stone (i.e. crusher run stone with a maximum particle size of 35mm) armouring layer of 70mm compacted thickness. The laterite was placed, watered and compacted in two layers since the overall thickness exceeded 150mm. The crushed stone armouring layer was then placed and compacted over the laterite layer. A larger volume of water was applied to the armouring layer prior to and during compaction such that the armouring layer would penetrate the laterite and a single roadbase layer would result rather than a stratified layer. The penetration of the crushed stone into the laterite was checked by the site engineer and found to be 20-30mm in depth. This was deemed adequate to ensure the two layers would remain strongly bound together during service, due to the 35mm downgraded aggregate size used for the armouring. The surface of the crushed stone upper portion of the roadbase required some repair work prior to application of a prime coat and a surface treatment. This was carried out using crusher dust. A firm solid surface resulted. However the repair work was found to be extremely time and labour intensive. There was found to be problems in particular at the outer edges of the carriageway next to the shoulders. This was possibly due to a combination of in-homogeneity of the materials used to construct the crushed stone armouring layer and a lesser degree of compaction at the outer edges where only the outer half of the roller was allowed to bear on the roadbase.

Once the surface had been corrected a prime coat was applied to the roadbase. When the prime coat was applied for section 4 there was particularly bad weather and no sooner had the prime coat been completed than it started to rain heavily. The site engineer checked the surface after the rains and it was noticed that a longer breaking time was required for the prime coat. No primer was seen to mix with the rain water however. A similar occurrence was noted for the emulsion when the single chip seal was constructed over the prime coat. The rain water did not mix with the emulsion; however an excessively long breaking time was noticed for the emulsion after construction.

It had been intended that a single sand seal be applied over the single bituminous surface treatment, however the application of sand seal over chip seal was delayed for the reasons previously described.

5.6 SECTION 5: DRESSED STONE PAVEMENT WITH BITUMEN-SAND SEALED JOINTS

This section was constructed as section 3. Work progressed slowly for the dressed stone pavement of section 5 for the same reasons as section 3. The contractor MS had difficulty in obtaining stone for the dressed stone pavement. For section 5, the joints between the stone blocks were filled with a sand-bitumen emulsion seal to produce an impervious surface layer. The joint seal was formed by filling the joints with sand and applying the emulsion to the joints only with a watering can. It is intended that the performance of the two sections will be able to be directly compared.

5.7 SECTION 6: SAND-AGGREGATE ROADBASE & SBST

Section 6 was the first section completed by contractor TBK. The construction period for this section was extremely short. No repairs were required to be carried out, a dense firm surface being achieved after compaction without any defects. This was because good quality aggregate was used as well as a 4 tonne non-vibrating roller followed by a 2 tonne roller with vibration. The roadbase was extremely simple to construct.

After construction of the roadbase a prime coat was applied. The site engineer had some concerns over the depth of penetration of the prime coat into the roadbase. It was noticeable from visual inspection that the primer formed a skin over the surface rather than penetrating into the surface. This was possibly due to the absorptive properties of the sand, the primer being utilised in coating the high surface area of the sand at the surface and hence not being allowed to penetrate the sand to any great depth. Varying dilutions of the primer were tested in an effort to achieve a greater depth of penetration. The primer could be diluted as much as required provided that the manufacturer's un-diluted application rate of 1Kg/m^2 was adhered to. The only adverse affect of increasing the dilution of the primer was an increase in breaking time required before application of the bitumen emulsion. It is possible that a greater depth of penetration could be achieved if coarser sand was used. Since construction was carried out during rainy season, coarse sand was not readily available and a suitable source was difficult to locate. Coarse sand is obtained from riverbeds and hence is difficult to locate during rainy season.

Following application of the prime coat a single bituminous surface treatment was constructed. The stone chips used for the section were not of very high quality and the site engineer had some concerns over their grading and particle shape. Flat and angular chips of varying size were obtained by the contractor TBK. The site engineer ensured adequate rolling of the surface treatment after application of the chips to the emulsion such that an adequate penetration of the chips into the emulsion would occur prior to opening the section to traffic. Construction traffic was then allowed to pass over the section and this aided the emulsion in working its way through the chips and developing a good bond. This was particularly important for sections 6 to 9 where the same stone chips were used for the surface treatments.

Contractor TBK was instructed to screen and wash all stone chips supplied for use in the construction of surface treatments. This was carried out for the purposes of material quality control. While the smaller particles could not be removed, any larger particles (larger than the specified chip size) were removed. Washing of the chips was carried out to ensure that bond between the chips and the bitumen would not be adversely affected by the presence of crusher dust on the surface of the chips.

Box 1: Summary of lessons learned in relation to labour-based sand-aggregate roadbase.

Sand-Aggregate Roadbase

- *Aggregate Grading:* Although aggregate grading is not required to be as stringent for sand-aggregate roadbase as for other crushed stone roadbases, a lack of any grading will lead to difficulty in attaining aggregate interlock. This is indicated by a seemingly excessive amount of sand in the mix proportion even though the mix has been proportioned correctly. Aggregate should be roughly downgraded (as per crushed stone roadbases). The best results were obtained for crusher-run aggregate used on trial section 6.

- *Aggregate Shape:* Aggregate shape has been found to be important in reducing the compaction effort required to achieve a densely interlocked matrix. Angular particles of irregular shape have been found to be preferable.

- *Compaction:* The originally specified 8-tonne vibratory roller is not absolutely necessary. Compaction of section 6 was carried out to the engineers' satisfaction with a 4 tonne static roller followed by a 2 tonne vibratory roller. It is possible that light compaction equipment is sufficient for the construction of sand-aggregate roadbase. This should be investigated further. Allowing construction traffic to pass over the roadbase prior to sealing is useful in identifying areas requiring spot repairs.

- *Construction Method:* Adequate mixing of the crushed stone aggregate is essential in order to prevent the occurrence of sand-rich soft spots of in-homogeneity which may lead to a localised roadbase failure in the future. This is indicated by areas requiring spot improvement after compaction, where adequate aggregate interlock has not developed. Mixing of aggregate and sand may be carried out using simple hand tools and labour provided adequate site supervision is present for quality control purposes.

- *Repair Prior to Sealing:* Correction of the roadbase after construction may be carried out easily. Where the fault is due to aggregate grading, larger hand broken aggregate has been found to be sufficient to correct the upper layers.

- *Application of Surface Treatment:* It has been found that the penetration of the prime coat was minimal when applying the prime to a sand-aggregate roadbase. This will be verified or disqualified during the monitoring and testing phase of the trial sections. The sand used for the roadbase was fine sand and it is probable that a large volume of emulsion was utilised in coating the large surface area of the fine particles on the surface. Higher dilution rates (20%, 30%, 40% and 60% water) had very little effect and extended the breaking time of the prime coat. The prime coat effectively formed a skin over the surface of the road base. The penetration of the prime may possibly be improved through the use of coarse sand. The onset of rainy season and a lack of experience with the construction method didn't allow for this to be tested at the trials site.

5.8 SECTION 7: TELFORD PAVEMENT & SBST

It was decided to construct this section after construction of the water bound macadam of section 8 had begun. The lack of good quality well graded aggregate was noticed and hence a solution was sought through the application of Telford construction methods. Telford's alternative method of making a roadbase, with small boulders coarsely dressed to the shape of elongated pyramids and keyed in place with small stones was proposed as an alternative to John Loudon Macadam's precept that no stone be greater than one inch in diameter during an era when labour was used to crush the aggregates. It was revived for the trials in an attempt to modify the design such that the SSC could employ more labour and less compaction equipment in the construction of a roadbase layer. It should also be noted that the pavement is more resilient to absolute neglect and lack of maintenance since the larger boulders and the majority of the overlying macadam will remain on the road for a longer period and hence the pavement will retain a greater portion of its original value. Given Cambodian conditions this is a distinct advantage.

5.9 SECTION 8: WATER BOUND MACADAM ROADBASE & DBST

Construction of the water bound macadam roadbase consumed considerable amounts of time and labour. Contractor TBK had to rework the section many times. The aggregates that contractor TBK had delivered to site did not correspond to the specified grading envelope. Difficulties arose when trying to force the grading onsite. The contractor was required to mix various aggregates as well as crushing some aggregates on site. However the mixing of aggregates was not carried out satisfactorily and the roadbase layer could not be compacted to an acceptable degree. In effect the poor grading and largely single sized and rounded aggregates made any degree of compaction very difficult to achieve. The section was completely remixed in an attempt to rectify the grading to some extent at least. Remixing of the section caused very little improvement in roadbase and the surface remained loose and unbound, even after the addition of crusher dust to the surface. The problem was compounded by a lack of larger size aggregates in the upper layer. Thus it was very difficult to attain the aggregate interlock from which water bound macadam draws its strength. The entire layer was remixed, to a sub base depth. This helped to a certain degree in that larger aggregate particles were mixed through the layer. However it was still deemed necessary to add gravel to the layer in a further attempt to force the grading of the macadam. This effort was successful and the gravel sized particles as well as the fines aided in adequate interlock of aggregates being developed. The fine particle sizes had to be brushed from the surface after construction, prior to application of prime coat. The high PI fine particles could have had an extremely adverse effect on the roadbase and overall pavement performance if a failure of the seal occurred. For this reason the fine gravel particles were cleaned from the surface.

Following construction of the water bound macadam roadbase a prime coat and double bituminous surface treatment was applied. The application rates of 1.6Kg/m^2 for the first layer of the double chip seal and 1.3Kg/m^2 for the second layer could not be conformed to due to the construction method used. A minimum application rate of 1.5Kg/m^2 could only be achieved using the construction method applied. Thus two layer of 1.5Kg/m^2 were utilised regardless of the size of chippings used. 12-14mm stone chips were used for the first layer with a greater number of passes of the roller without vibration being specified by the site engineer. This was carried in order to ensure a smooth surface for receiving the second application of emulsion. Thus an overall emulsion spread rate of 3.0Kg/m^2 was achieved rather than 2.9Kg/m^2 as specified by the manufacturer. 5mm nominal sized stone chips were used for the second layer rather than the specified 8mm. There is a limited variety of grading available in Cambodia and certainly from the quarries of Banteay Meanchey Province. The smaller sized grading with little size variation required for the construction of chip seals are not readily available. For this reason aggregate denoted as having 20/10 grading by the local quarries had to be utilised for the first layer of the double chip seal and for the single chip seals. This aggregate was screened on site. 5mm gravel was then used for the second layer since no 8mm nominal sized aggregate was available. Since bitumen spread rates were calculated on the basis of covering 70% of the area of a single sized aggregate, problems of bleeding were inevitable for the double chip seal. Indeed a few weeks after opening of the trials sections, bleeding was noticed on section 8. There is a need to reassess the method with a view to lowering the spread rate for the purposes of constructing double bituminous surface treatment using bitumen emulsion.

The section shall be treated with crusher dust or more chips to alleviate the situation.

Box 2: A summary of the lessons learned in relation to labour-based water bound macadam roadbase.

Water Bound Macadam Roadbase

Aggregate Grading: Well-graded aggregate is essential for the proper construction of water bound macadam. Forcing the grading on site is difficult and crushing of aggregates by labour may often be required. If aggregate delivered to site does not encompass the entire macadam grading envelope great difficulty may be experienced in rectifying the materials deficiencies. This in turn may lead to time delays and disproportionately large labour costs. It is actually preferable to use hand crushed stone for macadam roadbases in Cambodia since hand crushing results in good particle shape albeit less controlled grading. The trade-off between the two requirements, ensuring at least one is conformed to, leads to a better chance of achieving a good result on site. The following are macadam grading envelopes for machine crushed and hand crushed aggregates. It may be noticed that the grading envelope for hand crushed aggregates is more relaxed, thereby indirectly emphasising the importance of particle shape.

Aggregate Shape: Angular (yet cubical) particle shape is preferable for the construction of water bound macadam. An angular particle shape aids in the compaction of the roadbase since aggregate interlock may develop more easily. Rounded particle shape, even when good grading exists, will require a greater compaction effort and aggregate interlock may not develop in any case. It has been found that hand crushed stone will in most cases possess a satisfactory part

Compaction: Compaction with vibration is beneficial to the development of aggregate interlock. An 8-tonne vibratory roller was specified for the construction of the water bound macadam in layers of 125mm at the trials site. A reduction in size of compaction equipment would necessitate a reduction in layer thickness to be compacted. Vibration also aids in forcing the finely graded particles to move between the voids of the larger particles creating a dense solid layer. Historically water bound macadam has been constructed in a time when vibratory compaction equipment was not available (early 20th century) and so it is possible that an 8 tonne static roller could produce satisfactory results if aggregate grading and particle shape adheres to the specification. Previously water bound macadam has been constructed for the approach slabs of vented causeways by the ILO Upstream Project using an 8-tonne static roller followed by a 1-tonne vibratory roller to force fine particles into the voids between the larger particles.

Construction Method: The water bound macadam road base was constructed in two layers of 125mm. Each layer was compacted separately and the surface was treated with crusher dust to achieve a smooth dense base for the application of a surface treatment. It has been found to be preferable not spread the aggregate using labour since this results in segregation of the aggregate leading to difficulties during compaction and an inhomogeneous roadbase layer.

Repair Prior to Sealing: It has been found that correction of the roadbase was extremely difficult, involving large quantities of labour and an extensive amount of time. Forcing the grading after receiving poorly graded aggregate to site was the major difficulty experienced. Remixing the ensure homogeneity and addition of fine material to force the grading was required. Crushing of aggregate by hand w

Application of Surface Treatment: Few difficulties were experienced in applying a surface treatment to the water bound macadam roadbase. Penetration of the prime coat between the aggregate particles at the surface was noticed to be greater than for other roadbases. A dense solid surface existed prior to application of prime coat.

5.10 SECTION 9: ARMOURED LATERITE ROADBASE & SINGLE SAND SEAL

The roadbase of section 9 was constructed in a similar manner to that of section 4. However better quality aggregate, which was roughly downgraded and included larger sized particles (>35mm), was obtained for the construction of the crushed stone armouring. This allowed the section, which was only 50m in length, to be constructed very quickly with no repair work being required at all. Crusher dust was applied to the surface of the armouring to obtain a smooth surface onto which the prime coat was applied. A spread rate of 1Kg/m^2 was specified for the sand seal by the manufacturer. As was already stated, this spread rate could not be achieved and so a spread rate of 1.5Kg/m^2 was used. The difficulties encountered with constructing a sand seal have been discussed previously. Further study and monitoring of the sand seal constructed at the site will hopefully yield answers as to why the difficulties were encountered.

Box 3: Summary of the lessons learned in relation to labour-based armoured laterite roadbase

Armoured Laterite Roadbase

Laterite: The construction of the 180mm laterite layer was carried out in two layers in a manner identical to standard gravel road construction.

Aggregate Grading: Better results were noticed where well graded aggregate was used. Approximately 35mm downgraded aggregate should be utilised for a layer of 70mm of armouring. Where poorly graded material was utilised, repair afterwards was difficult and time consuming.

Aggregate Shape: The armouring layer is effectively a thin crushed stone layer and as such downgrading should be accompanied by angular particle shape for best results.

Compaction: Because of the thickness of the layer, light compaction equipment was found to adequate. Vibration however is essential. The best results were obtained with good quality aggregate and compaction using a twin drum pedestrian 1-tonne vibratory roller.

Construction Method: Once the laterite layer of 180mm had been constructed the crushed stone armouring layer may be placed and compacted in one layer of 70mm. Water was applied using watering cans to aid the penetration of the upper layer into the laterite below as well as to assist compaction. Water was applied to facilitate this although not to the extent where the crushed stone layer would become waterlogged. It was found that application of crusher dust to the surface was required after compaction. A penetration of the stone into the laterite of depth of 20-30mm was measured on site. Application rates for water should be developed in the future, for a compacted and un-compacted laterite layer. It is essential when constructing this type of roadbase to ensure the quality of the materials used prior to instigation of the w

Repair Prior to Sealing: Correction of the roadbase prior to application of a surface treatment was found to be difficult and so time consuming. Application of crusher dust is undoubtedly the most effective way achieve a smooth firm surface for the reception of bitumen, however this may be expensive in some locations. The use of sand was investigated and found to be laborious and time consuming. Superior results were achieved through the use of crusher dust.

Application of Surface Treatment: Where crusher dust was used to finish the surface, few if any difficulties were experienced in applying a surface treatment. Penetration depths of prime coat are also dubious however since the uppermost layer is extremely dense and inhibits the ingress of the prime coat. The construction method should be reviewed to assess whether the construction of the armouring layer over a compacted laterite layer, which necessitates the replacement of washed through fines, is the most appropriate. Construction of the armouring layer on an un-compacted laterite layer could possibly result in less water being required during compaction and hence mitigate the need for replacement of the fine particles in the surface of the armouring layer.

5.11 SECTION 10: HAND-PACKED STONE WITH LATERITE WEARING COURSE

Construction of the hand packed stone of section 10 was carried using waste stone from the dressed stone pavement. The stone was placed and packed over a sand cushion and laterite was rammed between the joints of the pavement using metal bars prior to construction of a 70mm laterite wearing course. Continuous filter drains were also constructed in an identical manner to those provided for the dressed stone pavement. The construction method was found to be very simple and the workers used for the construction of the dressed stone pavement had little difficulty in constructing the section at a very quick pace. The knowledge gained during the construction of the dressed stone pavement was used to good effect in the construction of the hand-packed stone of section 10. Upon completion of section 10, a laterite ramp was constructed since the new road elevation was 350mm above the old one.

Box 4: Summary of the lessons learned in relation to labour-based surface treatments

Bituminous Surface Treatments

- *Application of Prime Coat:* Prime coat was applied at the manufacturers recommended spread rate of 1Kg/m^2. The manufacturer stated that the prime coat could be diluted up to and above 20% of the spread rate with water provided that that the residual prime coat spread rate adheres to the specified spread rate for the prime coat according to design specifications. Therefore to aid in achieving adequate penetration of the prime into the roadbase, a dilution rate of 40% water was opted for. A dilution rate above this extended the breaking time to more than 2 days which was unacceptable at the time of construction (rainy season). It was also noted that when rain fell upon a freshly applied prime coat, while mixing of the rainwater with the prime did not occur, an excessively long breaking time (greater than 2 days in some cases) occurred. Application of the prime coat using watering cans and brushes as described in the weekly progress reports compiled by the site engineer was a relatively simple matter and very effective. Dry season or arid area use of bitumen emulsions by labour may achieve good results with greater speed.

- *Application of Bitumen Emulsion:* Application of bitumen emulsion using watering cans and brushes proved to be more difficult. It was found to be very difficult to achieve the application rate specified for the specified chip sizes. This was because the bitumen emulsion was considerably more viscous than the prime.

- *Spread Rates:* A spread rate of 1.6Kg/m^2 was specified for 14mm nominal size chippings and 1.3Kg/m^2 for 8mm nominal size chips. A minimum spread rate of 1.5Kg/m^2 could be achieved using the method that was applied. Thus a single chip seal could be constructed with ease, whereas a double chip seal was a little more difficult to construct and an excess of emulsion had to be applied, albeit an excess of 0.1Kg/m^2. The excess of bitumen applied was greater than this if one considers the less than specified sizes of chips that were used. For the single chip seal a nominal chip size of 14-15mm was used and no problems were encountered apart from minor bleeding in areas. For the second layer of the double chip seal 5mm chippings were used and so problems of bleeding did occur. The method of applying the bitumen emulsion needs to be reviewed. Slight heating of the emulsion could reduce the viscosity, without affecting labourers' ability to handle the material, enough to facilitate lower spread rates. A lance sprayer could also be considered.

- *Breaking Time:* The breaking time for the bitumen emulsion could not be clearly defined since the emulsion remained soft and pliable for a number of weeks after application. Opening of the road to traffic aided the setting of the chippings into the emulsion and the bitumen was noticed to rise through the overlying stone chippings to produce a good surface in most cases.

- *Cohesion of Aggregates:* Because the breaking time was excessive the cohesion of aggregates was not as hoped in the weeks after the construction of the surface treatments. The chippings could be prised from the emulsion with little effort. With time and traffic the situation improved and the bond between the emulsion and the chippings became stronger.

- *Cohesion of Sand:* It was found that sand and indeed crusher dust would not adhere to the particular bitumen emulsion used for the trials. It was thought initially that the cationic emulsion would not bond to sand which was most likely also cationic. However crusher dust from the same source as the stone chippings used would also not bond well with the sand. Initially the bond of crusher dust seemed better, although all had worn off the surface within a week or two. The reason for lack of adhesion of sand is most likely related to the long breaking time in which time the emulsion is too soft to hold the sand in place under traffic loading.

- *Aggregates:* It was found to be difficult to obtain single sized aggregates of cubical particle shape for the construction of surface treatments. Aggregates delivered to site were often flaky and elongated in shape as well as having very variable particle size distribution. Screening of aggregates on site improved the quality only very slightly and the soft emulsion used was actually advantageous to the development of a dense mosaic of aggregate on surface treatments, behaving in a similar manner to MC3000 in an otta seal. Consideration should possibly be given to utilising otta seals in the future given the aggregates that are currently available for the construction of surface treatments.

6. KNOWLEDGE GAINED THROUGH CONSTRUCTION PHASE

The knowledge gained through the trials extends beyond documentation through site control sheets and in situ testing of materials and pavement layers and compilation of weekly progress reports. A core goal of the trials was the assimilation of knowledge not only for the engineers, organisations and ministries involved in the implementation of the project but also for the SSCs, workforce, local communities and local professional staff. In this way the trials have offered an insight into current engineering, social and economic issues of prominence within the sector.

It should be noted that a socio-economic study of the trials is underway and was initiated at the onset of the project. This study has been carried out by the ILO Upstream socio-economic team. Surveys of workers have already been carried out at varying stages of the construction phase. The outputs of this study will deal with economic, social and environmental issues of the trials. These will form a vital part of the trials documentation.

6.1 ENGINEERING & CONSTRUCTIONAL KNOWLEDGE

The LCS trials have been one of the first attempts to construct higher class pavements using labour-based methods in the region. The majority of literature and resources currently available in relation to labour-based road construction is predominantly concerned with gravel roads. The trials have successfully proven that higher class pavements may be constructed using labour-based methods. A source of valuable engineering and practical construction knowledge is now at hand. Labour constructed paving can now be extended with confidence to secondary, main and urban paving situations, bringing economic and social benefits to the communities and local enterprises.

6.1.1 LABOUR-BASED ROADBASES

A number of factors were found to play a key role with regard to the ease with which a roadbase could be constructed using labour-based methods. These included:

- Grading requirements on aggregates used
- Availability of aggregates required
- Volume of aggregates required
- Machinery required

Difficulties were encountered particularly during the construction of the water bound macadam road base. The water bound macadam roadbase was specified to be constructed in two layers, the first having 50mm maximum particle size and a layer thickness of 125mm thickness, the second having 35mm maximum particle size and a layer thickness of 125mm thickness. Well graded angular aggregate approximately cubical in shape is required for the construction of water bound macadam. Such aggregate is only available from Banteay Meanchey Province. However it soon became apparent that the quality of aggregates available was often dubious. Some of the aggregate delivered to site was of very poor grading and shape. Either aggregate of single size grading or aggregate with no grading was delivered to site. The aggregates produced in Cambodia are very often of very poor quality, despite the parent rock being of very high quality. This is due to the crushing plant used to produce the aggregates. The machines are very old and from a variety of sources. Thus parts are difficult to obtain. Typically the teeth of the crushing plant will wear quickly and good quality replacement teeth cannot be sourced easily. The aggregate resulting from the crushing process therefore has very poor grading. The aggregate is also very often of a rounded shape, which does little to aid compaction and development of aggregate interlock.

It was found that where the grading requirements were less stringent, as for sand-aggregate road base and armoured laterite roadbase, fewer difficulties were encountered. Proper macadam graded aggregate is simply not available in most of Cambodia.

Aggregates were available in various grading although the closest grading to downgrading (as per required for crushed stone roadbases for example) was crusher run stone. It was also found that there was a great variance in particle shape from one delivery to another. Larger stone was found to be very difficult to obtain and this undoubtedly hindered the construction of the dressed stone pavement. There seemed to be confusion at the quarries over the orders of the SSC and it is likely that technical capacity problems exist at the quarries. This was demonstrated when aggregates were delivered to site that contravened the orders of the SSC. When contractor MS arranged for his site supervisor go to the quarry sites and choose aggregates by himself in many cases and this resulted in better quality aggregates being delivered to site. However in the case of the trials, with a 130km travelling distance it was not the most satisfactory solution. It is possible that there is a requirement for intervention at the quarries with training and transfer of small scale appropriate technology for the production of aggregates. This should possibly be investigated further in the future through inspection of quarries used as sources for aggregate at the trials site. It is hoped that the stone type and method of extraction may be studied in more detail.

It was found that more difficulties were encountered for sections with a higher requirement for machinery to supplement the labour. This was certainly true for the water bound macadam where an 8 tonne roller was required and preferably with vibration. Although such equipment might be expected to be commonly available (by a western professional) the reality in Cambodia was found to be very different. The contractor TBK experienced extreme difficulty in obtaining adequate compaction equipment. Large static rollers are available for hire from the Provincial Department of Public Works & Transport. However large vibratory compaction equipment is not available for hire anywhere in Siem Reap Province. Moreover hire of large compaction equipment is very expensive when possible, which can be difficult for the SSC to cope with financially. Mobilisation and demobilisation costs can be a substantial component of equipment hire in these cases. Usually hire days have to be paid for transportation each way as well as the cost of transportation vehicle. It was found that adequate compaction could be achieved for the sand-aggregate road base with 4 tonne roller followed by a 2 tonne ride on roller with vibration. A 1 tonne vibratory roller was sufficient to attain good compaction for the armoured laterite roadbase also and hence water bound macadam has been found to have the most costly compaction requirements. In terms of the goal of machinery only being used to support the activities of labour, this is something of a contradiction. Indeed for water bound macadam it is possible for haulage and compaction cost to equal that of labour costs.

6.1.2 LABOUR-BASED SURFACE TREATMENTS

The primary factors affecting the construction of labour-based surface treatments were found to be:

- Bitumen spread rate
- Quality of chips available
- Weather constraints

Bitumen spread rates were specified by the manufacturer of the (main seal) bitumen emulsion used at the trials site. These were: 1.6Kg/m^2 for 14mm chips, 1.3Kg/m^2 for 8mm chips and 1.0Kg/m^2 for sand seal. It was found that a minimum spread rate of 1.5Kg/m^2 could be achieved using the method of application described in the weekly progress reports of the trials. This is of little concern when larger size chips are used for the surface treatment. The chips used on site for single bituminous surface treatment were approximately 14mm nominal size, having been screened on site. Therefore in this case the spread rate of 1.6Kg/m^2 could be adhered to without large problems occurring after construction. However when the spread rate for the second layer of the double bituminous surface treatment could not be adhered to and smaller sized chips were used, bleeding inevitably occurred. The spread rate for the sand seal also could not be adhered to and so the sand seal became a little expensive, which in effect defeats its purpose as the lowest cost seal for low volume roads. Clearly the method of applying the bitumen emulsion using watering cans and brushes requires some refinement.

It was found to be very difficult to obtain good quality chips of uniform shape and size as required for a single or double chip seal. Stone chips supplied to site were often flat, angular and flaky, requiring washing and screening on site. This resulted in wastage of stone chips which cost a minimum of US$15/m^3 at the trials site. This is clearly an unacceptable situation and points once more to a requirement for intervention at the quarries or on site to improve the quality of materials available. There is also a requirement to reassess the spread rates used for the various surface treatments and calculations should be made on site in the future if required to modify the spread rate depending upon chip size and shape.

As with all bitumen, dry weather was required for the application of prime coat and bitumen emulsion. Since the works were carried out during the rainy season, the weather was unpredictable and often wet. Typically a prime coat or surface treatment would be applied in the morning and it would begin to rain at noon. The wet weather seemed to have no adverse affects other than delaying the breaking time of the prime coat and emulsion. This should be borne in mind if intending to use emulsion in the future on a larger scale. Small scale bitumen heating and spraying equipment with adequate quality control systems would be of great benefit to labour-based road construction and a comparison between emulsion and hot bitumen can then be made. At present such equipment is not available within Cambodia and the bitumen heaters available for hire are of very poor quality/condition with little or no control systems.

Despite the foregoing, it is notable that labour orientated surfacing works could be continued throughout the rains. This augurs well for the future of labour-based options for paved roads in South East Asia, where many equipment-based roadworks contracts are severely constrained or cease in the rains.

6.2 REQUIREMENT FOR TRAINING PRIOR TO MOBILISATION

It has become apparent after the implementation of the construction phase of the LCS Project that there is a requirement for training of the contractors prior to implementation of the alternative surfacing works on site. This is particularly true when using SSC previously only accustomed to constructing gravel roads. In such a situation one's project success may be directly restricted by the legacy of laterite in that the SSC have limited knowledge of alternative construction methods required for roadbases and surfaces other than gravel roads. It would be more economical to provide the site technicians and supervisors of the SSC with classroom training prior to initiation of the actual works. Once the contractor is on site and the works have been initiated, money is being spent until the works are completed. Time allotted to training on site could be reduced and fewer difficulties encountered if the SSC have been trained and provided with training materials to consult during the works.

The confusion of SSC over aggregate grading requirements as well as construction of the surface treatments was indicative of the requirement for training. Time spent explaining the designs to contractors, including the design principals and the source of each pavement's strength, would have lessened the time required on site for these tasks. For example a clear explanation inclusive of diagrams and grading envelopes detailing how to construct water bound macadam, how water bound macadam derives its strength from aggregate interlock and how aggregate interlock is developed would have been of great benefit to both contractors. The compilation of training material will result from the compilation of international guidelines and standards which is a vital part of the documentation of the project. The need for this work was highlighted during the trials. Future construction will benefit from the initial experience.

6.3 REQUIREMENT FOR ASSESSMENT OF CAPACITY PRIOR TO INITIATION OF WORKS

As with the requirement for classroom training there has been found to be a requirement for a detailed assessment of the SSCs capacity to carry out the works prior to granting of contracts. This is closely linked to the requirement for classroom training but also encompasses the ability of the contractor to hire equipment, the equipment the contractor has available for use immediately as well as the knowledge base of the contractor. This was found to be of great importance as the trials progressed. Again one may point to the legacy of laterite rather than faulting the contractor for a lack of diversity. Contractor TBK has a large amount of equipment and so it was thought that the construction of the water bound macadam sections would be less difficult for contractor TBK than for contractor MS, who had little heavy equipment. It appeared that contractor TBK has evolved into a haulage contractor through contracts for gravel supply. Contractor TBK certainly had the capital to obtain heavy compaction equipment required for the construction of water bound macadam and could have the aggregates required delivered to site. However because contractor TBK had been working principally as a haulage contractor and also solely in the construction of gravel roads (Contractor TBK was originally trained by the ADB project, not by the ILO Upstream as contractor MS was) his knowledge base was quite limited, never having constructed any other type of road than gravel.

On the other hand contractor MS had very little equipment being a true SSC in the sense that the minimum amount of equipment would be used to support the operations of the labour. Contractor MS had very little capital to hire larger plant, however it transpired that the contractor MS had a large amount of experience in constructing various types of roadbase as well as bituminous surface treatments. Indeed contractor MS had constructed water bound macadam before whereas contractor TBK had not.

6.4 SOCIAL ISSUES

The trials sought to maximise the amount of indigenous resources used, inclusive of knowledge, skills, labour and materials through the SSC. Furthermore, sustainability is a key aspect of the trials paving options. It could be said that laterite represents a maximisation of local resources. The sustainability of laterite as a wearing course material is certainly questionable due to the ongoing wear of the material and the resultant consumption of a finite resource for the purposes of maintenance. However utilising laterite while armouring it with a higher CBR crushed stone and sealing the resultant roadbase with a low cost surface treatment to preserve the road base layer represents a more sustainable use of this local resource.

The local materials were used in the various trials options in a sustainable manner as may be seen by the different pavement types' retention of a large part of the investment value, simply by not being washed, blown and worn away. Or put more simply the stone of the dressed stone pavement will still be here in 3 years, where as the wearing course laterite of section 10 will be long gone. By enabling a community to provide access utilising a maximum of their own resources which can be sustained through minimal maintenance, the road builder has a unique opportunity to address social and poverty issues in a more considerate holistic manner.

The construction of roadbases required in most cases large quantities of aggregates. These were not readily available in Siem Reap Province and hence had to be transported 130km to site. Thus a large portion of the project's funds were unavoidably diverted to haulage. It may be said that the more local a material the greater the benefit to that target community. The reasons for this are two fold: 1. Project funds stay in the local area and 2. the funds are diverted to the people since the haulage distance will be short, rather than a large bulk of the funds going to one haulage contractor. There was no option but to haul crushed stone aggregates 130km to site for the Puok Market trials, however steps may be taken to minimise the overall haulage distances materials travel to site in other cases. The use of sand-aggregate road base demonstrates this quite well since 35% of the roadbase is sand which is readily available only a few kilometres from the trial site, and is commonly available elsewhere in Cambodia. Similarly efforts could be made to utilise sandstone which is readily available 15km from the trials site. Clearly more investigations are required to demonstrate this option. The previous Kampong Cham stone paving trials (Reference 3) demonstrated that when good stone is available in the vicinity (within a few km), then nearly all of the construction costs can be recycled within the community in labour and local enterprises.

6.5 ECONOMIC ISSUES

The cost per square metre of each roadbase and surface treatment combination will be calculated by analysing the site control sheets. The maintenance costs will also be estimated in the coming years of monitoring of the trials. Thus life cycle costs will be compiled for each trial and disseminated to all stakeholders. The trials may also be studied in terms of their employment generation capacity whereby the amount of workdays generated both directly and through the back-employment effect of utilising local resources may be calculated.

6.6 ENVIRONMENTAL ISSUES

The socio-economic team has already documented many environmental aspects of the trials work. This was done through field surveys of workers on site in relation to work type, materials used and various other issues pertaining to environmental aspects of the work.

7. RECOMMENDATIONS FOR FUTURE WORK

Based upon the site engineer's experiences on the trials construction and the difficulties that have been discussed previously, the following future work is required. While these recommendations may be considered a little premature at the time of writing, they may be viewed in light of the experiences of the site engineer during the period of the trials and may well be corroborated by others working within the sector. Seven main areas are believed to affect the works on site directly and wider application of the alternative surfacing techniques. These are:

- Availability and quality of crushed stone aggregates
- Availability and quality of compaction plant
- Use of bitumen through labour-based methods
- Trials maintenance monitoring
- Further paving options investigations
- Materials inventories
- Dissemination

The quality of crushed stone aggregate has been discussed in the previous paragraphs as well as in the weekly progress reports. If resources allowed, the author would suggest to carry out a thorough investigation of all quarries used for supply of aggregates to the trials site. The method of extraction and processing of the stone as well as the type of parent rock would be examined and documented if possible. This could possibly reveal why such difficulties were experienced in obtaining good quality crushed stone aggregate of the required grading, be it for roadbase construction or use in bituminous surface treatment. There is most likely a requirement for intervention at the quarry to guarantee crushed stone aggregates of good quality are available for the future. It is possible that the lack of such aggregates could limit the sustainability of infrastructure in many areas of the country. The use of small scale crushing plant on site or at the quarries, and manufactured locally, could ensure availability of spare parts and alleviate the situation to some extent. Stone could be crushed and screened on site. However an intervention at the quarries themselves would most likely be more cost effective since the cost of aggregate depends primarily on haulage distance and not on processing. The large unprocessed stone is reported by contractor MS to have cost U.S.$15/m^3 which is the same cost as per crushed stone aggregate. Hence stone processed on site could become a very expensive option.

Likewise a study of compaction plant available for hire within Siem Reap Province (and elsewhere in Cambodia) could lead to an important insight into the construction industry in the Province and allow the road engineer to propose more considerate designs such that SSC would not be strained financially through the hiring of problematic equipment. The contractors had great difficulty in obtaining heavy compaction plant (8-tonnes or greater) and even greater difficulty in obtaining heavy compaction plant with vibration. The plant is simply not available for hire it would seem. This should be taken into account at the design stage in the future and designs proposed should minimise the heavy plant required to support the operations on site in order to maximise the viability of utilising SSC for the works.

It has become apparent that there is a requirement for the method of application of bitumen emulsion to be reviewed/refined. The higher viscosity of bitumen emulsion (in comparison to the primer) leads to difficulty achieving the correct spread rate. It is possible that slight heating of the bitumen emulsion would reduce the viscosity of the material sufficiently to allow the recommended spread rates or spread rates calculated for the particular aggregates being used to be achieved. This may also help to reduce the high breaking time noted for the emulsion. This may be a property of the particular emulsion used on site; however any reduction in breaking time would most likely be advantageous. Small scale heating and spraying plant such as a unit which could heat a single barrel and spray it using a hand operated lance would be useful for this work. It would possibly be beneficial to make a comparison of costs and material performance between hot bitumen (80/100 penetration grade) and bitumen emulsion for use in bituminous surface treatments.

Dry season experiences with emulsions should also be documented.

Follow up performance and maintenance monitoring of the trials sections are required in order to develop whole life costings.

Other labour-orientated and local-resource-based surfaces that should be investigated include:-

- Soft rock roadbases (possibly armoured),
- Clay brick paving,
- Concrete block paving,
- Stone chipping blinding,
- Ottaseal,
- Stone setts (pavé),
- Engineered earth roads (including sustainable maintenance arrangements),
- Stabilised soil earth roads/roadbases/subbases, possibly with rice husk pozzolan,
- Comparison of hot bitumen, warmed emulsion and cold emulsion techniques,
- Bituminous seals on traditional equipment based roadbases.

National roadbuilding materials inventories/mapping are also required so that guidelines can be provided on the most suitable paving techniques for each province and location.

The mainstreaming and application of the trials experiences need to be planned and implemented on a national basis, involving all stakeholders. National specifications and standards must be developed for the various paving techniques. Guidelines on policy, cost and social selection of paving options are required. Training and information availability will be crucial to achieve wider acceptance and adoption of the alternative and beneficial paving techniques. Suitable training material needs to be developed both in English and Khmer. The alternative paving techniques should be introduced and monitored on full scale construction projects.

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