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Cost Effectiveness of Interlocking Concrete Block Pavements for Low Volume Traffic Roads

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Abstract: ***Decision on choice of pavement type for roads is based on its service requirement, construction and maintenance costs and availability of the desired construction materials. In developing countries like India, the fund available for construction and maintenance is always limited and thus has a huge influence on such infrastructure projects. Traditionally, asphalt and concrete pavements are used in road construction. Interlocking concrete block pavement (ICBP) has been in use for some time now as an alternative pavement type. One of the advantages of such pavement in comparison to asphalt and concrete pavements is its easy availability, sophisticated design and construction methods. Past studies have shown that the interlocking pavements are economical. But it may not be every time. In this context, the present study has been undertaken to investigate the same. As a case study, the Ram Krishna Mission (RKM) road of Guwahati, a semi urban city of North East India is considered. To estimate the total life cycle cost, a basic mathematical equation has been formulated in the present work. The advantage of the mathematical formulation is that it can incorporate multiple cycles of pavement construction and maintenance costs. Also, one more advantage of the present equation is that it can consider analysis period any size. The present study uses an analysis period of 30 years. To incorporate the change of price value and inflation, a discount rate and inflation rate has been introduced in the formulation. The results of the current analysis show that interlocking pavements are costlier than asphalt pavements contrary to the findings of the past researchers. A sensitivity analysis is done to find whether the conclusion might vary with different discount rates. However, it was found that ICBP is not economical.***

Keywords: ***Interlocking concrete block pavement, Asphalt pavement, Net present value, Life cycle cost***

I. INTRODUCTION

The early use of interlocking pavement is found during the time of Roman Empire. Flat stone plates were tightly joined to one another along the edges and laid over a layer of lime mortar [1]. The thicknesses of the stone plates were in between 100 mm to 150 mm. The present day interlocking pavements are constructed with concrete blocks, which are available in different sizes, colour and in specific design grades.

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Such pavements had been in use particularly in areas such as vehicle parking lots, bays, footpaths and taxiways at airports. Interlocking pavements, also known as interlocking concrete block pavements (ICBP) are now being used as an alternate to conventional pavements such as asphalt and concrete pavements. ICBP are generally used in road sections where the traffic volume is low. Countries like India, which is a low income country, infrastructure projects such as road construction and maintenance are taken under strict economic constraints. Now a day, the economic impact due to environmental condition is also assessed in such projects. The cost of construction and maintenance of asphalt and concrete pavements is large. In India, approximately Rs.100 million is required to construct a four lane asphalt highway (1 US dollar=Rs. 70). Concrete paver blocks are easily available in the market and hence can be easily replaced if damaged. Owing to this advantage since the last two decades or so, in India also, highway agencies have started to opt for paver block roads over asphalt and concrete roads. Recently, in Guwahati, the local authorities have also started constructing roads with paver blocks. The city is situated along the southern bank of river Brahmaputra and has a population of around 1.8 million [2]. It experiences a good amount of rainfall throughout the year. Under repeated traffic loading combined with adverse climatic conditions, the roads undergo frequent wear and tear during its design life. The roads require routine maintenance but are often neglected due to financial constraints. As mentioned above, the local authorities in Guwahati has opted for pavers block as an alternative road construction technique. The selection of ICBP over asphalt pavement by the highway agencies could be due to its low maintenance cost during its lifetime. However, ICBP may not be economical every time. The main objective of the current work is to study the economic viability of the ICBP in Guwahati city as an alternative to asphalt pavements by estimating the life cycle costs for both the types of pavement. As a case study, the Ram Krishna Mission (RKM) road of Guwahati is considered, which has been recently constructed as ICBP. Fig. 1 shows the location of Guwahati city in North East India. The location of the RKM road in Guwahati is shown by the marking 'X'. The length of the road is 1 KM. It is an undivided road with one lane in each direction of travel.

The section wise discussion of the paper is presented here. The literature relevant to the current study and the objective is discussed in Section 2. The general feature of the RKM road is discussed in Section 3.

The yearly traffic of the RKM road is estimated for the calculation of yearly axle load repetitions and for the pavement design. The methodology of traffic count and axle load repetitions is discussed in Section 4. In Section 5, the life cycle cost analysis has been discussed. A sensitivity analysis is done in terms of three different discount rates. This analysis has been discussed in Section 5. The conclusion of the present study is discussed in Section 6.

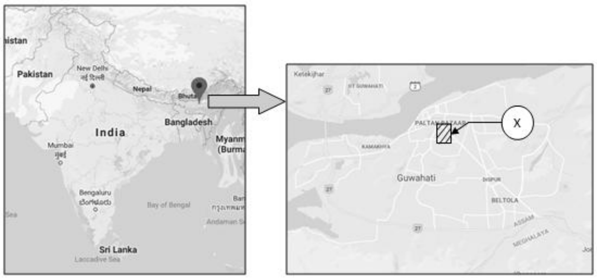

Fig. 1 Map of India showing location of Guwahati city (parachute symbol) and shaded portion (X) showing the location of RKM road. (Courtesy: Google maps)

II. Literature Review and Study Objective

To estimate the pavement life cycle cost, information on design thicknesses of pavement layers, type of distresses possible on the pavement and type of maintenance actions to be carried out to restore the damaged pavement etc. is required. For the design part, different methods are followed. The design of ICBP is similar to that of design of asphalt pavements [1-9]. This is due to the fact that the traffic load distribution and the types of distresses of ICBP are similar to that of asphalt pavement. The methods followed for the design of asphalt pavements are categorized into two groups: empirical and mechanistic methods [10-12]. Similar to asphalt pavement, ICBP design methodology also requires information such as expected traffic load repetitions in the design period and soil sub-grade strength etc. The design thickness of the base layer, subbase layer and the design grade of concrete paver blocks to be used in the road are found out from such analysis. As mentioned already, various types of distresses are possible in a pavement and it is important to understand these distresses so that appropriate measures can be taken such that maintenance cost remain minimal. In this context, the distresses of both ICBP and asphalt pavement are listed here. The ICBP distresses are damages to paver blocks, depression, heaving, horizontal creep, faulting, pumping and rutting etc. [13]. Fig. 2 shows a depressed ICBP. It can be seen that water has accumulated in the depressed area.

Fig. 2 ICBP pavement with depression and accumulated water in the depressed area

The primary distresses on an asphalt pavement are fatigue and rutting [10-12]. Several other distresses such as block cracking, heaving, depression, longitudinal cracking, pumping and roughness etc. are also seen on an asphalt pavement [13]. Depending on the extent and severity of pavement distresses, various types of maintenance actions are carried out. Such actions could be grouped into two categories: preventive and routine maintenance [14-15]. With each maintenance action, there are costs involved and are born by the highway agencies/governments. These agencies allocate money for maintenance work based on certain mechanisms. Few highway agencies/institutions have assumed that an average area of 25 to 40% of the total ICBP area has to be replaced due to distresses or damages during the pavement life (typically in a lifetime of 10 years) [16-17]. Similarly, for the maintenance of the asphalt pavements during its design period, agencies have considered a yearly sum of Rs. 150000 to Rs. 750000 [16-17]. Considering all such factors, researchers have carried out analysis to compare the life cycle cost between ICBP and asphalt pavements [17, 21-23]. Results from the studies have shown that the ICBP are economical compared to asphalt pavement. However, in some cases, it is found that ICBP might not be economical; the first installation cost of ICBP is higher than the asphalt pavements for low and medium traffic categories [17, 23-26].

The results of such analysis show that the cost effectiveness of a particular type of construction technique depends upon various factors such as the cost of materials, labour and machineries, selection of remedial/maintenance actions, frequency at which maintenance actions would be applied and the type of construction methods adopted. Keeping all these factors in view, it is essential that the construction projects are undertaken considering the entire economic scenario, particularly in roads and infrastructure projects. Construction and maintenance of roads in a low income country such as India, the available funds are always limited. In addition, the maintenance works of roads are undertaken after a long gap of several years and are often delayed. Thus, in this context, the current study makes an attempt to compare the life cycle cost between ICBP and asphalt pavement in Guwahati city to find the most economical one. As a case study, the RKM road of Guwahati has been considered which has been recently constructed as ICBP.

III. General Feature of the Studied Road

RKM road is an undivided road with low volume of traffic. RKM road is of 1 km in length. Fig. 3 show the road. Fig. 4, Fig. 5, Fig. 6 and Fig. 7 are photos of the road at location A, B and C. The road is on an average 7.5 m in width (location B and C). However, at some places the road width is found to be 9 m (location A). The road is undivided without any median. There is one lane on each direction for traffic movement. There are no lane markings on the road and the minor junctions that are present along the road are un-signalized. Footpaths are available for pedestrian along both the edges of the road. Footpaths are of 1.5 m in width.

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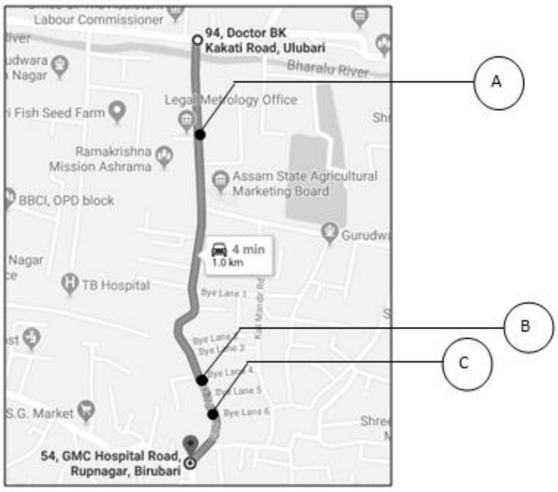

Fig. 3 Ram Krishna Mission (RKM) Road
(Source: Google map)

Fig. 4 First photo showing RKM road at location A

Fig. 5 Second photo showing RKM road at location A

Fig. 6 Photo showing RKM road at location B

Fig. 7 Photo showing RKM road at location C

The schematic cross section of the RKM road pavement which has been constructed as ICBP is shown in the Fig. 8. The pavement has a subbase layer (150 mm thick), a base layer (100 mm thick), a layer of sand bedding (30 mm thick) and the layer of concrete paver blocks. Fig 9 shows the shape of the paver blocks that have been used in the construction of the road. The dimension of the paver block is 220 mm×100 mm×60 mm.

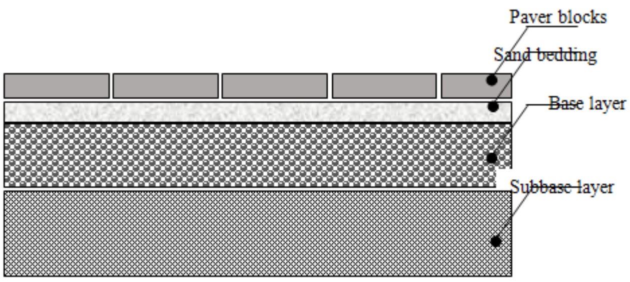

Fig. 8 ICBP layer structure of RKM road

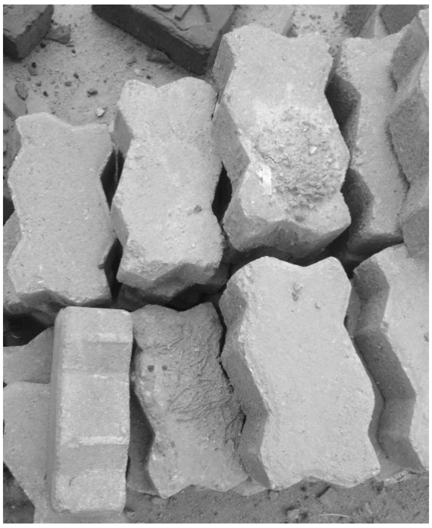

Fig. 9 Paver blocks used in RKM road

IV. TRAFFIC ESTIMATION ON THE ROAD

Traffic information of RKM road such as number of vehicles traversing through the road, type of vehicles, axle type and configuration is required for the current analysis. The duration and the days on which the traffic data is collected should be such that it can represent the typical traffic flow of an average day for the study area. The data collection duration is called count period. The range of count period can vary from 5 minutes to 1 year. To remove observational bias, count period should avoid special events and bad weather conditions. Literature shows that traffic counts on Monday and Friday should be avoided in analysis. Monday and Friday being the starting and closing days of a week may show exceptionally high and erratic volumes. Hence, traffic counts should be conducted on Tuesday, Wednesday and Thursday [25]. The following points are kept in mind during data collection:

- Traffic data collection should be conducted away from intersections;
- The road length for which the data is collected should be a geometrically straight;
- The section should have uninterrupted traffic flow and should have minimum animal and pedestrian movements.
- For the manual counting method, the observer must have an unobstructed view of the traffic and should be positioned away from the roadway edge.

Location A (refer to Fig. 2) has been selected for the traffic count. The discussion on traffic count is presented in next section.

A. Traffic Volume Count

In the current study, manual counting method is adopted to collect data on classified volume count on the road. Previous studies have suggested that a three-day traffic count would be able to estimate the daily traffic [27]. As per criteria, in order to get an unobstructed view of the straight section of the road, the observer positioned himself on the roof of a first floor residential building. The data is collected for 12 hours on three days: Tuesday, Wednesday and Thursday as per the following schedule:

Table 1 Period of traffic data collection

Time	Type of traffic
Morning, 9 to 11 AM	Peak period
Afternoon, 12 to 2 PM	Off peak period
Evening, 4 to 6 PM	Peak period
Late evening, 7 to 9 PM	Off peak period
Night, 12 to 4 AM	Truck traffic

Table 2 Traffic volume based on vehicle type classification

Time	Number of vehicles in both directions of travel								
	Car			LCVs			Truck		
	Tues	Wed	Thurs	Tues	Wed	Thurs	Tues	Wed	Thurs
9 to 11 AM	93	86	96	6	7	6			
12 to 2 PM	25	25	20	4	3	5			
4 to 6 PM	110	115	106	2	0	3			
7 to 9 PM	40	33	35	1	1	2			
12 to 4 AM							7	7	5

As per the above table, the average commercial vehicles are 280 during 12 hours of data collection (considering both directions of travel). Assuming that in the remaining 12 hours 5% of the cars and LCV will ply on the road, the number of commercial vehicles is 295.

V. LIFE CYCLE COST ANALYSIS

For the life cycle cost analysis, an appropriate and large analysis period is assumed keeping in consideration that multiple rehabilitation and numerous maintenance actions can be carried out in that time period. In addition, a discount rate and an inflation rate are assumed in the analysis to incorporate the price inflation and change in money value within that period. This rate is considered keeping in view of the current market situation of the country. The analysis period constitutes many design periods of the pavements. Within these design periods, routine maintenance would be carried out if any distresses occur on the pavement. The mathematical formulation to estimate the life cycle cost has been discussed in the following section.

A. Formulation for the life cycle cost analysis

The life cycle cost (C_T) is represented in terms of net present value (NPV) and calculated as per the equation below:

$$C_T = C_l + \sum_{n=p\times(n-1)}^{N} \left(\frac{C_n}{(1+d)^{p\times(n-1)}} \times (1+i)^{p\times(n-1)} + \frac{C_{m,\ n\ to\ n+1}}{(1+d)^{p\times n}} \times (1+i)^{p\times n} \right) \quad (1)$$

As per the equation, the cost of construction of layers below the paver block/asphalt pavement is considered separately (C_l). The cost of construction of the layer of paver blocks/asphalt concrete is considered as: *Cn* and as seen in the equation, is within an algebraic sum.

The algebraic sum is used to incorporate all the costs (construction and maintenance) in *n* number of times the pavement would be laid with paver blocks/asphalt pavement (within the analysis period). For example, if the analysis period is 30 years and design period (*p*) of pavement is 10 years, then N=(30/10=3) and thus it would mean that *n* varies from 1 to 3. Therefore, when *n+1*, it means that the pavement has been constructed as a new pavement. In Eq.1, *C m, n+1*, is the cost of maintenance within the design period or from *n* to *n+1* (between two successive relaying phases of paver block layer/asphalt concrete layer). In the equation, *d* is the discount rate and *i* is the inflation rate and are used to bring the future costs in terms of net present value. The costs thus calculated with the above equation have been discussed below.

B. Schemes of life cycle cost analysis

For the cost comparison, the analysis period has been considered as 30 years. The design period of pavement is taken as 10 years. The discount rate and the inflation rates are assumed as 4% and 2% respectively. As estimated, the daily traffic on the RKM road is 295 CVPD. The maintenance cost for ICBP has been assumed as the cost of replacing the 25% of the paver block area which has been damaged during the design period. For asphalt pavement, it has been assumed that an amount of Rs. 3×105 would be required every year for maintenance. Table 3 shows that unit rates of various items that have been considered in the cost analysis. The rates are as per current market price.

Table 3 Current market rates of different items used in ICBP for RKM road

Item	Unit	Rate in Indian currency (Rs.)
Concrete paver blocks	m^2	850
Sand bedding	m^3	950
Subbase layer	m^3	1000
Base layer	m^3	1300

C. Cost of RKM Road as ICBP

As already discussed, the RKM road is of 1 Km in length and the average width is 7.5 m. The pavement comprises a subbase layer (150 mm), a base layer (100 mm), a sand bedding layer (30 mm) and a layer of paver blocks (60 mm) on top of it. Using the Eq. (1), the total life cycle cost for the ICBP for the road is found to be Rs. 2.28×107.

D. Cost of RKM Road as Asphalt Pavement

To estimate the life cycle cost of RKM road as an asphalt pavement, a typical pavement has been considered. The pavement consists of an asphalt layer and a base layer resting on top of soil subgrade. The thickness of the granular base layer has been considered as 150 mm and subgrade layer thickness as 300 mm. The pavement properties considered are as follows: elastic modulus of asphalt concrete: 3000 MPa, granular layer: 250 MPa, soil subgrade: 25 MPa. Poisson's ratios are as follows: asphalt concrete: 0.45, granular layer: 0.4 and soil subgrade: 0.4.

Multilayer elastic analysis is used to design the asphalt pavement. The traffic load repetitions have been estimated as design million standard axles (msa). The yearly traffic growth rate has been considered as 5%. Mechanistic empirical equation method is used to calculate the design traffic against fatigue and rutting distress [3-5]. As per the analysis, to serve the design traffic of 1.92 msa, 3.15 msa and 5.12 msa for the 1st, 2nd and 3rd design periods of each equal to 10 years, the thickness of asphalt layers required are: 90 mm, 72 mm and 60 mm. Thus using Eq. 1, with the assumed discount rate, inflation rate and the yearly maintenance cost as assumed, the total life cycle cost in terms of NPV is Rs. 2.19×107.

The cost of ICBP and asphalt pavement is shown in Fig. 10. From the figure, it is seen that the cost of ICBP is 4% higher than the asphalt pavement.

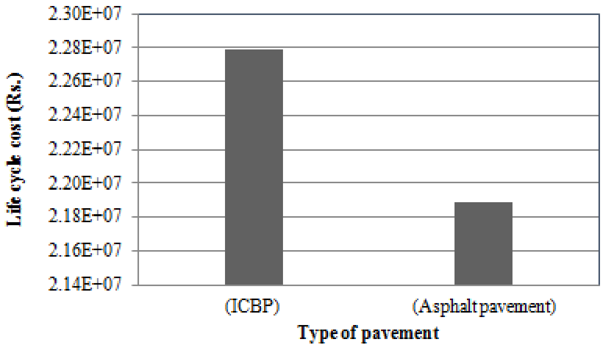

Fig. 10 Life cycle cost of RKM road as ICBP and as asphalt pavement

E. Sensitivity Analysis

A sensitivity analysis is performed in the present study in terms of discount rate. The objective of the analysis is to study the variation of life cycle cost with respect to discount rates. Three different discount rates are assumed: 4%, 5% and 6%. Using Eq. 1, the costs were estimated and are shown in Fig.11. From the figure, it can be seen that, with increasing discount rates, the life cycle costs of both the pavement type are decreasing. It is also seen that, for all the three discount rates, the cost of ICBP is higher compared to asphalt pavement.

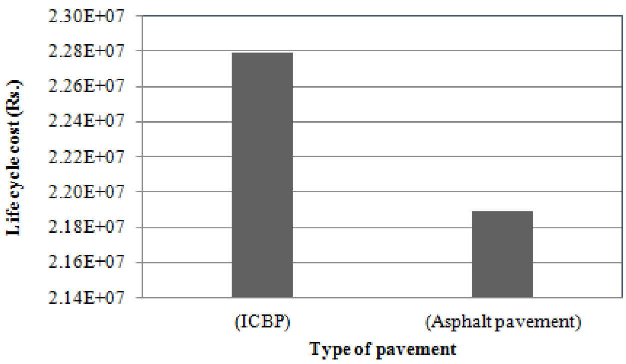

Fig. 11 A comparison showing the variation of life cycle cost with respect to discount rates between for RKM road as ICBP and as asphalt pavement.

VI. CONCLUSION

Recently, the roads of Guwahati city are constructed with concrete paver blocks, replacing the old practice of constructing pavements with asphalt concrete. Selection of ICBP is attributed mainly to its low cost of construction. In the current context, to verify the same, the current study makes an attempt to find the cost effectiveness of ICBP compared to asphalt pavement. Ram Krishna Mission (RKM) road of Guwahati, which is a low volume traffic road, is considered as a case study. The RKM road is constructed recently as ICBP. The life cycle cost of RKM road as an ICBP is estimated. As an alternate to ICBP, the life cycle cost of RKM road as an asphalt pavement is also estimated. A cost comparison of the two types of road is carried out. Results of the current analysis show that RKM road as an asphalt pavement is found to be more economical compared to ICBP. A sensitivity analysis is also done is terms of three different discount rates to study the variation of costs. The results of the analysis show that for all the three discount rates, the RKM road is most economical as asphalt pavement. Thus it seems that ICBP pavements are not always economical. However, the present conclusion may vary under different traffic condition and material costs.

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