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Research Study on Design of Perpetual Pavement for Expressways: Case Study of Bengaluru-Chennai Expressway

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ABSTRACT*:* Aiming for fast pace of development of road network to achieve connectivity between economic hubs and safe roads, the Government of India have taken initiative to build 800km of Expressways under Bharatmala Pariyojana. Apart from this the several State Governments are building Expressways. Conventional pavement has design life of 15 years. New construction technology has evolved for a long life pavement also known as "Perpetual Pavement" , designed for more than 30 years and can have a design life of up to 50 years without major structural rehabilitation and/or reconstruction activities and needing only periodic surface renewal in response to distresses confined to the top of the pavement. The Perpetual pavement concept is that thickly designed asphalt pavements with the appropriate material combinations, if properly constructed, will structurally outlive their design lives while simultaneously sustaining high traffic volumes/loads. The design philosophy is such that the pavement structure must have enough structural strength to resist structural distresses such as fatigue cracking, permanent deformation, and/or rutting; and be durable enough to resist damage due to traffic forces and environmental effects. This study discusses the use of Perpetual Pavement design for Expressways in India using Indian Design Codes.

KEYWORDS: Perpetual Pavement Design, Fatigue Life, Rut Resistant, Pavement Material

I. INTRODUCTION

A case study of the Bengaluru Chennai Expressway was carried out to design the Perpetual pavement using the data from the project and making an assessment for the various parameters used for design of pavement.

Fig.1 Bengaluru Chennai Green Field Corridor

Bengaluru Chennai Expressway (Phase I) is a Greenfield alignment. The project stretch commences at Design Chainage Km (-) 0+700 near Hoskote Bengaluru Rural District & traverses parallel to SH-95; Hoskote – Malur – Bangarpet and Bethmangala ends at Design Chainage Km 71+000 near Bethmangala in Kolar District. The project highway is to be constructed as a fully access controlled Expressway. The total project design length is 71.700 Kms and divided into three packages PK I km (-)0.700 to km 26.400 (Length – 27.100 km), PK II km 26.400 to km 53.500 (Length – 27.100 km) and PK III km 53.500 to km 71.000 (Length – 17.500 km)

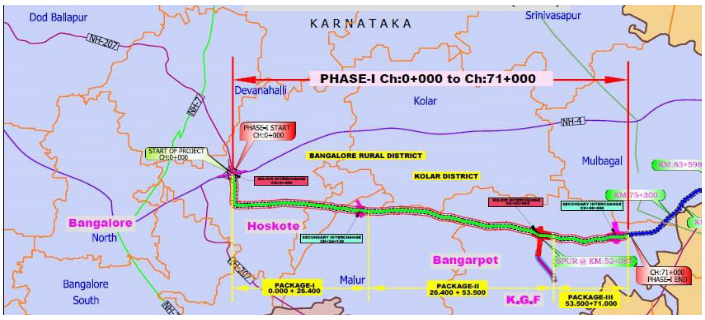

Fig.2 Bengaluru Chennai Green Field Corridor (Phase – I)

The project is been developed as 4 Lane access controlled Expressway as per IRC SP 99 2013, and The Flexible Perpetual Pavement type is designed and proposed for construction for a design traffic of 300 MSA for a design period of 30 years.

The data collected for analysis and design are Classified Traffic Volume Count (ADT/AADT), Axle Load and O-D surveys carried out on parallel connecting roads and the traffic expected on project road after development considering potential generated and diverted traffic. The future traffic forecasted by determining growth rates by vehicles type based on the future GDP, NSDP, Population and PCI growth rates and future elasticity values. However As per Cl: 5.5.4 of IRC: SP:99-2013, annual growth rate of commercial vehicles should be minimum 5% is adopted.
The natural ground soil properties and borrow area soil properties are analyzed to determine the CBR results for proposed pavement. The comparison is shown below:

Table 1 Comparative Soil (NGL) Properties Soil

Soil Test	PK –I	PK –II	PK –III
LL (%)	32.0 - 36.5	29.0 - 36.7	32.0 - 35.0
PI (%)	6.7 – 15.5	9.2 - Non Plastic	3.12 - 11
OMC (%)	10.5 – 12.8	10.2 – 16.45	9.9 – 11.9
MDD (gm/cc)	1.890 – 1.835	1.698 – 1.987	1.85 – 2.01
4 Days Soaked CBR	7.17 – 8.90	3.02 – 18.09	9.2 – 11.45

Similarly Borrow area soil samples shows Liquid Limit (LL) ranges between 25% and 34%, Plasticity Index ranges around 10 to 12%., and CBR value is 12.08% to 18.25% for Package I and II, however in Package III, subgrade CBR is in the range of 9.40% to 11.45%.

II. CONCEPT OF PERPETUAL PAVEMENT

Recent developments in materials selection, mix design, and performance tests are said to offer the potential to construct pavement structures that will last over 50 years with periodic replacement of the pavement surface. A Perpetual pavement structure will comprise of three-layered bituminous pavement system

- A rut-resistant, impermeable, wear-resistant and renewable top structural bituminous surface layer
- A rut-resistant and durable bituminous intermediate binder layer
- A fatigue-resistant and durable bottom bituminous base layer resting over a durable foundation (sub-base and sub-grade)

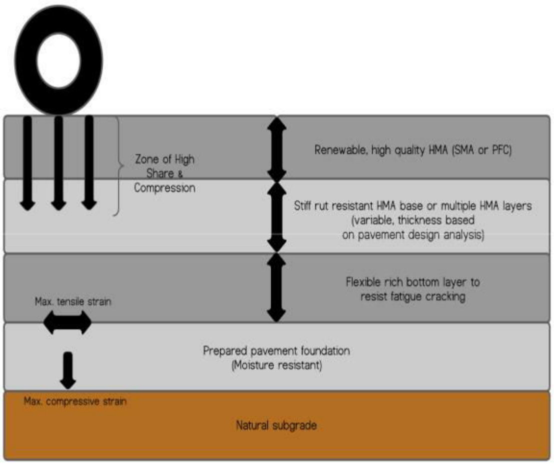

Fig 3 General Perpetual Design

As per IRC 37-2018, Guidelines for the Design of Flexible Pavements, the pavements for very high density corridors (more than 300 MSA) and Expressways shall preferably be designed as long-life pavements and proposes the vertical compressive strain 200µ and horizontal tensile strain 80µ for rutting and fatigue limits.

III. METHODOLOGY

The methodology adopted for study of "Perpetual Pavement for Expressways" is suggested in IRC 37-2018 which is followed for the design of pavement. The basic inputs are traffic data, material used for pavement design and the soil properties.

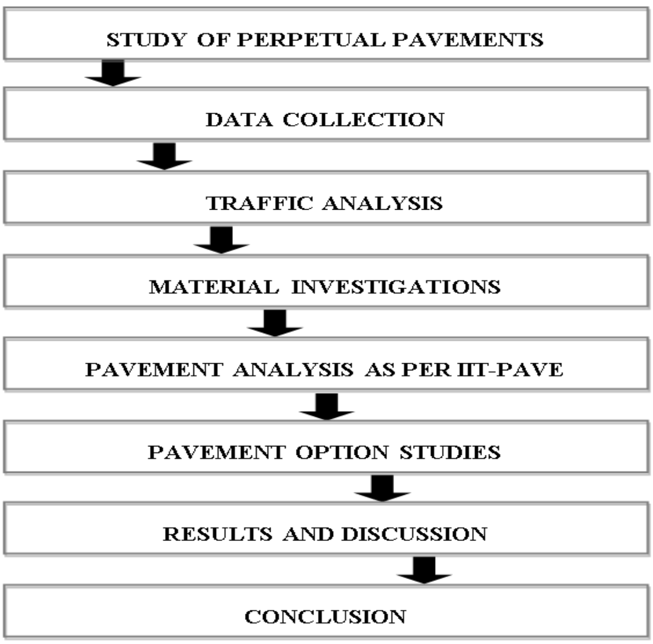

Fig 4 Flow Chart

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IV. PAVEMENT DESIGN

The total thickness of pavement structure and the individual layer thickness required for the estimated traffic load are determined in the pavement design. IRC 37-2018 recommends pavement design methodology based on empirical method. The method is based on standard axle load of 80kN with 0.56MPa to 0.8MPa tyre pressure.

The strain coming along the various pavement layers are shown in the figure below:

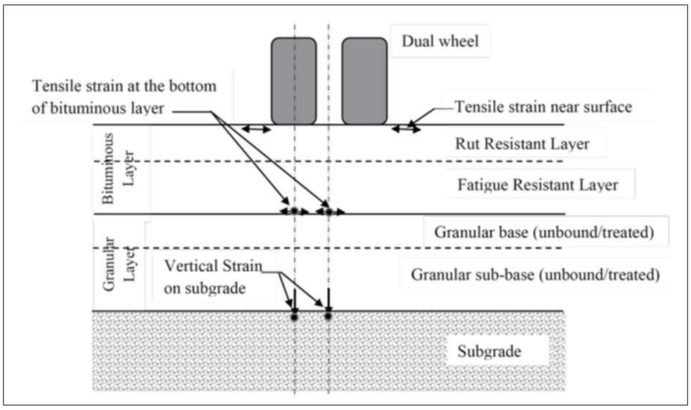

Figure 5 Critical Strain Location on Various Layers of Flexible Pavement

As per IRC 37-2018, Pavements for very high density corridors (more than 300 msa) and Expressways shall preferably be designed as long-life pavements. Otherwise, for such corridors, the pavement shall be designed for a minimum period of 30 years. The commercial traffic, converted into equivalent repetitions of the standard axle, and adjusted for directional distribution, lateral distribution over the carriageway width, etc., is the design traffic.

A flexible pavement displays a near elastic behaviour under a fast-moving traffic and it is, therefore, modelled as an elastic multilayer structure. Stresses and strains at critical locations are computed using a linear layered elastic model. The Stress analysis software IITPAVE used for the computation of stresses and strains in flexible pavements. Tensile strain, εt at the bottom of the bituminous layer and the vertical subgrade strain, εV on the top of the subgrade are conventionally considered as critical parameters for pavement design to limit cracking and rutting in the bituminous and non- bituminous layers respectively.

Resilient Modulus of the Subgrade (MRS)

Resilient Modulus is the measure of its elastic behaviour determined from recoverable deformation in the laboratory tests. The relation between Resilient Modulus and the effective CBR is given as:

MRS (MPa) = 10 * CBR------------------------ for CBR <5
MRS (MPa) = 17.6 x (CBR) 0.64------------- for CBR > 5

Sub-Base Layer (Cemented/ Unbound) Unbound Sub-Base Layer

The material conforming to the grading's given in MoRTH clause 401, Table 400-1 and physical requirements given in MoRTH clause 401, Table 400-2.

Cementitious (Cement Treated) Sub-base (CTSB) Layer

The material used for cementitious (cement treated) sub-base may consist of soil, river bed materials, natural gravel aggregates, reclaimed concrete aggregates, crushed aggregates or soil aggregate mixture modified with different cementitious materials such as cement, lime, lime, flyash, commercially available stabilizers, etc.

Bound Sub-Base Layer

The material for bound Sub-base consist of soil, aggregate or soil aggregate mixture modified with chemical stabilizers with 2% by weight of cement while retaining the permeability. The mix design is done to achieve compressive strength of 1.7 MPa for 7 days conforming MORHT clause no.403.

Unbound Base-Layer

The base layer consist of lying, spreading and compacting, clean, crushed, and graded aggregate and granular material, premixed with water, to a dense mass.

Wet Mix Macadam (WMM)

Wet Mix Macadam is a base course of the pavement consists of laying clean, crushed graded aggregates and granular material, premixed with water and rolled to a dense mass on a prepared surface conforming to MoRTH clause no. 406 and IRC: 109 -2015 specification.

Cementitious bases layer

Cemented base layers consists of aggregates or soil-aggregate mixture stabilized with cement to achieve minimum strength of 4.5 to 7 MPa in 7/ 28 days, conforming to MORTH specification.

Crack Relief Layer

A crack relief layer of wet mix macadam of thickness 100mm sandwiched between the bituminous layer and treated layer is much more effective in arresting the propagation of cracks from the cementitious base to the bituminous layer.

The WMM layer is compacted to 100% of dry density.

Bituminous Layers

Bituminous layer was constructed multiple layers of compacted crushed aggregate with a bituminous binder, conforming to MoRTH specification.

Dense Bitumen Macadam (DBM)

DBM is used in base course laid in two layer of 65 mm and 60 mm. It consists of Grading-2 have nominal maximum aggregate size of 25mm, composition conforming to MoRTH table no. 500-10. The mix design as per Asphalt Institute Manual –MS-2 and MoRTH specifications.

Bituminous Concrete (BC)

Bituminous concrete is used for wearing course. It is in single layers of 50 mm thick conforming MoRTH clause 505 specifications. It consists of Grading-2 conforming to MoRTH table no. 500-17. The physical requirement coarse aggregate conforming to MoRTH table no. 500.16. The mix design is done as per Asphalt Institute Manual –MS-2 and MoRTH specifications.

The objective of the pavement design is to provide the best combination and thickness of pavement structure materials, over the sub- grade that will reduce the stress caused by loading to within the load-carrying capacity of the sub- grade soil. Pavement design has been studied for Conventional as well as Proposed Pavement in Expressway.

Option-I: Flexible Pavement with Granular Base & Sub-Base. (Conventional Pavement Design)
Option-II: Flexible Pavement with Cement Treated Base (CTB) & Cement Treated Sub-Base (CTSB).
Option-III: Flexible Pavement with Cement Treated Base (CTB) & Granular Sub-Base.

Table 2 Comparative Pavement Composition

Sr No	Pavement layer	Conventional Type	Proposed Crust Thickness (in mm) for Perpetual Flexible Pavement with Min Design Traffic of 300 MSA		
		CBR 12%	CBR 12%	CBR 12%	CBR 9%
1	Bituminous Concrete (BC) (CRMB)	50	50	50	50
2 (a)	Dense Bitumen Macadam Top (DBM) (VG-40)	60	60	60	65
2 (b)	Dense Bitumen Macadam Bottom (DBM) (VG-40)	75	65)	65	65
2 (c)	Dense Bitumen Macadam Bottom (DBM) (VG-40)	100	-	-	-
3	Crack Relief Layer (Wet Mix Macadam)	-	100	100	100
4	Wet Mix Macadam	250	-	-	-
5	Cementitious Base (CTB)	-	200	200	175
6	Cementitious Sub Base (CTSB)	-	200	200	-
7	Granular Sub Base (GSB)	200	-	-	200
8	Subgrade	500	500	500	500
9	Total	1235	1175	1175	1155

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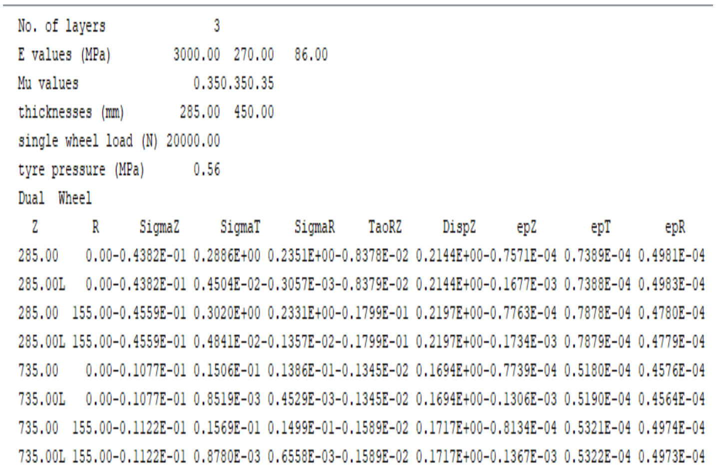
The IIT Pave results of all Pavements Types are shown below:



```
No. of layers              3
E values (MPa)        3000.00  270.00   86.00
Mu values                0.350.350.35
thicknesses (mm)       285.00  450.00
single wheel load (N) 20000.00
tyre pressure (MPa)      0.56
Dual  Wheel
  Z        R      SigmaZ      SigmaT     SigmaR     TaoRZ      DispZ      epZ        epT        epR
285.00    0.00-0.4382E-01 0.2886E+00 0.2351E+00-0.8378E-02 0.2144E+00-0.7571E-04 0.7389E-04 0.4981E-04
285.00L   0.00-0.4382E-01 0.4504E-02-0.3057E-03-0.8379E-02 0.2144E+00-0.1677E-03 0.7388E-04 0.4983E-04
285.00  155.00-0.4559E-01 0.3020E+00 0.2331E+00-0.1799E-01 0.2197E+00-0.7763E-04 0.7878E-04 0.4780E-04
285.00L 155.00-0.4559E-01 0.4841E-02-0.1357E-02-0.1799E-01 0.2197E+00-0.1734E-03 0.7879E-04 0.4779E-04
735.00    0.00-0.1077E-01 0.1506E-01 0.1386E-01-0.1345E-02 0.1694E+00-0.7739E-04 0.5180E-04 0.4576E-04
735.00L   0.00-0.1077E-01 0.8519E-03 0.4529E-03-0.1345E-02 0.1694E+00-0.1306E-03 0.5190E-04 0.4564E-04
735.00  155.00-0.1122E-01 0.1569E-01 0.1499E-01-0.1589E-02 0.1717E+00-0.8134E-04 0.5321E-04 0.4974E-04
735.00L 155.00-0.1122E-01 0.8780E-03 0.6558E-03-0.1589E-02 0.1717E+00-0.1367E-03 0.5322E-04 0.4973E-04
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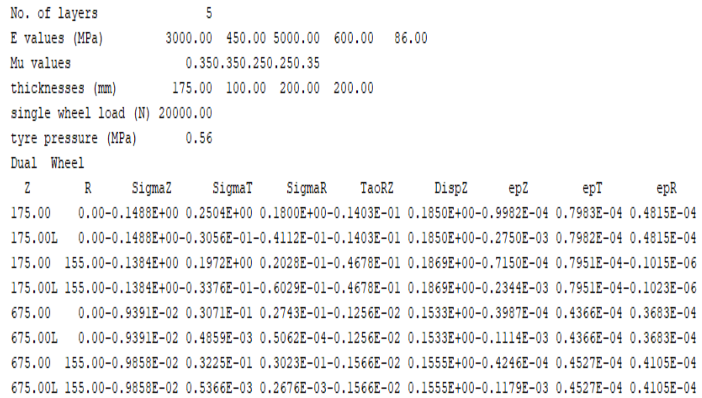
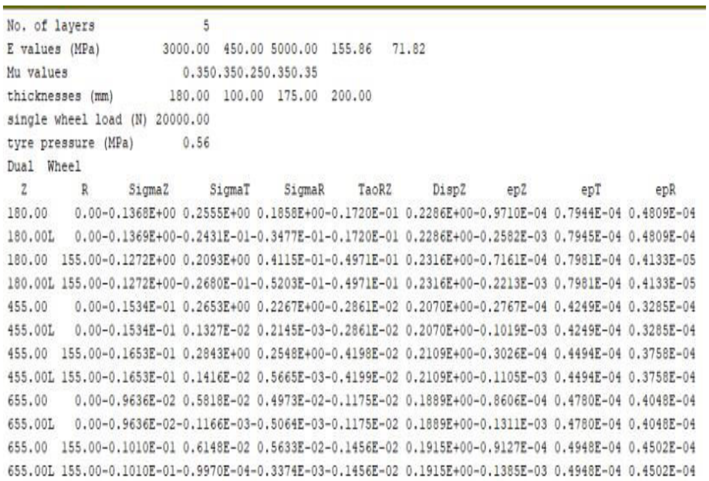
Figure 6 – Option I Output of IITPAVE Software



```
No. of layers              5
E values (MPa)        3000.00  450.00 5000.00  600.00   86.00
Mu values                0.350.350.250.250.35
thicknesses (mm)       175.00  100.00  200.00  200.00
single wheel load (N) 20000.00
tyre pressure (MPa)      0.56
Dual  Wheel
  Z        R      SigmaZ      SigmaT     SigmaR     TaoRZ      DispZ      epZ        epT        epR
175.00    0.00-0.1488E+00 0.2504E+00 0.1800E+00-0.1403E-01 0.1850E+00-0.9982E-04 0.7983E-04 0.4815E-04
175.00L   0.00-0.1488E+00-0.3056E-01-0.4112E-01-0.1403E-01 0.1850E+00-0.2750E-03 0.7982E-04 0.4815E-04
175.00  155.00-0.1384E+00 0.1972E+00 0.2028E-01-0.4678E-01 0.1869E+00-0.7150E-04 0.7951E-04-0.1015E-06
175.00L 155.00-0.1384E+00-0.3376E-01-0.6029E-01-0.4678E-01 0.1869E+00-0.2344E-03 0.7951E-04-0.1023E-06
675.00    0.00-0.9391E-02 0.3071E-01 0.2743E-01-0.1256E-02 0.1533E+00-0.3987E-04 0.4366E-04 0.3683E-04
675.00L   0.00-0.9391E-02 0.4859E-03 0.5062E-04-0.1256E-02 0.1533E+00-0.1114E-03 0.4366E-04 0.3683E-04
675.00  155.00-0.9858E-02 0.3225E-01 0.3023E-01-0.1566E-02 0.1555E+00-0.4246E-04 0.4527E-04 0.4105E-04
675.00L 155.00-0.9858E-02 0.5366E-03 0.2676E-03-0.1566E-02 0.1555E+00-0.1179E-03 0.4527E-04 0.4105E-04
```

Figure 7 – Option 2 Output of IITPAVE Software



```
No. of layers              5
E values (MPa)        3000.00  450.00 5000.00  155.86   71.82
Mu values                0.350.350.250.350.35
thicknesses (mm)       180.00  100.00  175.00  200.00
single wheel load (N) 20000.00
tyre pressure (MPa)      0.56
Dual  Wheel
  Z        R      SigmaZ      SigmaT     SigmaR     TaoRZ      DispZ      epZ        epT        epR
180.00    0.00-0.1368E+00 0.2555E+00 0.1858E+00-0.1720E-01 0.2286E+00-0.9710E-04 0.7944E-04 0.4809E-04
180.00L   0.00-0.1369E+00-0.2431E-01-0.3477E-01-0.1720E-01 0.2286E+00-0.2582E-03 0.7945E-04 0.4809E-04
180.00  155.00-0.1272E+00 0.2093E+00 0.4115E-01-0.4971E-01 0.2316E+00-0.7161E-04 0.7981E-04 0.4133E-05
180.00L 155.00-0.1272E+00-0.2680E-01-0.5203E-01-0.4971E-01 0.2316E+00-0.2213E-03 0.7981E-04 0.4133E-05
455.00    0.00-0.1534E-01 0.2653E+00 0.2267E+00-0.2861E-02 0.2070E+00-0.2767E-04 0.4249E-04 0.3285E-04
455.00L   0.00-0.1534E-01 0.1327E-02 0.2145E-03-0.2861E-02 0.2070E+00-0.1019E-03 0.4249E-04 0.3285E-04
455.00  155.00-0.1653E-01 0.2843E+00 0.2548E+00-0.4198E-02 0.2109E+00-0.3026E-04 0.4494E-04 0.3758E-04
455.00L 155.00-0.1653E-01 0.1416E-02 0.5665E-03-0.4199E-02 0.2109E+00-0.1105E-03 0.4494E-04 0.3758E-04
655.00    0.00-0.9636E-02 0.5818E-02 0.4973E-02-0.1175E-02 0.1889E+00-0.8606E-04 0.4780E-04 0.4048E-04
655.00L   0.00-0.9636E-02-0.1166E-03-0.5064E-03-0.1175E-02 0.1889E+00-0.1311E-03 0.4780E-04 0.4048E-04
655.00  155.00-0.1010E-01 0.6148E-02 0.5633E-02-0.1456E-02 0.1915E+00-0.9127E-04 0.4948E-04 0.4502E-04
655.00L 155.00-0.1010E-01-0.9970E-04-0.3374E-03-0.1456E-02 0.1915E+00-0.1385E-03 0.4948E-04 0.4502E-04
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Figure 8 – Option 3 Output of IITPAVE Software

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V. LIFE CYCLE COST

The Life Cycle Cost (LCC) of an asset is defined as the total cost, in present value or annual value that includes the initial costs, maintenance, repair and renewal (MR&R) costs over the service life or a specified life cycle. LCC is based on an understanding that the value of money changes with time and as a result, expenditures made at different times are not equal. This concept, referred to as the 'time value of money', is the basis for Life Cycle Cost Analysis (LCCA). LCCA is a process for evaluating the total economic cost of an asset by analysing initial costs and discounted future expenditures such as maintenance, operational, user, and social costs over the service life or life cycle of an asset.

Table 3 Per Km Cost Comparative

Type of Pavement	**Conventional Pavement**	**Stabilised Pavement**	
Pavement Option	**Option I**	**Option II**	**Option III**
A	B	**D**	**E**
Per Km. Cost (Cr.)	11.23	8.68	8.47

Table 4 Pavement Life Cycle Cost Analysis

Pavement Life Cycle Cost Analysis for Expressway	
Main Carriageway 4 lane road	
Construction period	2
WPI growth per year	5%
Discount rate	12%
Periodic renewal of flexible pavement for every 5th year	6
Capital Expenditure (Cost in Crores per Km)	
Pavement Type	**Amount in Crores**
Flexible - Conventional	112,300,000
Flexible - CTB	86,800,000
Flexible - CTB & CTSB	84,700,000
Operational Expenditure (Rs /Km)	
Routine Maintenance - Every Year	628,550
Periodic Maintenance for every 6th Year	6,285,497
NPV Comparison in Crores for 30 + 2 years	
Capex + Opex for Flexible Conventional	10.93

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Capex + Opex for Flexible - CTB	8.78
Capex + Opex for Flexible - CTB & CTSB	8.60
Minimum NPV	**8.60**
Proposed Pavement Type	**Option III GSB + CTB + Bituminous**
The selection of pavement type shall be based on lower NPV values for 30 years of Operational & Maintenance	

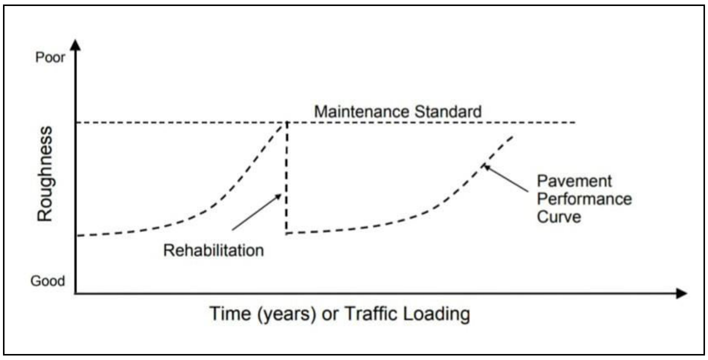

Figure 9 – Concept of Life Cycle Cost Analysis

VI. CONCLUSION

- The above pavement designs were checked as per IITPave and the results and Horizontal and Vertical Strain results are well within the specified limit as per IRC 37 2018.
- It is also observed that the most economical pavement composition is adopted in Package III.
- It is observed that Stabilised Pavements are more economical than Conventional Pavements as per Life Cycle Cost.
- Perpetual pavements are becoming more accepted and popular due to its sustainability. Users of Perpetual pavement enjoying benefits of improving safety and low user delay cost due to less maintenance activities, there are also concerns, including modification to the design procedure, economic application and material restriction.
- Perpetual Pavement provides long-term solution to ever increasing traffic volumes with sporadic overloading observed on Indian roads and therefore, it should be adopted in India. Perpetual Pavement design can save on materials and energy used in maintenance over the pavement lifecycle and reduces the noise and emissions accompanied by maintenance activities. All these benefits lead to decrease in maintenance cost through the pavement lifetime and improve sustainability and long lasting roads with minimal maintenance and other overheads for Indian conditions.

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