

LOW COST ROAD SURFACING (LCS) PROJECT

LCS WORKING PAPER No **7**

BAMBOO REINFORCED CONCRETE PAVEMENT ROAD CONSTRUCTION IN CAMBODIA

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Part 2
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FOREWORD

This document is the result of cooperation between the ILO Upstream Project Cambodia and the Low Cost Road Surfacing Initiative: "Low-cost, Labour-based Roads for Poor Communities".

This report describes the first of two alternative surfacing initiatives in the area of Puok Market, Siem Reap Province of Cambodia. Further road surfacing trials have been carried out and are described in other Low Cost Road Surfacing documents.

ILO UPSTREAM PROJECT IN CAMBODIA

In Cambodia, since 1992, the ILO has promoted labour-based appropriate technologies (LBAT) to generate employment through the improvement and maintenance of essential rural infrastructure. These technologies are "pro-poor" and effective weapons to combat poverty. The Royal Government of Cambodia (RGC) has endorsed LBAT as the technology of choice for the rural infrastructure programme. In support of this important decision, the project "ILO Technical Assistance to the Labour-Based Rural Infrastructure Works Programme, CMB/97/M02/SID", known as the "Upstream Project", was formulated. This project is primarily funded by Sweden with additional financial and technical support from the Netherlands, Ireland and Australia. This four-year project became operational on 1st July 1998. The Ministry of Rural Development (MRD), Cambodia is the main RGC counterpart to the project. The project has five capacity building targets:

1. To increase the capacity of the private sector by training **small-scale contractors** (SSC) to carry out the rural infrastructure works using LBAT. The RGC intends to maximize the role of the private sector. The project has been involved with the training of 22 SSC. Follow up studies indicate that the SSC are thriving.
2. To assist the Institute of Technology of Cambodia (ITC), in developing, instructing and institutionalising four engineering courses that include LBAT approaches. The project is also sponsoring ITC students to undertake their co-operative work term with the project.
3. To demonstrate best LBAT practices by implementing **construction and maintenance works** in Siem Reap province. These works have generated an employment effect of 575,000 workdays for rural people.
4. To improve the Institutional Capacity in the **MRD** so that infrastructure investments maximize the pro-poor impact. Together the MRD and the project are:
 - Formulating **Policies and Strategies** for the rural transport infrastructure programme,
 - **Training** the technical staff of the Department of Rural Roads in labour-based methods,
 - Applying **Integrated Rural Accessibility Planning** (IRAP) for rural infrastructure investments,
 - Undertaking **Socio-Economic** studies that will provide useful information for programme design, monitoring and impact assessment,
 - Convening the Cambodian **Forum for Rural Transport and Development**,
 - Investigating **road-surfacing** options. MRD and the project are currently collaborating with a DFID funded project entitled "Low-cost, Labour-based Roads for Poor Communities",
 - Translating and adapting essential relevant **training materials** and **technical literature**.
5. To promote partnerships and programme development: The project is collaborating with the World Bank and the Asian Development Bank to formulate and implement projects that feature LBAT and IRAP. The project is collaborating with the Engineering Institution of Cambodia to further mainstream these technological approaches.

THE LOW COST ROAD SURFACING INITIATIVE

The Low Cost Road Surfacing (LCS) initiative (Low-cost, Labour-based Roads for Poor Communities) 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, Chiang Mai University Thailand, the Committee C20 (Appropriate Development) of PIARC (World Road Association) and the International Focus Group. 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 a number of other agencies. 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

The document is intended to inform and provoke discussion, contributions and dissemination regarding surfacing aspects of rural roads. 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.

BAMBOO REINFORCED CONCRETE PAVEMENT, ROAD CONSTRUCTION IN CAMBODIA

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Abbreviations

ASEAN	Association of South East Asian Nations
CAFEO	Conference of the ASEAN Federation of Engineering Organisations
CSIR	Council for Scientific & Industrial Research
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
IRAP	Integrated Rural Accessibility Planning
ITC	Institute of Technology of Cambodia
ILO	International Labour Organisation
LBAT	Labour Based Appropriate Technology
LCS	Low Cost (Road) Surfacing
MRD	Ministry of Rural Development
RGC	Royal Government of Cambodia
SSC	Small Scale Contractors
TRL	Transport Research Laboratory
VPD	Vehicles Per Day

International Labour Organisation
Technical Assistance to the Labour-Based Rural Infrastructure Works Programme
CMB/97/M02/SID

In cooperation with Intech Associates (DFID - UK funded) Knowledge and Research investigations for R7782 'Low Cost, Labour Based Paved Roads for Poor Communities'

Bamboo Reinforced Concrete Pavement Road Construction in Cambodia

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Key Words: Bamboo Reinforced Concrete Road Pavement

Executive Summary

Cambodia's need for durable, alternative road surfaces is growing. This led the International Labour Organisation (ILO) Upstream Project to initiate a study to investigate different surfacing options. These studies examined the potential technical benefits, employment generation, utilisation of local resources, costs, environmental effects and benefits to the local community. As part of these investigations a 2km Bamboo Reinforced Concrete Pavement (BRCP) trial was designed and implemented in collaboration with the Ministry for Rural Development (MRD). Construction took place in the year 2000.

Laterite (a naturally occurring gravel material) is often used to surface rural roads. Although initial construction costs can be lower than other surface types, in the Cambodian conditions the laterite surface wears quickly (and needs to be regularly replaced), is costly to maintain and causes dust problems. Furthermore, the finances, resources and management for proper maintenance of laterite are often not available from within the government or local community.

The study found the following advantages of BRCP compared to gravel/laterite in many situations:-

- ❑ expected long life span,
- ❑ high residual value,
- ❑ minimal maintenance,
- ❑ minimal equipment requirements (and requires only simple equipment),
- ❑ labour intensive construction and maintenance,
- ❑ suitable for both male and female employment,
- ❑ good use of local resources (especially labour and materials),
- ❑ dust-free, easy-to-clean surface, and
- ❑ tolerance to flooding.

The disadvantages of BRCP compared to unpaved surfaces are:-

- ❑ slower speed of construction, and
- ❑ higher initial investment costs.

BRCP roads may be more economically feasible than laterite roads for high laterite haul distances (beyond about 10 km) in asset whole-life-cost terms for the circumstances prevailing in Cambodia.

It is recommended that BRCP should be one of the options to consider (in technical, whole life cost and management terms) for low volume road surfacing when:-

- ❑ laterite haul distances are long,
- ❑ laterite quality is poor,
- ❑ road surface/subgrade is liable to flooding,
- ❑ local communities live very close to the road (dust nuisance), or
- ❑ there are severe doubts about future maintenance funding or capacity.

Accordingly, it should be incorporated in the Cambodian National Standards as a surface option for rural roads, and training programmes should incorporate these techniques.

It is recommended that the performance and maintenance requirements of the Puok BRCP trials should be monitored to enable the whole-life-cost estimates to be validated.

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..... ***PART 2***

5. CONSTRUCTION

5.1 Preparatory Work

Setting Out

The extent of the embankments were marked by fixing wooden pegs along the road alignment at ten to twenty metre intervals or closer if required. The pegs were placed approximately half a metre beyond the outer edge of the embankment and painted with luminous paint. Standard surveying practice was used to obtain the grade and profile specified by the design.



Image 9: Setting out of road alignment and level

Preparation of Existing Ground as Sub-grade

As much as was practically possible, the embankment material and previous laterite wearing course was left untouched since a degree of consolidation, which would be beneficial to the new construction, was achieved through the everyday use of the road. The surface was simply shaped and levelled in accordance with the design specifications. Following this the surface was wetted using a water bowser and hand held watering cans and then compacted using a one tonne twin drum pedestrian vibrating roller. The number of passes was specified such that satisfactory compaction of any new material or remixed layers would be achieved.

5.2 Sand Sub-base

A sand sub-base was required in order to ensure good load transfer and distribution to the supporting sub-grade. A 50mm thick sand sub-base, of Fineness Modulus (F.M.) not lower than 1.80 and well compacted, was provided. The sand sub-base was compacted by a one tonne twin drum pedestrian vibrating roller to obtain compaction of not less than 95% Maximum Dry Density (M.D.D).

Proper compaction of sub-grade and sub-base layers is of paramount importance with regard to the satisfactory performance of a rigid pavement. This is particularly essential in Cambodia where in-situ soils tend to be very weak, as demonstrated by the low California Bearing Ratio (CBR) values, derived from the Dynamic Cone Penetrometer (DCP) test. For this reason particular attention was given to the compaction of sub-grade and sub-base layers. All layers were placed and compacted in layers of not more than 150mm thickness. The material was laid in the dry state and wetted to as near as Optimum Moisture Content (OMC) as practically possible using a

locally constructed water bowser. Efforts were made to ensure that the material was within $\pm 5\%$ limits of OMC. Immediately after each layer was placed, wetted, shaped and graded to the required camber, it was thoroughly compacted using a one tonne pedestrian vibrating roller. The number of passes was specified in the construction specifications and all compaction work was overseen meticulously.



**Image 10: Placement of Sand Sub-base
Compaction of Sub-grade and Sub-base Layers**

Image 11: Sub-base Compaction Construction of Pavement (to be inserted)

5.3 Construction of Formwork

All forms were constructed of 30mm planks of local wood. The forms were constructed to be mortar tight and rigid enough to retain the specified shape and position during placing and compaction of the concrete. This was achieved through the use of bracing, metal ties and anchors.

5.4 Bamboo Reinforcement

Care was taken to vary the basal and distal ends of the bamboo splints when fabricating the bamboo mesh. This would ensure that a uniform area of reinforcement would be obtained throughout the area of the pavement. The bamboo was placed 50mm from the top of the pavement such that it would serve to control cracking during initial setting and also assist in the control of cracking that could occur due to temperature variations. The bamboo mesh of $250 \times 250\text{mm}$ was placed on 100mm wooden spacers, which ensured the desired 50mm cover to the reinforcement would be maintained. The wooden blocks were removed as pouring of concrete progressed. The construction configuration and methodology utilised was similar to those found to produce satisfactory results in larger projects in Thailand.



Image 12: Placement of Bamboo Mesh, wooden spacers to be inserted under mesh

5.5 Mixing of Concrete

All concrete was mixed on site in small capacity batch mixers. Mixers with a capacity less than one bag of cement were not used and no mixer was charged in excess of its' rated capacity. The first batch of materials placed in each mixer contained a sufficient excess of cement, sand and water such that the interior of the drum as coated in order to prevent loss of mortar to the mix. After any considerable pause in mixing the mixers were washed out thoroughly before use again. Containers for measuring aggregates, water and cement were manufactured locally. The coarse aggregate and cement were placed in the mixer first and mixed together for a number of minutes in order to ensure the coarse aggregate particles would be thoroughly coated in cement. Following this the sand was added and mixed in the dry state for some minutes.



Image 13: Mixing of Concrete

This was carried out in an attempt to obtain as homogenous a mix as possible and thus achieve the best results from the materials available locally. Finally water was added in two doses and mixed for not less than two minutes. Every batch was mixed until a concrete of uniform consistency was obtained. The mixing of each batch was observed and the volume of each constituent used in each batch was recorded.

5.6 Placement of Concrete

Prior to placing the concrete, all formwork and reinforcement was thoroughly inspected by the engineer. All wood chips, dust, sand, construction debris and any other deleterious material was removed from the formwork and reinforcement prior to placing the concrete. All formwork was wetted to ensure it was damp when the concrete was poured. This operation was carried out to prevent water being absorbed by the wood and hence prevent altering the specified concrete water/cement ratio, which would modify the characteristics of the fresh concrete. Care was taken during this operation such that pools of excess water did not form in the base of the formwork and also that the bamboo mesh was not wetted. Workers were organised such that one team mixed a continuous supply of fresh concrete, while another brought the concrete to the point of placement and yet another team spread and compacted the concrete.

A sun shelter was fabricated to protect the placement workers and fresh concrete.



Images 14 & 15: Placement of Concrete and Sun Shelter

Efficient organisation of labour ensured no construction joints in a slab were necessary, which would have weakened the pavement structure. Wheelbarrows and specially constructed stretchers were used to transport the fresh concrete. The position of the bamboo mesh within the depth of the pavement was modified as the pouring progressed to ensure that the desired position 50mm below the pavement surface was maintained. Any bracing or dowels used within the formwork were removed as pouring progressed.

5.7 Compaction of Fresh Concrete

Once the concrete had been placed uniformly within the forms, compaction was carried out using a mechanical poker vibrator of 25mm diameter, powered by a small portable generator. Care was taken to ensure a good bond between layers of fresh concrete placed separately by vibrating the two layers together until a satisfactorily homogenous cross section was obtained.

No concrete was compacted after initial setting had proceeded. Initial setting was recognised by a loss of flowability of the concrete. All concrete was compacted until no air bubbles appeared on the surface of the fresh concrete. Concrete was not compacted beyond this point, to prevent segregation within the mix. Care was also taken not to touch the formwork or embedded reinforcement with the vibrator since this would result in concrete having begun initial setting being exposed to re-vibration. It could also have a detrimental effect on the bond between the concrete matrix and the bamboo reinforcement.

5.8 Surface Finishing

A two per cent camber was ensured along the length of the pavement through the use of a straight edge screed plank. Details of this operation are shown in images 18 and 19. After placement and compaction of the fresh concrete the camber was shaped in the fresh concrete to lines and levels set out using the simple locally constructed hand tool. In order to improve the skid-resistance of the surface and to shorten the vehicles' breaking distance, grooves were etched in the fresh concrete surface. A special rake consisting of a steel wire teeth attached to a wooden head and handle was manufactured locally for this purpose.



Image 16: Grooving Rake



Images 17 & 18: Surface Finishing

5.9 Contraction Joints and Expansion Joints

Contraction joints, 10mm in width, were provided every 5m to relieve tensile stresses. Experience has shown that in most climates, joints are required at 5m intervals in order to inhibit early formation of cracks, to relieve temperature stresses, and to accommodate initial volume changes that take place in concrete as it hardens. With concrete roads constructed in hot weather, contraction of the concrete predominates as the weather becomes cooler. In any subsequent expansion it is unlikely that all joints will be able to close to their original dimensions. For this reason expansion joints were provided at 250m intervals. This configuration has been found to perform satisfactorily in similar pavements in Thailand. All joints were sealed using a mixture of bitumen and sand and a reservoir of bitumen was provided at the top of the joint. All joints were provided with load transfer devices to limit the vertical movement between slabs as vehicles pass over.

In the Puok market area where overloading of vehicles is common, the provision of load transfer devices between slabs was especially important. 14mm round steel dowels, 500mm in length, at 250mm centre – to – centre were provided at all joints. Where the joint was an expansion joint, the dowel bar was anchored into the concrete

at one end and the other end was coated with bitumen and the fitted into a PVC sleeve in order to ensure free movement in the longitudinal direction. Where the joint was a contraction joint, the PVC sleeve was omitted.

5.10 Curing of Concrete and Special Measures

High temperatures increase the rate at which concrete hydrates. Typically this results in two difficulties related to pouring concrete in hot climates. The concrete sets more rapidly, losing its workability resulting in difficulty in achieving thorough compaction. On site the workability was rigorously checked using concrete slump as an indicator. A slump test was carried out for each batch of concrete mixed, a slump of not less than 100mm being required. Rapid early gain in strength of concrete experienced in hot climates can be accompanied by shrinkage and cracking of concrete with the result that the subsequent gain in strength is much less than with concretes cured at lower temperatures. Specific measures were taken to combat the effects of high temperature and direct sunlight. All aggregates were stored under cover before use. Mixing water was kept in a shaded area of the site. As the concrete was being placed and compacted the surface was protected from direct sunlight and drying wind by a specially constructed tent structure, which was moved from bay to bay as pouring proceeded, plastic sheeting being used to replace the tent.



Image 19: Curing and Protection of Concrete

The concrete was cured by spreading sand over the surface of the pavement and repeatedly wetting the sand for a period of 28 days. A 14-day curing time, and even a 7-day period, may suffice depending upon the mix design and local circumstances. No traffic was allowed on the pavement until a period of 28 days had elapsed. Suitable temporary diversions were made for continued flow of normal traffic. Such measures were necessary due to the uncertainty in relation to loading and overloading of trucks delivering goods to the market or hauling road-building materials in the area. Simple bamboo barricades were constructed of bamboo failing to meet the criteria for use as reinforcement. These served to prevent pavement use until the 28-day curing period had elapsed.

5.11 Construction of Drainage

Particular attention was devoted to the design of drainage, given the importance of effective drainage on the overall satisfactory performance of the road structure. Drainage design resulted in a two per cent camber for removal of water from the pavement surface. In the urban section of the road, further provision was made to transport runoff to nearby drainage systems through a network of open box gutters and

v-shaped gutters at the side of the road. The design philosophy was towards interception of all surface water as quickly as possible rather than allow for infiltration into sub-base and sub-grade layers.

In the non-urban sections of road the carriageway was situated on an embankment; the laterite shoulders were shaped to fall away from the road surface at 4% and shed the rainwater evenly to the side of the embankment without causing erosion.

Excavation and Preparation of Channel Bed

All drains and gutters were set out by the site engineer prior to excavation. The drains, box or v-shaped as specified by the design specifications, were first excavated to the desired shape and depth. Next the required longitudinal gradient was provided. The beds of the channels were then lined with 50mm of sand, which was wetted and compacted using vibratory plate compactor or a hand rammer where necessary. Appropriate hand tools, shoulder baskets, stretchers and wheelbarrows were used in the excavation of the drains.



Images 20 - 23: Drainage Works

Lean Concrete Bed Lining

A 100mm thick layer of lean concrete was placed in the bed of each drainage channel and compacted using a mechanical poker vibrator. The concrete had proportions of 1:3:6, cement: sand: aggregate. The concrete was mixed by hand on plastic sheeting next to the area of use. Batches were small enough to ensure no concrete was wasted due to onset of initial setting before placement.

Brickwork

Bricks are manufactured in the proximity of the market and so brickwork was chosen for the structural form of the drainage channel walls. The bricks were cleaned before use and mortar joints of not more than 8mm were used. All walls were constructed to the engineers' lines and levels. Once the brickwork had been completed care was taken by the bricklayers to make sure the drainage channels had been cleaned of any debris or mortar that may have been left.

Plastering

One day after construction of the brickwork, plastering of the brickwork began. A standard mortar mix was used. The brickwork was wetted prior to application of the mortar coat. Experience has shown that where measures are not taken to mitigate against the effects of high velocity flows, pitting and other erosion effects rapidly appear on the surface of newly constructed concrete structures. Concern over the large volumes water, which the drainage system would have to transport lead to the decision to add a further layer of cement paste over the mortar in order to obtain a smooth finish.

5.12 Construction of Shoulders

As much as was possible, laterite from the original wearing coarse was used in the construction of the shoulders. Any imported material had to meet the specified standards following laboratory sieve analysis and testing. The laterite was placed in layers of not more than 150mm, wetted to OMC and then compacted using a one tonne twin drum pedestrian vibratory roller. The second layer of laterite was then placed in order to raise the thickness of the shoulders to 200mm after compaction and compacted in the same way.

5.13 Quality Control Measures on Site

Various quality control measures, many of which have already been briefly mentioned, were implemented on site. These may be broadly divided into to categories:

- Control of materials
- Control of works

Control of Materials

Material properties were specified in the design specifications such as; Fineness Modulus of sand, maximum coarse aggregate size, reinforcement dimensions, sealant type and quality etc. were all specified within the specifications of the contract documents. It was important to ensure such specifications were followed in obtaining all materials used. Relevant documentation was obtained, including suppliers' certificates and results of various material tests carried out at the Ministry of Public Works and Transport laboratory in Phnom Penh. Sand and coarse aggregate were screened on site to ensure a maximum particle size as specified. Coarse aggregate was washed prior to use. All aggregates and cement was stored in a shaded, clean and dry location on site. All cement was checked for lumps and dampness before use. Water for concrete mixing was obtained locally and stored in barrels in a shaded place on site. The water barrels were filled every night in order to ensure water of a minimum specified turbidity was obtained.

Control of Works

Various tests were carried out during the course of the works. Slump was measured for each batch of concrete prior to its' placement. All constituents of each concrete mix were measured in containers manufactured locally specifically for the purpose. All placement and compaction of concrete was carefully followed and registered. Formwork and reinforcement details were inspected before placement of concrete commenced. Where new aggregate was delivered to site and was judged by the engineer to be of too high a temperature, water was spread over the aggregate and the amount of water in the mix reduced accordingly.



Image 24: Slump Test

6. COST ANALYSIS

Road construction costs can be divided into two categories; direct costs and indirect costs. The direct costs involve all items that are directly incurred by, or related to, a specific construction activity carried out at site. These include material, labour, equipment hire, site camp and transportation etc.. Indirect costs are the costs that are not directly linked to the project activities at site. Indirect costs include such items as preliminaries, risks and company costs. Further discussion of costs can be found in Reference 21. It can be expected that costs would vary considerably in other regions and local costs should be verified for any cost comparison between techniques, particularly for materials haulage.

6.1 Direct cost of BRCP

Material cost

There is a large variance in cost of materials from province to province within Cambodia. The variation in material cost is mainly caused by the condition of primary road networks and material transportation costs. Costs can also vary by season, reflecting the road conditions. Table 1 below shows the typical material cost depending on haulage distance. It should be noted that the haulage distance affects mainly the natural gravel and the aggregate costs. Cost of cover sand usually does not vary much due to the availability of the material with short haulage distances in most areas of the country. It should be noted that ten per cent was added to the bamboo volume as waste.

Item	Unit	Quantity	Unit rate US\$			Cost per Km for haul		
			10 Km	50 Km	100 Km	10 Km	50 Km	100 Km
Sand	m ³	270.0	5.0	6.0	7.0	1,350.0	1,620.0	1,890.0
Aggregate	m ³	540.0	9.0	14.0	24.0	4,860.0	7,560.0	12,960.0
Cement	Ton	180.0	65.0	68.0	70.0	11,700.0	12,240.0	12,600.0
Form work	m ³	0.7	50.0	50.0	50.0	35.0	35.0	35.0
Sand (cover)	m ³	10.0	3.0	3.0	3.0	30.0	30.0	30.0
Bamboo	Bundle	138.0	1.5	1.5	1.5	207.0	207.0	207.0
Steel 14 mm dia	Ton	0.97	345.0	345.0	345.0	334.7	334.7	334.7
Binding wire	Kg	100.0	0.68	0.68	0.68	68.0	68.0	68.0
Bitumen	Kg	50.0	2.0	2.0	2.0	100.0	100.0	100.0
Total Cost in US\$ Per Km						18,685	22,195	28,225

Table 1: Cost of Materials for 1km of BRCP based on haulage distance¹

Labour Cost

The labour may be divided into two categories: skilled and unskilled. Skilled labour refers to those tasks, which require some knowledge and previous experience such as operating equipment like concrete mixers, plate compactors, rollers, or acting as a gang leader. Unskilled labour refers to those tasks that do not require previous experience or knowledge such as loading, unloading, spreading, etc. The cost of an

¹ Based on 4 metre wide pavement, mid-2000 prices.

unskilled labourer was 4000 Riel (*US\$1.05 equivalent*)² and 6000 Riel (*US\$1.55 equivalent*) for an skilled labourer per day. It was also estimated that each twenty five workers will form a gang led by a skilled labourer called gang leader. Table 2 below shows labour costs for construction of one kilometre of BRCP based on the Puok Market trials field experiences.

No.	Activity	Unit	Quantity	Work Norm Unit/worker -day (Wd)	Worker- days	Wd Cost USD	Total Cost USD
1	Survey & set out	m	10,000	50	200	1.05	210
2	Clearing	m ²	7,000	70	100	1.05	105
3	Sand spreading	m	1,000	20	50	1.05	52.5
4	Binding Bamboo	m ²	4,000	20	200	1.05	210
5	Form work	m	1,000	20	50	1.05	52.5
6	Concreting (mixing, loading, etc.)	m ³	600	0.22	2,728	1.05	2,865
7	Earth work at side slope	m ³	2,090	2	1,045	1.05	1,098
8	Gravel spreading at shoulders	m ³	252	5	51	1.05	54
9	Compaction	m	5,000	50	100	1.05	105
10	Curing of concrete	m	1,000	50	20	1.05	21
11	Side slope	m ²	6,000	20	300	1.05	315
12	Turfing	m ²	6,000	30	200	1.05	210
13	Gang leader and skilled workers				200	1.55	310
Total Cost in US\$ per Km							5,608

Table 2: Labour Cost for Bamboo Reinforced Concrete Pavement

Equipment Cost

The equipment used for the construction works consisted of mainly hand tools and simple small plant to complement the labour where necessary. All equipment was of the type already in use by small-scale contractors within the sector. Equipment costs were based on daily rental fees from the market. Table 3 below shows the cost of equipment used for the bamboo reinforced concrete pavement construction.

No.	Activity	Equipment	Unit	Quantity	Unit cost USD	Total Cost USD
1	Transport	Etan (light truck)	Day	33	20.0	660
2	Water transport	Etan bowser	Day	33	20.0	660
3	Concrete mixing	Concrete mixer 0.2 m3	Day	33	15.0	495
4	Concrete compaction	Concrete Vibrator	Day	33	2.0	66
5	Electrification for equip.	Generator	Day	33	5.0	165
6	Compaction	Plate Compactor	Day	66	5.0	330
7	Operation cost			33	10.0	330
Total Cost in US\$ per Km						2,706

Table 3: Equipment Costs

2 US\$1 = Riel 3,900 mid 2000.

Tools

Simple hand tools can be used for the pavement construction. Table 4 below shows a list of tools that are required for 1 Km of BRCP road construction.

No.	Activity	Tools	Unit	Quantity	Unit cost USD	Total Cost USD
1	Setting up alignment	Ranging Rod Profile board	No.	10	6	60
2	Carriage	Wheel barrow	No.	5	25	125
3	Spreading, loading	Hoes	No.	10	3	30
4	Spreading, loading	Shovel	No.	10	5	50
5	Checking alignment	Steel template	No.	1	30	30
6	Finishing	Traveller, Finisher	LS			50
7	Loading	Basket	No.	10	0.25	2.5
8	Water	Bucket	No.	20	1	20
9	Setting up	String line	Kg	5	1.2	6
10	Measurement	Measuring tape (5m)	No.	2	2.5	5
11	Measurement	Measuring tape (5m)	No.	1	7	7
12	Form work	Hammer (2Kg)	No.	5	2	10
13	Form work, corrections	Chisel	No.	5	1	5
14	Safety	Safety requirements	LS.			30
Total Cost in US\$ per Km						431

Table 4: Hand tools cost

Total Direct Cost

The total direct cost of the Bamboo Reinforced Concrete Pavement (BRCP) will depend primarily on the haulage distance as shown in Table 5. Note that these figures are specific for the circumstances of the Puok Market trials area.

No.	Item	Cost US\$ per Km for principal materials haul distance of		
		10 Km	50 Km	100 Km
1	Material	18,685	22,195	28,225
2	Labour	5,608	5,608	5,608
3	Equipment	2,706	2,706	2,706
4	Tools	431	431	431
Total Cost US\$ per Kilometre		27,430	30,940	36,970
Total Cost US\$ per square metre		6.86	7.74	9.25

Table 5: Total Direct Costs for BRCP per Kilometre and per Square Metre

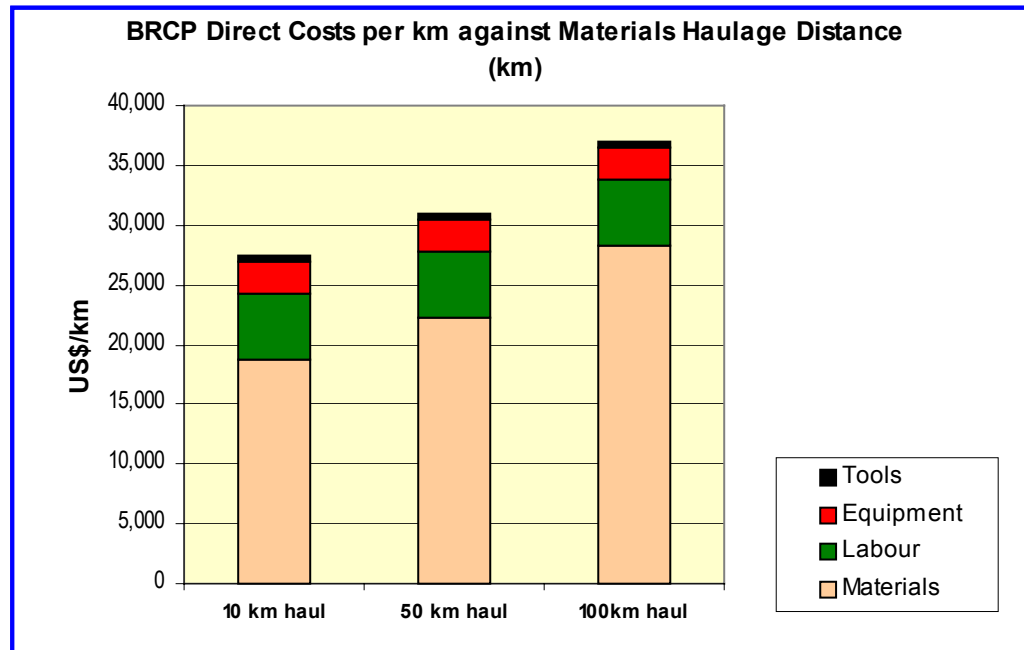


Chart 1: BRCP Direct Costs per km against Materials Haulage Distance

6.2 Indirect Costs of BRCP

As mentioned earlier in the document, indirect costs may be divided under the following sub-headings:

Preliminaries: additional costs directly related to the work such as mobilization, setting up site base, supervision, supervisors transport, quality control arrangements, health and safety insurance for workers and equipment, security and other similar costs.

Risk allowance: this factor includes risks related to construction projects such as bad weather, re-work, clients' financial security and other similar costs.

Company costs: these costs involve the cost of the company such as bidding and marketing costs, office rental, administration staff, interest on bank loans and other. This cost can be distributed on different projects carried out by the contractor at the same time.

In addition after covering all costs the contractor will expect to make a profit for his efforts and deployment of resources.

From the experiences of the project the indirect cost can be assessed as a percentage of the direct cost. Four per cent of the direct cost was added for preliminaries and risks. Ten percent was added for overheads and profit, based on the 10km haul of principal materials. The trials were held under a closely supervised environment with training and mentoring provided for the contractor, and prompt payments of all due amounts. It would be expected that preliminaries, risk, overhead and profit elements could vary somewhat for other contractual circumstances.

No.	Item	Cost US\$ per Km for principal materials haul distance of		
		10 Km	50 Km	100 Km
1	Material	18,685	22,195	28,225
2	Labour	5,608	5,608	5,608
3	Equipment	2,706	2,706	2,706
4	Tools	431	431	431
5	Overheads+Profit	3,840	3,840	3,840
Total Cost US\$ per Kilometre		31,270	34,780	40,810
Total Cost US\$ per square metre		7.82	8.70	10.20

Table 6: Overall Construction Costs of BRCP

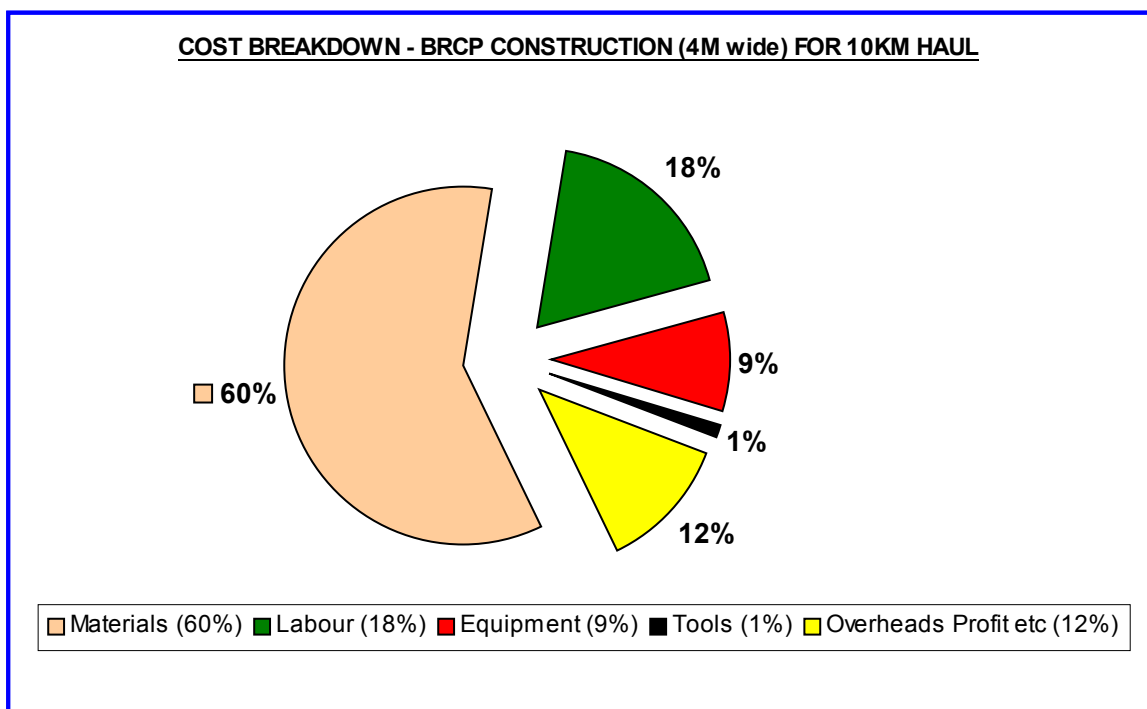


Chart 2: Cost Breakdown - BRCP Construction (4m wide) for 10km haul

6.3 Other Related costs

Side drains

Side drains were constructed around the market only. The costs of the side drains are separated in this report to show a more detailed analysis. Separation of the cost of drainage structures allows a direct comparison of pavement costs only. This is necessary to correlate the expenses rather than the analysis resulting in a comparison of costs between individual projects as a whole, which could be misleading.

The costs of labour and material for the two types of drainage structure applied at Puok Market are presented in the following tables.

No.	Item	Unit	Quantity	Unit rate US\$			Cost US\$ per m for haul		
				10 Km	50 Km	100 Km	10 Km	50 Km	100 Km
1	Sand	m ³	0.0225	5.00	6.00	7.00	0.1125	0.135	0.1575
2	Aggregate	m ³	0.045	9.00	14.00	24.00	0.405	0.63	1.08
3	Cement	kg	11	0.07	0.07	0.07	0.77	0.77	0.77
4	Sand bedding	m ³	0.03	5.00	6.00	7.00	0.15	0.18	0.21
5	Cement (mortar)	kg	7.35	0.07	0.07	0.07	0.5145	0.5145	0.5145
6	Sand (mortar)	m ³	0.012	5.00	6.00	7.00	0.06	0.072	0.084
7	Bricks	Pcs	75	0.03	0.03	0.03	2.25	2.25	2.25
8	Cement (plastering)	kg	2.73	0.07	68.00	70.00	0.1911	0.1911	0.1911
9	Sand (Plastering)	m ³	0.06	5.00	6.00	7.00	0.3	0.36	0.42
	Cement (Net Finishing)	kg	2.27	0.07	0.07	0.07	0.1589	0.1589	0.1589
Total Cost in US\$ per metre run							4.91	5.26	5.84

Table 7: Side-drain Material Cost

No.	Activity	Unit	Skilled	Unskilled	Total Cost US\$
1	Concrete work	%			0.47
2	Walls	Wd	0.13	0.195	0.41
3	Plastering	Wd	0.065	0.13	0.24
4	Net cement finishing	Wd	0.033	0.033	0.09
5	Curing of concrete	Wd		0.033	0.35
6	Local carriage	Lump sum			0.02
Total labour cost in US\$ per metre run					1.58

Table 8: Side-drain Labour cost

V-Shape Side Gutters

The calculation of the gutter costs are similar to the one for the side drain. Table 9 shows the material costs for the construction of the side gutter.

No.	Item	Unit	Quantity	Unit rate US\$			Cost US\$ per m for haul		
				10 Km	50 Km	100 Km	10 Km	50 Km	100 Km
1	Sand	m ³	0.0155	5.00	6.00	7.00	0.0775	0.093	0.1085
2	Aggregate	m ³	0.031	9.00	14.00	24.00	0.279	0.434	0.744
3	Cement	kg	7.59	0.07	0.07	0.07	0.5313	0.5313	0.5313
Total Cost in US\$ per metre run							0.89	1.06	1.38

Table 9: V-Shape Gutter Material Cost

It was observed that labour cost consists of approximately thirty five percent of the material cost i.e. about US\$ 0.31 per linear metre. Hand tools costs was assumed to be 1 per cent of the material costs.

Indirect costs

Six per cent of the direct costs were added for preliminaries and risk and ten percent for contractor overheads and profit.

PART 3