LIFE CYCLE COST ANALYSIS OF OVERLAY FOR AN URBAN ROAD IN BANGALORE

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Abstract

Pavements are subjected to severe condition of stresses and weathering effects from the day they are constructed and opened to traffic mainly due to its fatigue behavior and environmental effects. Therefore, pavement rehabilitation is one of the most important components of entire road systems. This paper highlights the design of concrete pavement with added mono fibers like polypropylene, steel and hybrid fibres for a widened portion of existing concrete pavement and various overlay alternatives for an existing bituminous pavement in an urban road in Bangalore. Along with this, Life cycle cost analyses at these sections are done by Net Present Value (NPV) method to identify the most feasible option. The results show that though the initial cost of construction of concrete overlay is high, over a period of time it prove to be better than the bituminous overlay considering the whole life cycle cost. The economic analysis also indicates that, out of the three fibre options, hybrid reinforced concrete would be economical without compromising the performance of the pavement.

Keywords: - *Fatigue, Life cycle cost analysis, Net Present Value method, Overlay, Rehabilitation*

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1. INTRODUCTION

Road network in India has grown exponentially from 0.4 million km in 1951 to 3.32 million km presently with increase in motor vehicles from 0.3 million in 1951 to 108 million in 2008 [1]. Due to this gigantic increase in traffic load, its intensity, tire pressure, inadequate design of pavement thickness and ill-drained effects, highway engineers are finding themselves at a great disadvantage in keeping pavements in a traffic- worthy state. The scarcity of resources for the road sector in the past has lead to the adoption of stage wise construction strategies with a short design period [2]. Therefore road construction in our country will be a never ending process, with pavement strengthening to be a major activity for many years to come. An overlay is a layer of suitable thickness provided on top of an existing pavement to improve its structural adequacy and riding quality. The two principal options for overlay in terms of specification of binder are [3]:

- Flexible overlay, consisting of granular layers and bituminous layers
- Cement concrete overlay

Cement concrete overlay on top of an existing bituminous surface is commonly known as white-topping. White-topping based on thickness and bonding conditions are again classified as: Conventional white-topping : thickness range : 200-300 mm, Thin white-topping : thickness range : 100-200 mm and Ultra thin white-topping : thickness range : 50-100 mm.

Overlay practice in India: In India, the most common strategy for pavement maintenance and rehabilitation was to provide bituminous overlays on existing black topped surface. This was mainly due to abundant supply of bitumen, in addition to the comfort levels of construction methods among engineers. In recent times all these advantages are reversed and petroleum industry is using refined processing technology leading to reduction in the production of bitumen thereby increasing imports [4, 5]. The rapid developments in concrete material technology and mechanization are favoring concrete overlays as a sustainable option. A typical mix proportion of concrete overlays by taking into consideration polypropylene fiber, mineral admixtures like fly-ash, granulated blast furnace slag, silica fume have shown increase in density of concrete due to particle packing theory [6].

2. OBJECTIVES & SCOPE OF THE STUDY

The main objective of the research is to study the structural adequacy of existing pavement and to design the overlay alternatives along with cost evaluation of each alternative.

3. DATA ACQUISITION

3.1 Stretch Selected

The stretch selected is located in eastern part of Bangalore city and acts as a link between NH-4 (Old Madras road) on north western side and Old Airport road on south western side as shown in Figure 1. This is one of the busiest stretches in the city. The traffic in the area chosen was moderately dispersed

at all times of the day, since the either side of corridor is populated with establishments like HAL, BEML limited, Bagmane Tech park, HAL engine division etc. The road is 2 lane with a total length of about 3.8 km in which 2.7 km is rigid pavement and the remaining 1.1 km is flexible pavement as shown in Figure 2.

3.2 Benkelman Beam Deflection Study

Surface deflections of existing flexible pavements are usually measured by Falling Weight Deflectometer (FWD) and Benkelman Beam Deflection test (BBD). A good correlation strength was obtained between FWD and BBD values in a study done by Jundhare.D.R [9] on conventional white-topping of 320 mm thickness. Benkelman beam deflection study was done on the stretch, and the characteristic deflection obtained was 1.67 mm.

3.3 Traffic Data

For the design purpose, analysis is being made on the number of commercial vehicles of laden weight having 3 Tons or more. From traffic analysis, the commercial vehicles per day obtained for section 1 and section 2 was 1146 cvpd and 982 cpvd respectively.

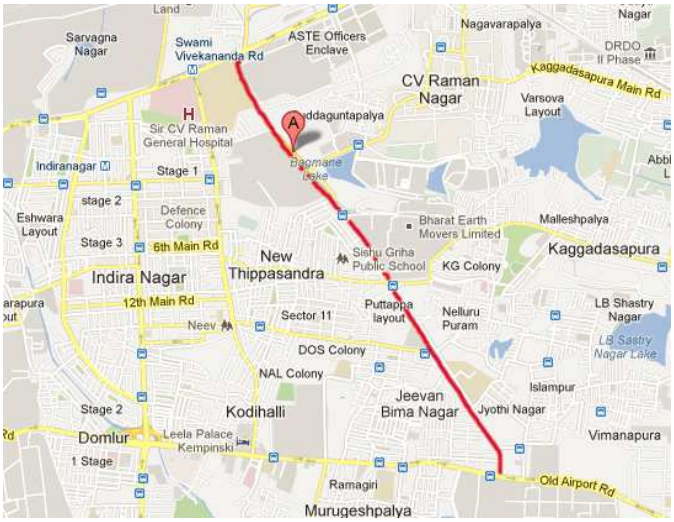

Fig 1: Map showing the selected stretch

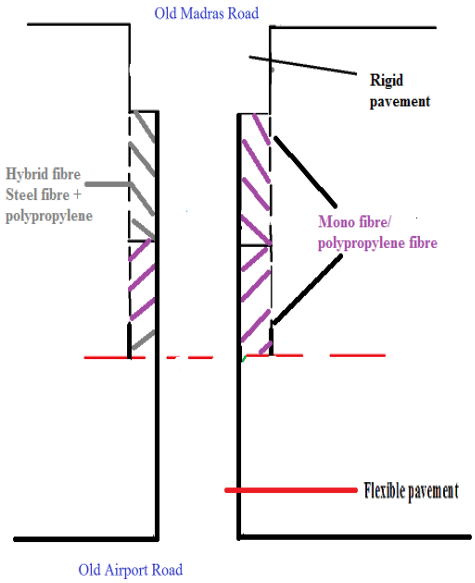

Fig2: Different pavement sections in the selected stretch

4. DESIGN OF SECTIONS

Design of flexible overlay has been done as per IRC:81-1997 using Benkelman Beam Deflection value and traffic in msa [6]. Rigid overlay design has been done as the same procedure for new pavement given in IRC: 58-2002 [7]. White-topping design is done as per IRC: SP: 76-2008 [8].

4.1. Section 1: Widening of Concrete Road

Existing single lane concrete road was to be widened on either side. Concrete pavement combined with fibres where used for this. Fiber reinforced concrete (FRC) is mixtures of cement concrete containing short discrete, uniformly dispersed and randomly oriented suitable fibrous material which increases its structural integrity. The amount of fibers added to concrete mix is measured as percentage of the total volume of composites. Aspect ratio (l/d) is calculated by dividing fiber length (l) by its diameter (d).The types of fibres used for the design along with the flexural strength and obtained thickness is given in Table 1.

Table 1: Thickness of concrete with different fibers

Concrete	Flexural strength ,MPa	Thickness obtained, mm
Plain	4.62	290
Polyproplyene	4.762	280
Steel	5.129	270
Hybrid	5.54	250

4.2 Section 2: Flexible Pavement

The existing flexible pavement has developed distresses like rutting. So overlay has to be provided as a rehabilitation strategy. Flexible or concrete overlay can be provided over the bituminous surface.

4.2.1 Design of Flexible Overlay

Based on Benkelman Beam deflection data and commercial vehicles per day using IRC-81, the thickness of flexible overlay has been found out to as 150 mm BM. The thickness deduced is the overlay thickness in terms of BM construction. The equivalent overlay thickness to be provided can b determined using equivalency factors. So the total individual thicknesses obtained are: BC thickness: 40 mm and DBM thickness: 65 mm

4.2.2 Design of Thin White-Topping

Thin white-topping design is carried as per IRC; SP: 76-2008 and IRC: 58-2002. The thickness obtained was about 200 mm. The cumulative fatigue life consumed is less than 1. Hence design life is safe from fatigue consideration. Total of temperature warping stress and highest axle load stress = 21.98 kg/cm2, which is less than 45kg/cm2, the flexural strength.

5. ECONOMIC EVALUATION

The alternative methods of strengthening or repairing of roads should be based on their durability rather purely by initial cost. The cost comparison for such alternative strengthening/repair methods should be based on the concept of life-cycle cost analysis

5.1 Life Cycle Cost Analysis between Different Types of Fibres in Concrete for Section 1

In Section 1 the existing concrete pavement has to be widened with addition of fibres to enhance its performance. The quantity of work item involved in section 1 per km length is given in Table 2.

Table 2: Quantities of work item involved per km length

	Control concrete (cum)	Concrete with polypropylene fibre (cum)	Concrete with steel fibre (cum)	Concrete with hybrid fibre (cum)
Heavy traffic	1160	1120	1080	1000

In the present analysis the rates considered are Rs. 5191/ Cum for control concrete, Rs. 376/kg for polypropylene fibre, Rs. 140/kg for concrete with steel fibre. Inorder to obtain flexural strength of 4.762 MPa for polypropylene fibre reinforced concrete, the percentage of recron 3s fibre used was 0.036% (900g/cum of concrete). Therefore its cost will be Rs. 5529/ Cum. Similarly cost of steel and hybrid fibre concrete was found out to be Rs. 8691/ Cum and Rs. 9029.4/ Cum respectively. Traffic volume survey was conducted at stretch 1 and the volume of commercial vehicles obtained is given in Table 3.

Table 3: Traffic volume obtained from traffic survey

Type	Count
Bus	166
HCV	570
MAV	44
LCV	332

A study made by CRRI, New Delhi on Delhi-Agra (NH-2) found that there will be saving of 14% in fuel on concrete road as compared to bituminous road for commercial vehicles [9]. The parameters considered for life cycle cost analysis by Net Present Value method is given in Table 4.

Table 4: Parameters considered for analysis of section 1

Commercial Vehicles Per Day	1146
Traffic growth rate	7.50%
Inflation	5.00%
Diesel Cost	Rs.54.21/l
Fuel Savings	14.00%
Mileage	4kmpl
Annual Fuel Savings (Rs)	CVPD*365*FuelSavings*Mileage*DieselCost

5.2 Economic Comparison between Flexible and Concrete Overlay for Section 2:

It will be assumed that bituminous overlays need following interventions during the analysis period: 10th, 20th years : 50 mm BC + 75 mm DBM for heavy traffic , 40 mm BC + 75 mm DBM for medium traffic [10]. Surface renewals are provided as per MORTH as 25 mm BC once in 5 years. The cost of ordinary repairs as per 2011 price is 2,10,000 Rs/ Km. Quantity of work item involved per km length of road is given in Table 5.

Road User Cost:

The user cost comprises of vehicle operating costs (VOC), time cost of passengers and commodities in transit and accident costs. In present analysis, only VOC is considered, it being assumed that time costs and accident costs on both types of surfaces are the same [11]. The parameters considered for the analysis is given in Table 6.

Table 5: Quantities of work item involved per km length

Flexible overlay	Tack Coat (sqm)	DBM (cum)	BC (cum)	Concrete M-40 (cum)
				Thin white topping
Heavy traffic	7000	455	280	1400

Periodic renewal once in 5 years

Heavy traffic	7000	-	175	-	-

Overlay once in 10 years

Heavy traffic	7000	455	280	-	-

Table 6: Parameters considered for analysis

Parameter	Value
CVPD	982
Traffic growth rate	7.5%
Inflation	5.00%
Diesel cost	Rs.54.21/liter
Fuel savings	14.00%
Mileage	4 kmpl
Annual fuel savings (Rs)	(cvpd x 365 x fuel savings x mileage x diesel cost)
Analysis period	30 years

The rates for calculation of initial cost of flexible and white topping are taken from schedule of rates Bangalore 2011-2012. In the present analysis the rates considered are Rs. 6975/ Cum for DBM, Rs. 8632/Cum for BC, Rs.12/Sqm for tack coat and Rs. 5,191/Cum for M-40 cement concrete. From traffic volume survey the count obtained was as given in Table 7.

Table 7: Traffic count at section 2

Type	Count
Bus	154
HCV	416
MAV	38
LCV	374

6. RESULTS AND DISCUSSION

From the analysis for section 1, the thickness of widened portion of concrete was less when hybrid fibres are used. The initial cost of hybrid fibres when used in concrete pavement was less compared to steel fibres. In case of section 2, the initial cost of concrete overlay is more compared to flexible overlay. But in view of availability of cement in plenty within the country and scarcity and rising prices of bitumen, as crude oil prices in the International market are rising and bulk of crude oil has to be imported from other countries it will be prudent to consider rigid pavements. Initial cost of concrete after addition of fibers at section 1 and cost of flexible and rigid overlay at section 2 is given in Table 8 and 9 respectively. Life cycle cost analysis by net present value method for two sections are given in Table 10 and 11.

Table 8: Initial cost of concrete at section 1per km length

Control concrete	PFRC(recron-3s)	SFRC	HFRC
60.22 lakhs	61.92 lakhs	93.86 lakhs	90.29 lakhs

Table 9: Intial cost of overlay for section 2 per km length

Flexible overlay	Concrete overlay
56.74 Lakhs	72.67 Lakhs

Table 10: Net present analysis of concrete with different type of fibre for section 1

Roughness		2000 mm/km			2000 mm/km			2000 mm/km			2000 mm/km		
		Concrete Overlay Rs-Lakhs			Concrete Overlay with Polyproplyene fiber Rs-Lakhs			Concrete Overlay with steel fiber Rs-Lakhs			Concrete Overlay with hybrid fiberRs-Lakhs		
Years	CVPD	Construction/Maintenance	VOC	Total Cost	Construction/Maintenance	VOC	Total Cost	Construction/Maintenance	VOC	Total Cost	Construction/Maintenance	VOC	Total Cost
0	1146	60.220	0.000	60.220	61.920	0.000	61.920	93.860	0.000	93.860	90.290	0.000	90.290
1	1232	0.776	0.065	0.840	0.776	0.065	0.840	0.776	0.065	0.840	0.776	0.065	0.840
2	1324	0.814	0.070	0.884	0.814	0.070	0.884	0.814	0.070	0.884	0.814	0.070	0.884
3	1424	0.855	0.075	0.930	0.855	0.075	0.930	0.855	0.075	0.930	0.855	0.075	0.930
4	1530	0.898	0.080	0.978	0.898	0.080	0.978	0.898	0.080	0.978	0.898	0.080	0.978
5	1645	0.943	0.086	1.029	0.943	0.086	1.029	0.943	0.086	1.029	0.943	0.086	1.029
6	1769	0.990	0.093	1.083	0.990	0.093	1.083	0.990	0.093	1.083	0.990	0.093	1.083
7	1901	1.039	0.100	1.139	1.039	0.100	1.139	1.039	0.100	1.139	1.039	0.100	1.139
8	2044	1.091	0.107	1.199	1.091	0.107	1.199	1.091	0.107	1.199	1.091	0.107	1.199
9	2197	1.146	0.115	1.261	1.146	0.115	1.261	1.146	0.115	1.261	1.146	0.115	1.261
10	2362	1.203	0.124	1.327	1.203	0.124	1.327	1.203	0.124	1.327	1.203	0.124	1.327

11	2539	1.263	0.133	1.397	1.263	0.133	1.397	1.263	0.133	1.397	1.263	0.133	1.397
12	2730	1.327	0.143	1.470	1.327	0.143	1.470	1.327	0.143	1.470	1.327	0.143	1.470
13	2934	1.393	0.154	1.547	1.393	0.154	1.547	1.393	0.154	1.547	1.393	0.154	1.547
14	3154	1.463	0.166	1.628	1.463	0.166	1.628	1.463	0.166	1.628	1.463	0.166	1.628
15	3391	1.536	0.178	1.714	1.536	0.178	1.714	1.536	0.178	1.714	1.536	0.178	1.714
16	3645	1.613	0.192	1.804	1.613	0.192	1.804	1.613	0.192	1.804	1.613	0.192	1.804
17	3919	1.693	0.206	1.899	1.693	0.206	1.899	1.693	0.206	1.899	1.693	0.206	1.899
18	4212	1.778	0.221	1.999	1.778	0.221	1.999	1.778	0.221	1.999	1.778	0.221	1.999
19	4528	1.867	0.238	2.105	1.867	0.238	2.105	1.867	0.238	2.105	1.867	0.238	2.105
20	4868	1.960	0.256	2.216	1.960	0.256	2.216	1.960	0.256	2.216	1.960	0.256	2.216
21	5233	2.058	0.275	2.333	2.058	0.275	2.333	2.058	0.275	2.333	2.058	0.275	2.333
22	5626	2.161	0.296	2.457	2.161	0.296	2.457	2.161	0.296	2.457	2.161	0.296	2.457
23	6048	2.269	0.318	2.587	2.269	0.318	2.587	2.269	0.318	2.587	2.269	0.318	2.587
24	6501	2.382	0.342	2.724	2.382	0.342	2.724	2.382	0.342	2.724	2.382	0.342	2.724
25	6989	2.502	0.367	2.869	2.502	0.367	2.869	2.502	0.367	2.869	2.502	0.367	2.869
26	7513	2.627	0.395	3.022	2.627	0.395	3.022	2.627	0.395	3.022	2.627	0.395	3.022
27	8076	2.758	0.425	3.183	2.758	0.425	3.183	2.758	0.425	3.183	2.758	0.425	3.183
28	8682	2.896	0.456	3.352	2.896	0.456	3.352	2.896	0.456	3.352	2.896	0.456	3.352
29	9333	3.041	0.491	3.531	3.041	0.491	3.531	3.041	0.491	3.531	3.041	0.491	3.531
30	10033	3.193	0.527	3.720	3.193	0.527	3.720	3.193	0.527	3.720	3.193	0.527	3.720
NPV @	12.00 %	62.234	0.909	63.144	63.752	0.909	64.662	92.270	0.909	93.179	89.083	0.909	89.992

Table 11: Life cycle cost analysis of section 2

Roughness		3000 mm/km				2000 mm/km		
		Flexible Overlay Rs-Lakhs				Concrete Overlay Rs-Lakhs		
Years	CVPD	Construction /Maintenance	VOC	Extra Fuel Cost (Rs) Lakhs	Total Cost	Construction/Maintenance	VOC	Total Cost
0	982	56.740	0.000	5.27	62.009	72.670	0.000	72.670
1	1056	3.103	0.059	5.66	8.825	0.776	0.057	0.833
2	1135	3.258	0.063	6.09	9.410	0.814	0.061	0.876
3	1220	3.421	0.068	6.55	10.034	0.855	0.066	0.921
4	1311	3.592	0.073	7.04	10.701	0.898	0.071	0.969
5	1410	21.247	0.078	7.56	28.890	0.943	0.076	1.019
6	1516	3.960	0.084	8.13	12.176	0.990	0.082	1.072
7	1629	4.158	0.091	8.74	12.990	1.039	0.088	1.127
8	1751	4.366	0.097	9.40	13.860	1.091	0.094	1.186
9	1883	4.584	0.105	10.10	14.790	1.146	0.102	1.248
10	2024	85.538	0.113	10.86	96.510	1.203	0.109	1.312
11	2176	5.054	0.121	11.67	16.849	1.263	0.117	1.381
12	2339	5.307	0.130	12.55	17.986	1.327	0.126	1.453

13	2514	5.572	0.140	13.49	19.202	1.393	0.136	1.529
14	2703	5.851	0.150	14.50	20.503	1.463	0.146	1.608
15	2906	34.609	0.162	15.59	50.361	1.536	0.157	1.692
16	3124	6.450	0.174	16.76	23.383	1.613	0.168	1.781
17	3358	6.773	0.187	18.02	24.976	1.693	0.181	1.874
18	3610	7.111	0.201	19.37	26.680	1.778	0.195	1.972
19	3880	7.467	0.216	20.82	28.503	1.867	0.209	2.076
20	4171	139.332	0.232	22.38	161.945	1.960	0.225	2.185
21	4484	8.232	0.249	24.06	32.542	2.058	0.242	2.300
22	4821	8.644	0.268	25.86	34.777	2.161	0.260	2.421
23	5182	9.076	0.288	27.80	37.169	2.269	0.279	2.548
24	5571	9.530	0.310	29.89	39.730	2.382	0.300	2.683
25	5989	56.375	0.333	32.13	88.840	2.502	0.323	2.825
26	6438	10.507	0.358	34.54	45.406	2.627	0.347	2.974
27	6921	11.032	0.385	37.13	48.549	2.758	0.373	3.131
28	7440	11.584	0.414	39.92	51.914	2.896	0.401	3.297
29	7998	12.163	0.445	42.91	55.518	3.041	0.431	3.472
30	8597	226.957	0.478	46.13	273.564	3.193	0.464	3.656
NPV @	12.00%	142.219	0.824	84.246	227.290	73.350	0.799	74.150

CONCLUSIONS

The following broad conclusions can be drawn from the present investigation on mono steel, mono polypropelene and hybrid fibres in concrete pavements:

- The thickness of pavement slab with hybrid fibres is less by 40 mm compared to mono steel and polypropylene fibres separately.
- From NPV method, the life cycle cost of polypropylene fibres was less than hybrid fiber and steel fibers.
- When mono steel and hybrid fibres are considered separately, hybrid fibers are cost effective and perform better than other mono fibers.
- The life cycle cost analysis for 12 percent discount rate and 5 percent inflation rate suggests that flexible overlay becomes expensive than rigid overlay due to its heavy maintenance inflow over the life period.

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