A Sustainable Road Construction Material for Low Volume Roads

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Abstract

The need of spending highway investments more efficiently is greater than ever before, due to escalation of prices of the conventional paving materials (asphalt, concrete). Hence, the road designers are in the verge of using alternative materials for the road construction which brings sustainable living conditions. Thus, focus has been on "Concrete Block Paving (CBP)", a road construction methodology which is based on ancient road construction technology "Stone Paving". In general, the applications of CBP are categorized according to the traffic condition as non-traffic, light traffic, medium traffic and heavy & very heavy traffic. The results of the study indicate that the life cycle cost of CBP is lower than the other paving materials although the initial construction cost is slightly high. When the performance of the three types of paving materials are evaluated, in addition to the low life cycle cost, the ability of accommodating and maintaining utility services, thermal comfort, aesthetic appearance and environmentally friendly behaviour can be highlighted as the key advantages of CBP.

Keywords: *Concrete Block Paving (CBP), Interlocking mechanism, Sustainable road construction materials*

Introduction

The past century has revealed an intense process of urbanization which has resulted rapid construction of roads and the infrastructure development. Different materials have been used for the road surfacing in these rapidly constructed roads, since the surface of the road should have the strength to withstand the vehicle load and resistance to wearing. Meanwhile, it should be durable.

Asphalt is the road surfacing material which is widely used in every type of road. The viscous nature of the bitumen binder allows asphalt to withstand a certain amount of plastic deformation, although it is possible for fatigue failure due to repeated loading for a longer duration.

Eventually, concrete also became a widespread road surfacing material for road construction. Concrete surfaces are created using a mix of cement, sand, coarse aggregates and water. Concrete roads became popular due to the higher strength and durability than asphalt roads. Higher construction cost could be stated as a drawback of this construction method.

Since the demand for road and infrastructure increased, it exposed the world to innovative construction methods which economize construction and increase durability. Thus, Concrete Block Paving (CBP) which is based on ancient road construction technology "Stone Paving" has been discovered as a better alternative than other conventional paving materials which have a lesser durability.

Objectives

The objectives of the study can be listed as follows:

1. Identification of the most economical paving material by considering the life cycle cost of several paving materials.
2. Performance evaluation of the selected paving materials.

Construction techniques

The three types of road surfacing materials mentioned above have different construction techniques.

Asphalt paving

Hot Mix Asphalt (HMA), generally known as asphalt concrete is a mix of aggregates with bitumen as the binding agent. It is produced at the HMA plant and delivered to the construction site by trucks. HMA which is transferred to the paver by the truck is spread as the surfacing material on the base layer constructed on sub base and sub grade. Compaction of the paved asphalt using different types of rollers is carried out consecutively (Gnasekaran, 2010).

Concrete paving

Concrete mix produced according to the required proportions of materials is poured on prepared base or sub base or sub grade depending on the design. Contraction and expansion joints are essential in concrete pavements in frequent interval to accommodate drying shrinkage and thermal stresses of concrete. Reinforcement is required to construct joint free concrete pavement and cost of reinforced concrete is significantly high compared to the plane concrete pavement (Karunaratne, 2011). After compaction of the paved concrete, it is left for the process of curing in order to gain strength.

Concrete block paving

Concrete Block Pavement consists of individual blocks of brick size arranged closely with joint space filled with sand on a bed of sand. The horizontal movement of blocks is constrained by the edge supports (curbs, etc.) The whole structure is supported by the sub base and sub grade. The load applied on the road surface is transferred horizontally to the substructure of the pavement. Hence, the interaction between the blocks, sand joints and support conditions are important (Concrete manufacturing Association, 2004).

Challenges in rural road construction

Many challenges have arisen in rural road construction due to various reasons such as insufficient funding, lack of proper construction technology and skilled labour, need of utility services due to urbanization.

Since the process of allocation of money for provincial level tasks from the central government varies due to different reasons as political influences funding may be insufficient to perform the required development in the area. In case of the technology used for construction, contractors in rural areas may not be aware of the proper techniques that should be adopted for road construction. They may not have sufficient skilled labour to work under them.

Once the construction of roads is completed, due to rapid urbanization, demand for infrastructure increases. Thus, there is a need to provide space for utility services such as water supply services and telephone services. In such situations, digging of constructed roads will be the only solution to accommodate utility services if it was not a consideration at the design stage of the roads. As a result, the stability and the durability of the road pavement are affected because the reconstruction of damaged locations would not take place afterwards.

Hence it is a necessity to introduce road construction methods other than the conventional methods which minimize the above mentioned complications.

However in the current state, the road surfacing material is selected arbitrarily by the road agencies in the provincial sector and life cycle cost is not considered in making decisions.

Cost comparison of alternatives

The life cycle costs of the three surfacing materials mentioned above (asphalt, concrete, CBP) were studied and the most economical paving material was identified.

Two major cost components are associated with road construction; initial cost and maintenance cost. Initial cost is mainly the construction cost of the road pavement. The cost due to the maintenance of the road surface is maintenance cost (Mamperachchi, Kosgolla, 2011). In each of the road pavement material, above two aspects were considered and the Net Present Value (NPV) per square meter for a design period of 20 years was calculated.

Net Present Value (NPV)

NPV technique recognizes the time value of money. The initial cost takes place in the year zero. The annual cost from the year zero to 'n' must be discounted to find the zero year value of such annual cost. The following equation is used to estimate the present worth of each annual cost.

$$NPV = \sum \frac{A_i}{(1+i)^n}$$

Where A_i – cost in i^{th} year
i – Discounting factor
P – Life cycle cost

Discounting factor

The value of money changes due to the effects of inflation and interest rate. Based on several economic parameters the discounting rate should be estimated. The discounting factor changes with the inflation and interest rate.

The mathematical relationship for discounting factor (i) is shown below.

$$i = \frac{(1+e)}{(1+d)} - 1$$

Where i – discount rate
e – Interest rate
d – Inflation rate

Interest rate – 10 % (Considering 10 previous years: Central Bank of Sri Lanka)
Inflation rate – 7 % (Considering 10 previous years: Department of Census and Statistics)
Therefore, **discounting rate (i) = 2.8 %**

Asphalt paving

Cost break down and the calculated unit cost for the construction of a typical asphalt pavement are shown in Table 1. Initial construction cost (Rs. 2554.83) is inclusive of the sub grade preparation cost, sub base, base and sub grade construction cost, costs for the application of the prime coat & the tack coat and the asphalt surfacing cost. Pothole patching, slurry sealing, crack sealing etc. are considered for the maintenance cost (Rs. 127.74) once in 2 years. In addition, resurfacing of the pavement is done once in 8 years. Application of tack coat, laying of asphalt and slight repairs of the base layer (about 5% of the initially constructed base) is considered in this. The user cost due to additional maintenance activities is neglected in the calculations. Even if it was considered, the obtained unit cost would be higher.

Table 1: Cost break down of asphalt pavement construction

Description	Qty	Unit cost	Cost
Sub grade preparation	0.15 m^3	566.15	84.92
Construction of sub base	0.1 m^3	920.29	92.03
Construction of aggregate base course	0.15 m^3	4,525.24	678.79
Application of prime coat	1 m^2	195.24	195.24
Application of tack coat	1 m^2	52.41	52.41
Asphalt laying - 50 mm)	1 m^2	1,161.15	1,451.44
Total Initial cost			**2,554.83**
Maintenance once in 2 years (5%)			127.74
Resurfacing once in 8 years			1,571.73

The cash flow for the construction of an asphalt pavement for a 20 year design period is shown below.

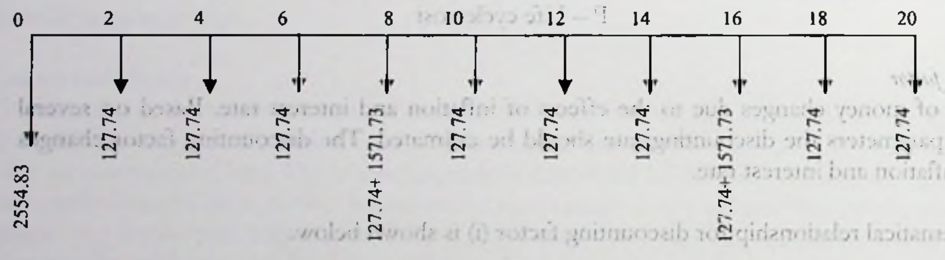

Figure 1: Cash flow for the construction of an asphalt pavement

Hence **NPV** of the asphalt pavement = **Rs. 4386.69**

Concrete paving

In the Table 2, the cost breakdown and the calculated unit cost for the construction of a concrete pavement are listed. Initial construction cost (Rs. 3279.07) is inclusive of the sub grade preparation cost, sub base, base and sub grade construction cost and the concrete pavement construction using Grade 30 ready mix concrete. Joint construction cost is also included for the calculation. It is considered that for a 3 m length, one joint is constructed. 5% from the initial construction cost is considered as the maintenance cost (Rs. 163.95) for once in 2 years. Sealing of joints and repair of joint faults and joint break is considered in this. User cost due to the curing process is not considered in the calculations.

Table 2: Cost breakdown of concrete pavement construction

Description	Qty	Unit cost	Cost
Sub grade preparation	0.15 m^3	566.15	84.92
Construction of sub base	0.1 m^3	920.29	92.03
Construction of aggregate base course	0.15 m^3	4,525.24	678.79
Concrete pavement construction (Grade 30)	0.15 m^3	15,600.00	2,340.00
Joint construction cost	0.33 m^3	250.00	83.33
Total Initial cost			**3,279.07**
Maintenance once in 2 years (5 %)			163.95

Source: Road Development Authority: Pavement rates 2013

The cash flow for the construction of a concrete pavement for a 20 year design period is shown below.

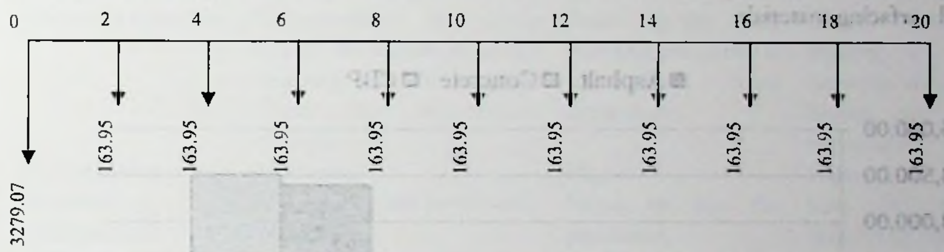

Figure 2: Cash flow for the construction of a concrete pavement

Hence **NPV** of the concrete pavement = **Rs. 4504.36**

Concrete block paving

For this calculation, 7m wide (full width of the road), 1m long road pavement is considered in order to include the costs of the edge restrains (curbs, etc.). Cost breakdown and the calculated unit cost for the construction of CBP are listed in Table 3. Concrete blocks of 30 N/mm² strength and thickness of 80mm are considered for the calculation. Maintenance cost is taken as 1% of the initial cost since it would be only the replacement of a few block units.

Table 3: Cost breakdown of CBP construction

Description	Qty	Unit cost	Cost
Block laying 30 N/mm² - 80 mm thickness	7 m^2	2,926.70	20,486.90
Construction of the curbs	1m	1,350.00	1,350.00
Total			**21,836.90**
Unit cost (1 m^2)			**3,119.56**
Maintenance once in 2 years (1 %)			31.20

Source: Road Development Authority: Pavement rates 2013

The cash flow for the construction of CBP for a 20 year design period is shown below.

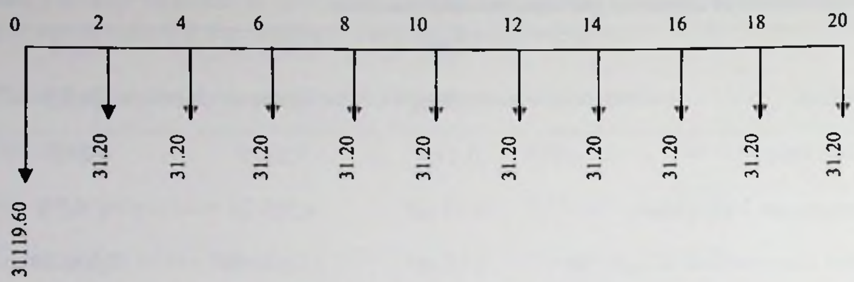

Figure 3: Cash flow for the construction of CBP

Hence **NPV** of CBP = **Rs. 3352.77**

Cost comparison

It is clearly apparent from the Figure 4, although the initial cost of asphalt is low the NPV for a design period of 20 years is high. Out of the three paving materials concrete has the highest NPV while CBP has the lowest NPV. Although CBP's construction cost is comparatively higher than that of asphalt and concrete, their maintenance cost is very much low. Thus a lower NPV is obtained. Hence it can be proven that CBP has the most economical life cycle cost from the selected surfacing materials.

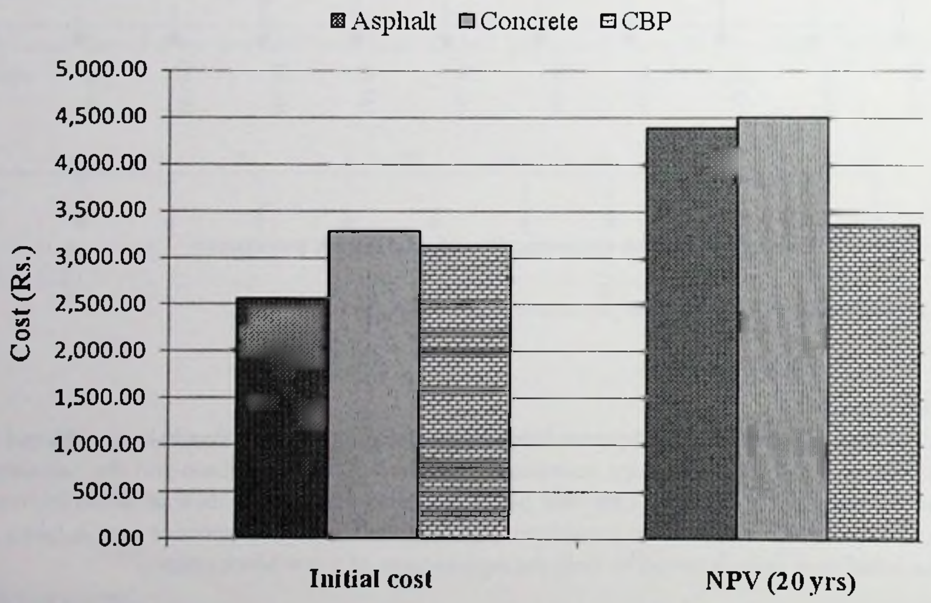

Figure 4: Cost comparison of the paving materials

Evaluation of performance

The performance characteristics of the three types of surfacing materials; asphalt, concrete & CBP differs under various aspects. A comparison of such characteristics is listed in Table 4.

Table 4: Performance evaluation of paving materials

	Asphalt	Concrete	CBP
Mix design	HMA is produced at the plant according to the bitumen content and the aggregate mix required for the construction	Concrete mix is produced according to the strength required for the construction	According to the application type mix design for the blocks are chosen
Site construction	Since HMA is transported to the site and paved, quality control measures are questionable	Since concrete is transported or mixed at the site quality control measures are questionable	Since precast concrete blocks are used high quality control can be expected (blocks are manufactured in a centralized location)
Accessibility to the traffic after construction	Some delay due to the compaction process	Closure for a certain period due to the curing process	Open to the traffic just after the construction
Strength	Moderate (can change due to temperature variations)	High	High
Deflection	Moderate (can change due to temperature variations)	Low	Low
Thermal expansion	Deformations can occur due to the variation of the viscosity of the asphalt when the temperature changes	Since joints are constructed there is no effect from expansion	Blocks are arranged leaving a 5 mm gap between two blocks and hence no effect from expansion
Skid resistance	Moderate	High	High
Access to underground utilities	Need to dig the pavement	Need to dig the pavement	Can be accessed by removing the blocks and these blocks can be replaced
Maintenance	High (resurfacing, crack sealing, pothole patching etc.)	Moderate	Low (replacement of a few blocks)
Life cycle cost	Very high	High	Low
Eco-friendliness	Not an eco-friendly material	Good	Good
Appearance	Moderate	Moderate	Very high

Source: Mamperachchi, Pilanavithana, 2011
Gnasekaran, 2010
Karunaratne, 2011
Concrete Manufacturing Association, 2004

Sustainability of CBP for road construction

The information mentioned in Table 4 has proven that CBP as the most sustainable road paving material. Although, the initial cost is somewhat higher, the life cycle cost is reasonably lower than the other two types of paving materials. This would be ideal for rural road construction, since allocation of long term funding for maintenance etc. does not happen frequently. Hence, it would be more appropriate to use a paving material which requires less maintenance activities.

Another key benefit of CBP is the accessibility for utility services. Without much effort, some blocks can be removed and underground construction could be done. After the work is finished, the blocks could be replaced if they are not damaged.
CBP minimizes the user delays which occur as a result of the closure of roads, since the construction is easy and it can be open to the traffic immediately after the construction.

As the world is in a state where every single mechanism is moving towards fast and easy methods, CBP is the most suitable paving material, which meets the challenges in rural road construction.

Good practices in CBP construction

Applications of CBP are categorized according to the traffic condition as non-traffic, light traffic, medium traffic and heavy & very heavy traffic. Concrete blocks have become a widespread road construction material for low volume roads due to their simplicity in construction and low maintenance requirement compared to other types of roads. CBP is widely known as interlocking blocks because of the mechanism which generates restraining vertical, horizontal and rotational movement simultaneously, with the application of tire load (Algin, 2007, Knapton and Barber, 1979).

Grades and thicknesses

In Sri Lanka, standards have been established mentioning the strength and thickness requirement for each traffic category as shown in Table 5.When the thickness of the block is increased the frictional area of the block increases and the movement resistance ability increases. Hence, the deflection of the road pavement decreases.

Traffic Category	Grade (N/mm^2)	Block thickness (mm)
Non - Traffic	15	60
Light Traffic	30	80,100
Medium Traffic	40	80,100
Heavy to very heavy Traffic	50	80,100

Table 5: Grades and thicknesses of CBP

Source: Mampearachchi, Pilanavithana, 2011

Block shapes

Numerous block shapes can be found in the industry. Some of them are namely uni style, keystone, satin pave, cobble, honey etc. It has been discovered that uni style block as the most effective block shape since it allows geometrical interlock between vertical or side faces of adjacent blocks. In a study by Gunarathna (2009) it has been identified that uni style blocks have the lowest maximum deflection under the tire load as shown in Figure 5. Most of the other shapes are being used for their aesthetic appearance.

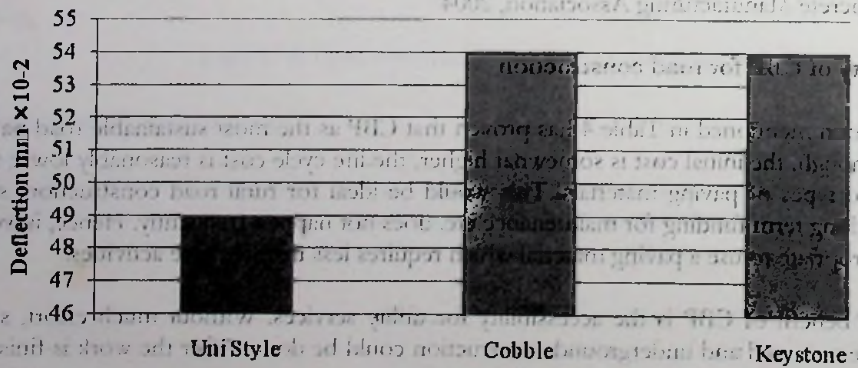

Figure 5: Block shape vs. maximum deflection
Source: Gunarathna, 2009

Laying patterns and laying angles

There are various types of laying patterns namely, herring-bone, stretcher, basket weave and stack bond. As per the previous studies (Gunarathna, 2009), stretcher bond and herring-bone bond types are the most appropriate laying patterns for road construction due to the lower deflections in pavements under the tire load (Figure 6). It is highly recommended to lay the block patterns in line or at right angle to the direction of traffic, since the interlocking action is more effective in this manner.

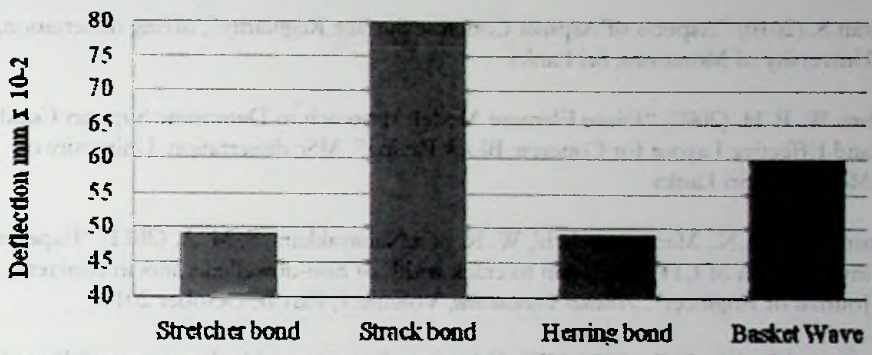

Figure 6: Block laying pattern vs. maximum deflection
Source: Gunarathna, 2009

Summary

- Although the initial construction cost of CBP is slightly higher than other conventional paving materials, it has the lowest life cycle cost
- Applications of CBP are categorized according to the traffic category and standard grades and thicknesses have been established with respect to that.
- Block shape with the highest performance is the uni style block.
- Most effective laying pattern is herring-bone pattern
- Block laying patterns should be in line or right angle to the direction of traffic, in order to achieve the best interlocking action
- The ability to accommodate and maintain utility services, thermal comfort, aesthetic appearance and environmentally friendly behaviour can be highlighted as other key advantages of CBP

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