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Software Based Analysis of Perpetual Pavement in Indian Scenario

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Abstract- Perpetual pavements are modern long lasting pavements designed for a life span of about 50 years, without needing major rehabilitation and requiring periodic surface renewal only. These types of pavements are very useful for structures like airfields and important highways. The mechanistic empirical approach is generally observed for analysis and design of perpetual pavements. Various limiting values of strain for different layers of pavement are considered while designing or analysing the performance of perpetual pavements. For this purpose, various software are available like MEPDG, PerRoad, KenPave, WESLEA, IITPAVE, etc. This study focuses on comparing the outputs obtained through the use of some of these software with the help of a data suitable to Indian scenario. The study further focuses on the process of selection of a particular design and analysis software according to the region and also highlights the problems associated in using such software in context with Indian Conditions.

Index Terms- Perpetual pavement, Mechanistic design, Design software, Indian scenario

1. INTRODUCTION

MORTH (Ministry of Road Transport & Highways), IRC (Indian Road Congress), PWD (public works department) and other agencies. The original road networks were designed for lighter loads and lower traffic volumes than those which are present today. As a result the pavement structures are needed to be enhanced resulting in increased consumption of construction materials and its funding. The general practice in India is to accommodate increasing traffic to correspondingly increase the pavement thickness which results in uneconomical and environmentally unsustainable pavements. Such conservative designs exert a heavy financial burden on developing countries like India. The use of the perpetual pavement design concept and if possible monitoring of these pavements to understand its superiority over conventional pavements is necessary for a sustainable pavement development in India.

A Perpetual pavement is an asphaltic road designed to last for about 50 years without requiring major structural rehabilitation or reconstruction. In India, not many efforts have been made in adaptation of modern perpetual pavements. Indian Road Congress, in one of its latest publication (IRC: 37-2012) is also advocating use of mechanistic-empirical design for pavements and perpetual pavements and also suggested that the guidelines given in publication are tentative and detail field study is recommended for verification of guidelines which requires study of dynamic responses, it also indicates that the guidelines may require a revision from time to time in the light of future developments and experience in the field. It is also suggested that all the organizations intending to use the guidelines should keep a detailed record of the year of construction, subgrade CBR, soil

characteristics including resilient modulus, pavement composition and specifications, traffic, pavement performance, overlay history, climatic conditions etc. and provide feedback to the Indian Roads Congress for further revision. Another critical issue with perpetual pavement adaptation in India is that some of the most important factors related to pavement design are not adequately addressed by existing Indian mechanistic design approaches. Following are the objectives

1. Examine the use of various design software considering Indian scenario
2. Discuss problems faced while using these software considering data availability in India
3. Compare the outputs of these software with the data available for Indian scenario

In the following section, details about various available software are discussed.

2. PERROAD SOFTWARE

PerRoad is a mechanistic-based pavement design and analysis program that utilizes layered elastic analysis and Monte Carlo simulation to develop probability-based flexible pavement designs (Timm and Newcomb 2002). PerRoad can design up to five-layer structures and consider a maximum of five seasons. Seasonal air temperatures can be entered and the program will automatically calculate HMA stiffness as a function of pavement temperature and performance-graded (PG) binder. Now, in Indian scenario, difficulty arises while using this software because:

1. Heavy monsoon season remains unaccounted
2. PG grade is not used, instead VG (viscosity grade) grades are used
3. Conversion of units before data is required

The variability of individual layer thicknesses and stiffnesses can be incorporated in design. The "Variability" buttons allow the designer to characterize the variability as either normally or log-normally distributed with default coefficient of variation values recommended within the software. This feature allows designers to rationally consider the impact of improved construction practices and specifications on required pavement thickness, but in Indian standard codes there is no information about variation values to be adopted for Indian scenario; hence an engineer would depend on default values provided in software.

The "Performance Criteria" buttons enable the designer to input performance thresholds and transfer functions for each layer. The top, middle or bottom of each layer can be selected and various pavement responses like deflection, stress, strain can be specified. However, typical perpetual pavement design relies upon controlling the horizontal tensile strain at the bottom of the HMA layer and the vertical compressive strain at the top of the subgrade (Timm and Newcomb 2006).

Now in Indian scenario The Indian Roads Congress, IRC 37:2012, has proposed the strain values of 70 and 200 microstrain (μs) for the fatigue and rutting endurance limit from the studies done elsewhere but in china Yang et al (2006) has considered 120μs by arguing that 70μs is too conservative for China's heavier traffic loads. There is however consensus in the limiting value of structural rutting taken as 200μs. However as earlier discussed there has not been a detailed study about the strain values in Indian conditions and traffic scenario, there is a doubt about the limiting values of strain to be considered in India.

2.1 Load Spectra Characterization

The second input for PerRoad is load characterization. The designer can select a default vehicle classification based upon the functional classification of the roadway. The defaults are based upon data available from the Mechanistic empirical pavement design guide software (2002), and Federal Highway Administration study (1997) and data available from the Long Term Pavement Performance database, Datapave 3.0. The program will then automatically load the representative load spectra (single, tandem and tridem axle weights) that correspond to the vehicle type The designer also enters traffic volume, percent trucks, truck growth rate, percent trucks in the design lane and the directional distribution. Now in Indian Scenario, the vehicle configurations and classifications ,especially in case of heavy vehicles is completely different which results in great difficulty while entering these vales also there is no database available like Datapave 3.0.

2.2 Analysis and Design

After the structural cross section, materials, performance criteria and traffic have been defined, the designer proceeds to analysis and design. The designer can alter the pavement cross-section and evaluate the results of the Monte Carlo-based M-E analysis. The three primary outputs are the percent below the threshold criteria, the damage accumulation per million axle and the estimated number of years until damage equals 0.1. The damage computations are based upon Miner's Hypothesis, a standard damage accumulation model used in M-E design. In conventional M-E design, pavement sections are designed to a damage of 1.0 which corresponds to a terminal level of pavement distress. It was decided, for perpetual pavement design, to lower the damage value to 0.1 since the objective is to observe no structural distress at the end of the design period. For high-volume perpetual pavement design it is recommended that damage equal 0.1 after 35 years. (Timm and Newcomb 2002).

3. KENPAVE SOFTWARE

KenPave software was developed by Huang, 1993 (Huang, 2004). It is a Microsoft-Windows based version that combines the old Kenlayer flexible pavement software and Kenslabs rigid pavement software. It accepts the use of linear elastic, nonlinear, and viscoelastic properties of the materials for the different layers. The software can handle up to 19 layers and performs damage analysis. The interface between the different layers can be specified as either unbonded or fully bonded. KENLAYER can be applied to layer systems under single, dual, dual-tandem, or dual-tridem wheels with each layer behaving differently, linear elastic, nonlinear elastic, or viscoelastic. Damage analysis can be made by dividing each year into a maximum of 12 periods, each with a different set of material properties. Each period can have a maximum of 12 load groups, either single or multiple. The damage caused by fatigue cracking and permanent deformation in each period over all load groups is summed up to evaluate the design life (Huang, 2004).There are so many input parameters in this computer program. The parameters can be inputted both in SI and U.S. customary units. Acceptable parameters for linear elastic analysis are traffic load, material properties, thickness of each layer, number of periods, number of load groups etc. For a single and multiple load groups, a maximum of nine and ten responses can be obtained, respectively. Only the vertical compressive strain on the surface of subgrade and the tensile strains at the bottom of asphalt layer are used for damage analysis. As it is the case in Perroad, there is need to convert data in desired unit forms applicable in Kenlayer software. Also season wise material characteristics data is not available.

4. WESLEA AND IITPAVE SOFTWARE

The WESLEA model is created to calculate the strains, displacement, normal and shear stresses at any point. The data required includes the number of layers, thickness of each layer, the material of the layer, modulus and Poisson's ratio for the layers. In addition the loading configuration, load magnitude and tyre pressure are required to calculate the load applied on the pavement section defined in the model. (Mohab Y. El-Hakim 2009).

IITPAVE is a multilayer elastic layer analysis programme developed in India. Any combination of traffic and pavement layer composition can be tried using IITPAVE. The designer will have full freedom in the choice of pavement materials and layer thickness. The traffic volume, number of layers, the layer thickness of individual layers and the layer properties are the user specified inputs in the Program, which gives strains at critical locations as outputs. The adequacy of design is checked by the Program by comparing these strains with the allowable strains as predicted by the fatigue and rutting models in Indian standard code 37-2012. A satisfactory pavement design is achieved through iterative process by varying layer thicknesses or, if necessary, by changing the pavement layer materials.

5. PAVEMENT DESIGN FOR INDIAN SCENARIO

The concept of the perpetual pavement design is to keep the tensile strain at the bottom of the asphalt layer so small that the fatigue life of the base layer becomes virtually infinite (Prowell et al. 2006). The limiting strain that leads to this infinite fatigue life is called an endurance limit. An endurance limit of 70 µs (µs) is the most common value used (Garcia and Thompson 2008).

For analysis let us consider the data (Table 1, Table 2) for typical Indian highway of expected life estimate design period of 15 years from information given in Indian standard code (IRC: 37-2012). Allowable subgrade strain and tensile strain in the bituminous layer for perpetual pavement design is considered as 200µs and 70µs respectively. Design traffic is 300msa in terms of cumulative number of equivalent standard axle load of 80 KN in millions of standard axles (msa).Thickness of granular subbase is 350 mm for separation and drainage where lower 200 mm (7.87 inch) of GSB is close graded to act as separation layer and the top 150 mm (5.90 inch) is an open graded granular material treated with 1.5 to 2 per cent bitumen emulsion. Design life expected in IRC code is 15 years, average annual temperature for most parts of India is considered as 35^0C i.e. 95 F (Fahrenheit).

Contact radius is given by $a = (P/p\pi)^{1/2}$

Where a is Contact radius, P is total load on the tyre which is 20000N, p is tyre pressure which is 0.56Mpa .Hence a equals 108.45 mm or 4.27 inches.

In India Standard axle load is an 80 KN load distributed over two dual wheel sets on either side of the axle and with a tyre pressure of 0.56 MPa that is about 80 psi. But for analysis we considered only one dual wheel system. Because the other dual wheel system is at such distance it will not have any significant effect in the parameter that we are calculating at these locations. So normally instead of considering the total 80 KN axle load, consider only one dual wheel set ignoring the other wheel set that is at the other end of the axle. Hence, when we consider half of the axle load assume 20 KN distributed over two wheels ,assume tyre pressure of 0.56 MPa (IRC: 37-2012) and typically it is seen that the center to center distance between these two dual wheel loads will be about 310 mm. This is what has been observed on several measurements that have been made on typical commercial vehicles in India.

As discussed earlier, due to lack of expose to mechanistic design approach, difficulties arise while using these design software hence some values are assumed with the help of available information, literature. All the traffic data is converted according to software's unit system requirements some default values in software like variability in perroad are kept as it is.

Table 1. Material Characteristics in Layers

No. of layers	**1 (VG40)**	**2**	**3**	**4(Subgrade)**
E values in (Mpa)	3000	600	209.37	75
E values in Psi	435113	87023	30367	10878
Poisons ratio	0.40	0.35	0.35	0.35
Thickness (mm)	225	150	200	-
Thickness (in)	8.86	5.90	7.87	-

By using above data, responses at bottom of asphalt layer i.e. at 225mm and at top of subgrade i.e. at 575mm are determined in following section

5.1. KenPave Analysis-

By using the above data, KenPave software was run. Responses at (0, 8.86) and (0, 22.63) were determined i.e. bottom of bituminous layer and top of subgrade Analysis of above data with KenPave software gives following results.

Table 2. Additional Data Consideration for Analysis

No	Specification	Values
1	Contact radius (inch)	4.27
2	Contact radius (mm)	108.45
3	Contact pressure (psi)	81.22
4	Contact tyre pressure (Mpa)	0.56
5	No. Of points at which results are desired	2
6	Wheel spacing along x-axis	0
7	Wheel spacing along y-axis (inch)	12.21
8	Expected load repetitions with standard axle of 80KN	2649680
9	Coefficients for layer 1 (IRC)	K_1= 0.000221 K_2= 3.89
10	Coefficients for layer 4 (KenPave default)	K_1= 1.365e-09 K_2= 4.477
11	Average annual daily traffic Average annual growth rate Vehicle Damage Factor Lane distribution factor	33121 5 % 2.30 0.50

Table 3. KenPave Output

No	Descript-ion	Allowabl-e Load Repetitio-ns	Damage Ratio	Strain (Tensile –ve, Compressi ve +ve)
1	At bottom of layer 1	1.290e+12	2.054e-06	- 88.51 µs
2	At top of layer 4 (sub-grade strain)	7.837e-02	3.381e+07	+ 217.9 µs

Design life in years according to software analysis is 12.76 years. Hence it is evident that even though road was designed for 15 years, with mechanistic approach analysis it will have a design life of 12.76 years.

5.2 WESLEA Software Analysis

As shown in table 5, at bottom of layer 1 tensile strain is 94.53 µs and at top of layer 4 i.e. subgrade compressive strain is 235.29 µs.

Table 4. WESLEA output with stress values

Layer	Coordinates (in)			Normal Stress (psi)		
	X	Y	Z	X	Y	Z
1	0	0	8.86	-41.86	-51.18	11.72
1	4.27	0	8.86	-37.62	-51.68	11.24
4	0	0	22.63	-0.14	-0.26	2.29
4	4.27	0	22.63	-0.19	-0.28	2.4

Table 5. WESLEA output with strain values with similar coordinates

Layer	Normal microstrain			Displacement (milli-in)			Shear Stress (psi)
	X	Y	Z	X	Y	Z	XZ
1	-59.94	-89.92	112.48	-0.33	0	11.79	-3.04
1	-49.29	-94.53	107.93	-0.09	0	12.05	-0.38
4	-78.42	-92.84	223.25	-0.51	0	9.82	-0.33
4	-85.94	-96.2	235.29	-0.16	0	9.97	-0.1

5.3 IITPAVE Software Analysis

For use of this software data values are converted to desired unit forms,

Table 6. IITPAVE output with stress and displacement values

Z	R	SigmaZ	SigmaT	SigmaR	TaoRZ
225	108.45	-0.06998	0.3228E	0.2325	-0.04753
225 L	108.45	-0.06998	0.03156	0.01283	-0.04753
575	108.45	-0.01485	0.01913	0.01768	-0.2631E-02

575 L	108.45	-0.01485	0.1720E-02	0.1201E-02	-0.2631E-02

Table 7. IITPAVE output strain values

Z (mm)	**R(contact radius)**	**epZ(vertical subgrade strain)**	**epT(tensile strain)**	**epR (strain in radial direction)**
225	108.45	-0.9738E-04	0.8594E-04	0.4380E-04
225 L	108.45	-0.1425E-03	0.8594E-04	0.4380E-04
575	108.45	-0.1325E-03	0.8663E-04	0.7729E-04
575 L	108.45	-0.2116E-03	0.8663E-04	0.7729E-04

As shown in table 7, at bottom of layer 1 tensile strain is 85.94 µs and at top of layer 4 i.e. subgrade compressive strain is 211.6 µs.

6. PER-ROOD DESIGN ANALYSIS

Now using same data and considering threshold values of 70 µs and 200 µs as endurance limit and assuming summer of 36 weeks and winter of 16 weeks for seasonal information with 95F temperature as average annual pavement temperature. For design purpose, distribution of axles as 45% single, 45%tandem and 10%tridem is considered and Structural Parameter variability in PerRoad is kept default .This software gives following results,

Table 8. Axle Distribution in PerRoad

Percentage of Axles (for 300msa)			
Wt Class (lb)	**Singles (%)**	**Tandems (%)**	**Trades (%)**
0->2000	0	0	0
2000->4000	0	0	0
4000->6000	0	0	0
6000->8000	0	4.86	0
8000->10000	0	4.28	0
10000->12000	0	6.65	0
12000->14000	0	7.5	12.61
14000->16000	0	7.65	6.7
16000->18000	0	6.98	0
18000->20000	0	6.04	5.89
20000->22000	2.4	5.73	4.84
22000->24000	27.06	5.62	0
24000->26000	27.06	5.05	4.51
26000->28000	13.28	4.99	4.66
28000->30000	13.28	5.22	0
30000->32000	5.9	5.7	4.89
32000->34000	5.9	5.36	5.07
34000->36000	1.83	4.78	0
36000->38000	1.83	3.79	6.66
38000->40000	1.46	2.91	6.69
40000->42000	0	2.08	0
42000->44000	0	1.4	6.57
44000->46000	0	0.98	5.47
46000->48000	0	0.72	0
48000->50000	0	0.47	5.39
50000->52000	0	0.34	4.13
52000->54000	0	0.23	0
54000->56000	0	0.21	3.71
56000->58000	0	0.13	3.4
58000->60000	0	0.08	0
60000->62000	0	0.06	2.07
62000->64000	0	0.05	1.56
64000->66000	0	0.04	0
66000->68000	0	0.03	1.46
68000->70000	0	0.03	0.8

70000->72000	0	0.02	0
72000->74000	0	0.02	0.89
74000->76000	0	0.01	0.55
76000->78000	0	0.01	0
78000->80000	0	0	0.48
80000->82000	0	0.01	0.27
82000->84000	0	0	0
84000->86000	0	0	0.27
86000->88000	0	0	0.11
88000->90000	0	0	0
90000->92000	0	0	0.1
92000->94000	0	0	0.12
94000->96000	0	0	0
96000->98000	0	0	0.04
98000->100000	0	0	0.04
100000->102000	0	0	0
102000->104000	0	0	0.05

Table 9. Probabilistic Perpetual Pavement Analysis

Layer	**Location**	**Criteria**	**Threshold**	**Percent Below Threshold**	**Damage/ MESAL**	**Life Estimate, yrs**
1	Bottom	Horizontal Strain	-70 μs	59.44	0.00005	46.8
4	Top	Vertical Strain	200 μs	49.42	NA	NA

Hence it is evident that if endurance limit of 70 με and 200 με are taken into account, pavement life increases significantly. Following table summarises the analysis done in this study.

7. CONCLUSION

In this study various software of pavement design and analysis are used to compare the results. Even though mechanistic approaches are slightly different in the software depending on the place of origin of that software, results show that the values of horizontal strain at the bottom of surface layer and vertical strain at the top of subgrade are very similar with variation 2 to 6.5 % only. This shows that the understanding of the mechanistic approach is spreading.

Table 10. Software Analysis Summary

No	**Specification**	**Ken Pave**	**WES LEA**	**IITPAVE**	**Perroad**	
1	At bottom of layer 1 Tensile strain (μs)	88.51	94.53	85.94	70	Endurance limits are considered for PerRoad software
2	At top of layer 4 i.e. subgrade Compressive strain (με)	217.9	235.19	211.6	200	
3	Life estimate, years	12.76	-	-	46.8	

The main selection criteria to select any perpetual pavement design software should be availability of data inputs required for that particular software, suitable to local material characteristics, environmental and traffic conditions, in its desired unit form. As discussed earlier, practical use of mechanistic design approach is new to India, hence difficulty arises if required data is not available and even standard codes are lacking with the same. While using the above software, KenPave and IITPAVE were easy to use considering Indian scenario. The data inputs required for KenPave are available and most importantly if the data is not available KenPave have various guidelines to work out the input details. The main issue with availability is of the local loading configuration data; if it is not available then accuracy of results gets affected. The study also highlights the necessity for India to shift towards mechanistic empirical design approach as the design period expected by the IRC method felt short by almost 15% when the analysis is done with KenPave. The study also shows superiority of perpetual pavement over conventional pavements as life estimate of pavement increases vastly if endurance strain limit values in layers are taken into account while designing the pavement. This superiority of perpetual pavement must be endorsed in India and efforts must be made towards making data available for local conditions which would make adaptation of mechanistic empirical approach in India.

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