Study on Analysis of Flexible Pavement using Finite Element based Software Tool

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***Abstract*— Need for better road transportation facility is increasing day-by-day and in order to fulfill the need researches are carried out from a long period. Construction of a road becomes simple only after the design of a pavement is complete, today engineers are facing challenges in designing pavements that can serve a long duration without premature failures. Pavement design is one of the most important aspects of any transportation project. Poor and inadequate design may result to reduce the life of flexible pavement and increase the annual maintenance cost. It becomes the prime importance to design a durable and economic pavement structure. A durable structure can be designed only after proper analysis. Multilayered analysis is widely used but it assumes the pavement material to behave linearly which in practice is not true hence analysis of materials with nonlinear behavior is required. To obtain accurate response it is essential to analyse the pavement structure considering responses from each and every particle which is a tedious process with multilayered program, to make obtain accurate responses a powerful method like finite element method is used. In the present work an attempt has been made to study and analyse a pavement structure using a finite element based software tool and compare the results with that of a multilayer based program. Overall response helps in identifying the pavement parameters which has major impact on the performance of the pavement structure, by this it will be possible to design a pavement with long durability and high performance.**

Keywords*— Flexible Pavement;Finite element method, Pavement responses; tensile strain, compressive strain, Kenlayer;Michigan flexible pavement design software (MFPDS) Linear; non-linear analysis; Multi-layer theory.

I. INTRODUCTION

Road transportation forms the arteries and veins which plays vital role in economic growth of a nation. This makes the construction of good roads a priority. Flexible pavement are the major type of pavements constructed in India extensively, it has been observed that these pavements suffer premature failure due to variation in traffic volume, load, material properties and environmental factors. To overcome such failures in pavement it is essential to have an efficient analysis method. There are several available methods for pavement analysis, the Burmister's layered elastic theory is the commonly adopted method to analyse the pavement but the drawback is that we cannot analyse pavement with unbound base course or materials with nonlinear characteristics. Hence an advanced method evolved after an extensive research and it was referred as finite element analysis. In FEA the pavement structure will be discretized into uniform sized elements where the pavement responses are obtained by applying load on a mesh configuration. The pavement structure can be assigned with material properties which delivers a realistic mode to achieve pavement responses. It will be essential to predict the performance of pavements before construction since the estimate and cost before and after construction of pavements may vary, hence design can be finalized only after analyzing the pavement for its responses on load application. In order to view the responses and its impact on pavement with linear and nonlinear materials a finite element software tool Michigan Flexible Pavement Design Software (MFPDS) is used.

The pavement parameters having remarkable influence on pavement performance are observed from results and by performing sensitivity analysis.

II. BACKGROUND AND OBJECTIVES OF STUDY

A. Critical points of a pavement structure

The flexible pavement is of layered structure which comprises of many layers with varied thickness and material properties. The surface is composed of bitumen, base/subbase with granular material and the subgrade with natural or compacted fine grained soil. Fig – 1 represents the cross sectional view of flexible pavement with the critical locations for analyzing a pavement.

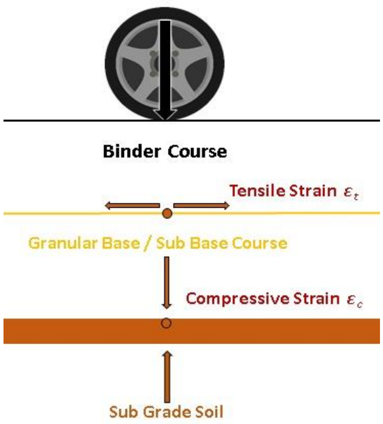


Fig -1: Typical cross section of pavement with critical locations.

Most of the pavements fail due to premature rutting and fatigue type of failures which originate from the critical locations as indicated in the Fig-1. By identifying these critical responses a pavement can be designed to overcome premature failures.

B. Software tool used

Today the road construction has spun into a new dimension where the construction is carried out extensively, which intern requires tool for analysis and design of durable pavement structure to satisfy the increasing demand.

It is well known fact that finite element method of analysis provides effective results than other methods of analysis with high accuracy and less time, hence a software based on finite element method serves the purpose and makes it handy for an engineer to analyse and design pavements. In the present study Michigan Flexible Pavement Design Software (MFPDS) is used to determine the pavement responses. MFPDS is a finite element analysis based software developed by Harichandran, R. S (2000). The software combines both multilayer based tool and finite element based tool. Using the software Mechanistic analysis may be performed with MichPave nonlinear finite element program or the Chevronx (enhanced Chevron) linear elastic layer analysis program. Both programs have been enhanced from previous versions. MichPave has been enhanced to use a distant lateral boundary and many more finite elements than previous versions. As a result the computed responses are significantly more accurate than in previous versions. New performance models to predict rut depth and fatigue life have been implemented. Each layer in a pavement cross section is assumed to extend infinitely in the horizontal direction. Displacements, stresses and strains due to a single circular wheel load are computed. Due to the assumptions used, the problem is reduced to an axisymmetric one. The pavement structure on MFPDS is converted into a finite mesh as in Fig – 2. The elements used are four nodes axisymmetric elements with aspect ratio of these elements less than 1:4

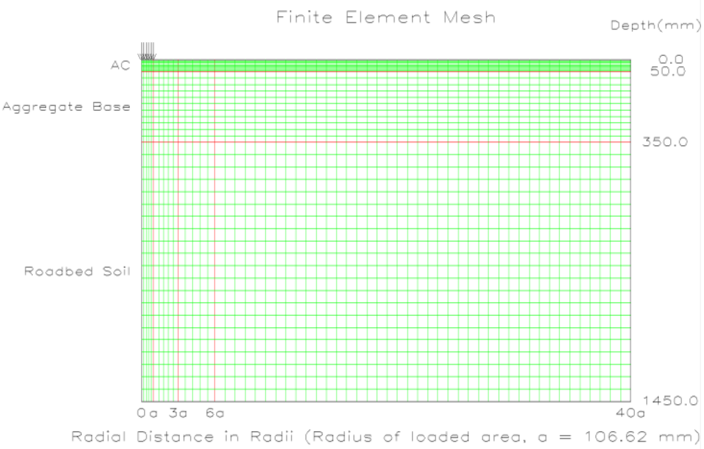


Fig – 2: Finite element mesh for the given pavement structure

MFPDS is a user friendly software, the input values given are wheel load, tire pressure, layer characteristics, and cross section details. For comparison of responses obtained from MFPDS a multilayer based software tool Kenlayer is used. Kenlayer computer program was developed by Prof. Huang. Using the Kenlayer program, tensile and compressive strains are calculated with linear and nonlinear material characteristics in base/subbase course.

C. Sensitivity Analysis

Sensitivity analyses demonstrate the effect of various parameters on flexible pavement. The analysis is being carried out using the finite element based software tool.

In general sensitivity analysis helps in predicting how much sensitive is the pavement response with respect to variation in pavement parameters.

Through the sensitivity analysis of pavement responses, the input variables mostly affecting the fatigue cracking and rutting are determined. In the sensitivity analysis, each of layer thickness and modulus of surface layer are varied one at a time from its assumed minimum value, while the other parameters will be kept constant.

D. Nonlinear material in base/subase and subgrade course of flexible pavement

It is well known that granular materials and subgrade soils have non-linear resilient behavior varying with the level of stresses. The resilient modulus of granular materials increases with the increase in stress intensity. A major disadvantage of the layered elastic theory is the assumption that each layer is homogeneous with the same properties throughout the layer. This assumption makes it difficult to analyze layered systems composed of non-linear materials like untreated granular bases and sub-base. The resilient modulus of these materials is stress dependent and varies throughout the layer.

Linear analysis is a simple approximation for design and analysis purpose. Several material models have been developed to analyse nonlinear material with multilayered method, but the output is not precise which hinders the prediction capability. By adopting nonlinear material behavior analysis becomes more difficult as the material behavior varies at particle level. This can be solved by combining the material model with finite element method which produces realistic and precise results.

In the present study software tool with K-θ and bilinear material model is used to analyse base/subbase course with linear as well as nonlinear material characteristics.

E. Objectives of the present study

i) To conduct linear and nonlinear analysis for the multiple thicknesses using IRC as the guidelines in order to evaluate horizontal tensile strains and vertical compressive strains in pavement layers using MFPDS and Kenlayer software.
ii) To compare the results obtained from both software tools.
iii) To assess the impact of pavement parameters on pavement responses.

III. Methodology Of The Present Study

Methodology involves the collection of data, method of analysis and results. Data for the present study are obtained from IRC 37-2012.

The data obtained are analyzed using the MFPDS software tool and the obtained pavement responses i.e., horizontal tensile strain under surface course and vertical compressive strain above subgrade layer are tabulated. Local sensitivity analysis is adopted for analyzing the data.

In the present study it is more focused on identifying tensile and compressive strains for varied pavement parameters using MFPDS software tool. The effect of input parameters over the tensile and compressive strains are observed and they are compared with that of values obtained from multilayer analysis software tool KENLAYER.

The input parameters used for the pavement structure are as shown in TABLE.1

TABLE 1. Input parameters and output obtained

Input Parameters	
h1, h2 in mm	Thickness of surface course, base course
E1,E2 & E3 in MPa	Young's modulus of Surface , base and Subgrade
μ1, μ2 & μ3	Poisson ratio of Surface , base and Subgrade
Output Obtained	
ϵ_t & ϵ_c	Tensile and compressive strains

The material properties for the pavement structure is considered from IRC 37-2012 [2] as given in the TABLE. 2

TABLE 2. Material properties adopted for analysis

SAL	80 KN
Contact Pressure CP	560 KPa
Contact radius CR	106.62 mm
BC, E1	1000 to 9000 MPa
Granular base, E2	Calculated from CBR (15%)
Subgrade, E3	Calculated from CBR (15%)
μ1	0.35
μ2	0.35
μ3	0.4
K1	12.4 to 55.2 MPa
K2	0.32 to 0.7
γ1	22.8 KN/m3
γ2	21.2 KN/m3
γ3	17.17 KN/m3

Also consider base course thickness h2=300mm, from CBR15% young's modulus of Subgrade is 100MPa and Base course is 259MPa respectively are calculated. K1 value is obtained from Allen's table, 1973.

This value can be obtained by varying K1 value suitably with respect to the strains obtained for linear analysis in kenlayer. E1 value 3000MPa is adopted.

After analyzing the above data for linear and nonlinear base course material with varied surface thickness and modulus of elasticity using kenlayer, the tensile and compressive strains (εt & εc) are obtained. With the same input values in MFPDS the responses are obtained. Here the mesh configuration is chosen suitably with the varied layer thickness with an aspect ratio of 1:4. The responses are obtained and tabulated as in the TABLE. 3

Table 3: Output strains with varied h1

h1	Linear (KL)		Nonlinear (KL)	
	εt	εc	εt	εc
50	-2.87E-04	4.10E-04	-2.99E-04	4.18E-04
75	-2.47E-04	3.30E-04	-2.73E-04	3.46E-04
100	-2.00E-04	2.68E-04	-2.28E-04	2.83E-04
125	-1.61E-04	2.21E-04	-1.86E-04	2.32E-04
150	-1.31E-04	1.85E-04	-1.52E-04	1.92E-04
175	-1.07E-04	1.57E-04	-1.25E-04	1.61E-04
200	-8.88E-05	1.35E-04	-1.04E-04	1.36E-04
225	-7.44E-05	1.17E-04	-8.68E-05	1.17E-04
h1	Linear (MFPDS)		Nonlinear (MFPDS)	
	εt	εc	εt	εc
50	-2.91E-04	4.08E-04	-2.62E-04	4.02E-04
75	-2.48E-04	3.29E-04	-2.33E-04	3.26E-04
100	-2.01E-04	2.67E-04	-1.93E-04	2.66E-04
125	-1.61E-04	2.20E-04	-1.57E-04	2.20E-04
150	-1.30E-04	1.84E-04	-1.28E-04	1.85E-04
175	-1.07E-04	1.56E-04	-1.05E-04	1.57E-04
200	-8.84E-05	1.34E-04	-8.76E-05	1.35E-04
225	-7.40E-05	1.17E-04	-7.36E-05	1.18E-04

The tensile and compressive strains are obtained by varying the modulus of elasticity of surface course from 1000 to 9000 with a constant surface thickness of 200mm, base course of 300mm, from CBR15% young's modulus of Subgrade is 100MPa and Base course is 259MPa respectively are calculated using Kenlayer and MFPDS software tools. Table 4 consists of the tabulated strains with varied surface modulus of elasticity.

Table 4: Output strains with varied E1

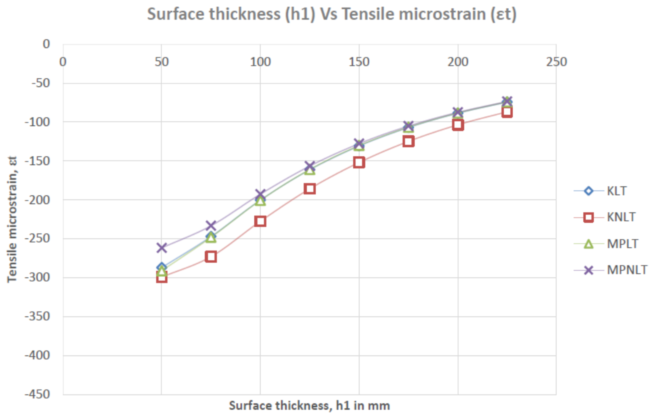
E1	Linear (KL)		Linear (MFPDS)	
	εt	εc	εt	εc
1000	-1.58E-04	1.92E-04	-1.57E-04	1.91E-04
3000	-8.88E-05	1.35E-04	-8.84E-05	1.34E-04
5000	-6.37E-05	1.10E-04	-6.35E-05	1.10E-04
7000	-5.03E-05	9.52E-05	-5.02E-05	9.47E-05
9000	-4.19E-05	8.48E-05	-4.18E-05	8.41E-05
E1	Nonlinear (KL)		Nonlinear (MFPDS)	
	εt	εc	εt	εc
1000	-1.95E-04	2.02E-04	-1.51E-04	1.92E-04
3000	-1.04E-04	1.36E-04	-8.76E-05	1.35E-04
5000	-7.24E-05	1.08E-04	-6.33E-05	1.10E-04
7000	-5.63E-05	9.12E-05	-5.02E-05	9.53E-05
9000	-4.63E-05	8.00E-05	-4.19E-05	8.46E-05

Note: The tensile strains are considered –ve in case of MFPDS values so that it helps in comparison. The strains tabulated are considered as micro strains (10E-6).

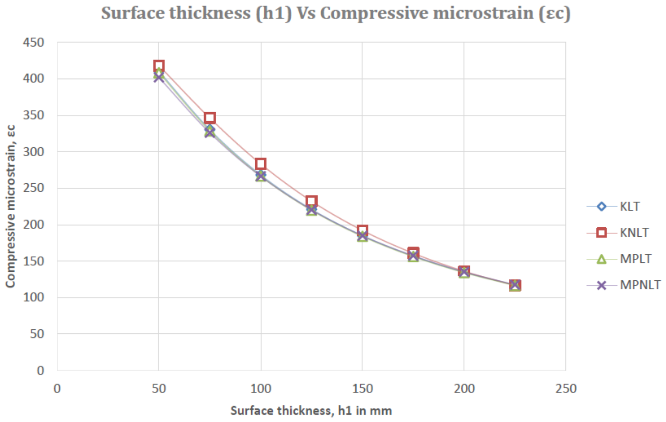
Plots for the above obtained values from table 3 and table 4 helps us in identifying the sensitivity of the pavement response with reference to the variation in thickness of surface course (h1) and Surface modulus (E1).

Plot 1 and Plot 2 represents tensile and compressive strains obtained with linear and nonlinear base course for varied h1, Plot 3 and plot 4 represents tensile and compressive strains obtained with linear and nonlinear base course for varied E1 respectively.

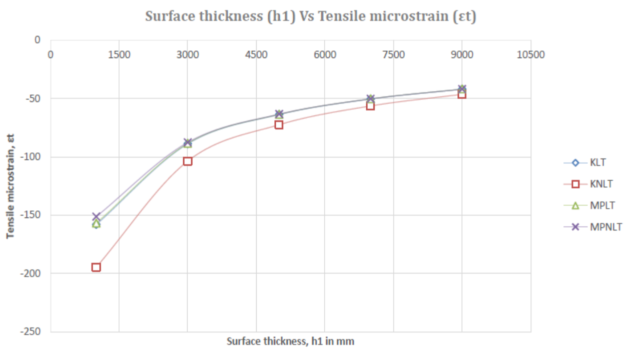
(KLT: Kenlayer linear tensile strain, KNLT: Kenlayer nonlinear tensile strain, KLC: Kenlayer linear compressive strain, KNLT: Kenlayer nonlinear compressive strain, MFLT: MFPDS linear tensile strain, MFNLT: MFPDS nonlinear tensile strain, MPLC: MFPDS linear compressive strain, MFNLC: MFPDS nonlinear compressive strain)



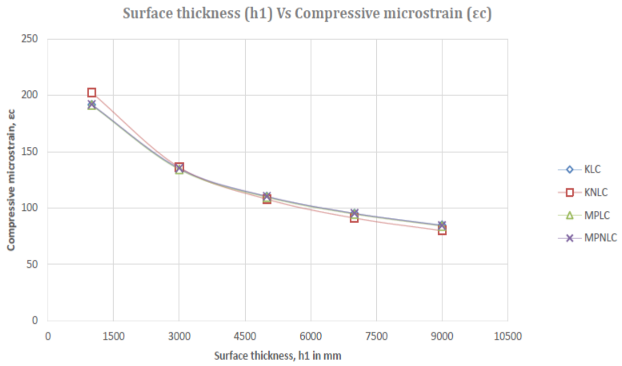
Plot 1: Comparison of linear and nonlinear tensile micro strain with varied h1



Plot 2: Comparison of linear and nonlinear compressive micro strain with varied h1



Plot 3: Comparison of linear and nonlinear tensile micro strain with varied E1



Plot 4: Comparison of linear and nonlinear compressive micro strain with varied E1

The plot 1 shows the relationship between tensile micro strains at the bottom of surface course obtained for linear and nonlinear base course versus varied h1, from the plot we can comment that with the increase in thickness; tensile strain decreases with a small increase at h1=75mm. It can also be observed the KNLT value is 15.06% more than the value obtained from MFPDS.

The plot 2 shows the relationship between compressive micro strains at the top of subgrade course versus varied h1, from the plot we can comment that with the increase in thickness compressive strain decreases. . It can also be observed the KNLC value differs from the value obtained from MFPDS by 3.32% avg.

The plot 3 shows the relationship between tensile micro strains at the bottom of surface course obtained for linear and nonlinear base course versus varied E1, from the plot we can comment that the tensile micro strain decreases with the increase in E1 value, also the εt values obtained from kenlayer and MFPDS for both linear and nonlinear base course are almost same except the KNLT. It exhibits a maximum variation of 22.5% with E1=1000 and a minimum variation of 9.5% with E1 =9000

The plot 4 shows the relationship between compressive micro strains at the top of subgrade course obtained for linear and nonlinear base course versus varied E1, from the plot we can comment that the compressive strain also decreases with the increase in E1 value, also the εc values obtained from both Kenlayer and MFPDS for linear and nonlinear base course are almost same.

IV. CONCLUSION

From the results obtained and the plots we arrive at few conclusions.

1) Finite element based software tool provides a reasonable responses when compared with mutlilayered software tool. MFPDS being a user friendly and being a combination of both finite element method and multilayer analysis method, this tool can be effectively used for analysis and design purpose.

2) The results obtained from both Kenlayer and MFPDS appears to be equivalent for linear analysis, but with a detailed review it can be noticed that, there is a considerable difference in tensile micro strain when the surface thickness is below 75mm.In case of nonlinear analysis the results does not correspond well.

3) The tensile micro strain KNLT with varied surface thickness exhibits 12.53% difference with the MPNLT with 50mm thickness and 15.25% with 225mm thickness. This shows that the compressive micro strain from KNLT increase with the increase in surface thickness with respect of MPNLT.

4) The tensile micro stain KNLT with varied E1 value for nonlinear material in base/ssubbase course using kenlayer exhibits a large difference with low modulus of elasticity of surface but this difference reduces with increase in the modulus of elasticity i.e., 22.3% with 1000MPa and 9.5% difference with 9000MPa when compared with MPNLT. This shows that the effect of nonlinear material of base course reduces with the increase in modulus of elasticity of surface course. The values obtained from Kenlayer and MFPDS tools converge at high modulus of elasticity.

5) It is more reliable to obtain responses from a finite element based software tool when compared with layer analysis base software tools as the results obtained are consistent.

6) Thus pavement failures can be reduced by increasing the surface thickness or by increasing the surface modulus. It is economical to design a pavement with a combination of ideal surface thickness and modulus of elasticity.

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