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Investigation on Stress Distribution in Granular Layer of Flexible Pavement Considering Nonlinearity

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Abstract—*Low volume roads in India comprises of unbound granular materials laid over the subgrade, Hence properties of granular materials plays a significant role in the performance of the pavement. In today s world, the pavement layers undergo many types of failures, among which fatigue cracking and rutting failures are the most common. In the present study, linear analysis is used for analysing the pavement system However, Nonlinear analysis of pavement with granular layers is undertaken. Three methods of nonlinear layers are investigated. It is observed that the Method 1 gives better results compared to other two. A linear analysis shows high modular ratio and leads to high tensile stresses in granular layer which they cannot resist. A nonlinear analysis shows low modular ratio and leads to low tensile stresses.*

Mechanistic-Empirical method of design is an emerging technology used to determine the design life of a flexible pavement. The current design process is based on layer system of analysis which is modified to account for nonlinearity by an iterative procedure. The analyses were carried out using computer software KENPAVE . The software can save the time and avoid the errors and difficulties during the design of pavement. In the present study, Pavement cross section recommended in IRC-37-2012 catalogue for flexible pavements for different cumulative traffic were taken for nonlinear analysis and the properties of granular layers were revised iteratively by changing the Witzack s constants K1 & K2 till the results conveyed. The final results were used to obtain the deflection bowls, stress bowls and strain bowls and estimate the fatigue and rutting life.

Index Terms*: Granular layer, KENPAVE , Nonlinearity, Pavement responses.*

1. INTRODUCTION

Low volume roads in India include district roads (ODR)&(VR) which over 80% of the total road network of the country. These roads are usually constructed as granular pavements with bituminous surfacing. Hence Granular materials comprise the main structural layer over the subgrade to carry the traffic load. In the present study the Mechanistic-Empirical method of design has been considered. Most of the analytical models used for the design of flexible pavements are based on linear elastic theory which assumes that each layer is homogenous, isotropic, linearly elastic with a constant modulus of elasticity and surface layer is free of shearing and normal stresses. But in reality, the materials are nonlinear, anisotropic and inhomogeneous. In addition to this, the boundary conditions are often quite complicated and different from the conditions assumed using layered elastic theory. Hence, the methods based on theory of elasticity need to be modified to accommodate nonlinear behaviour of pavement materials

Objectives of the study

1) To investigate the stress distribution in granular layers of flexible pavement considering nonlinearity.

2) To conduct linear and nonlinear analysis for the multiple thicknesses, CBR by using IRC as the guidelines in order to evaluate vertical compressive stress, horizontal tensile strains, vertical compressive strains, surface deflection in pavement layers using Kenlayer software.

3) To compare the linear and nonlinear elastic analysis.

2. REVIEW OF LITERATURE

1) Seong-Wan Park (2001) carried out the Analysis of Stress Dependent Behaviour in Conventional Asphalt Pavements. In this study, the non-linear stress-dependent finite element program for pavement analysis was developed. In his studies, the stress dependent behaviour of a pavement materials was accounted for nonlinear resilient response using the universal soil model. The influence of a stress dependent model was illustrated with field data. As a result it is observed that stress dependency approach is more suitable to predict the pavement performance particularly in low-volume roads.

2) Umesh Chandra sahoo et.al (2010) carried out the Effect of Nonlinearity in Granular Layer on Critical Pavement Responses of Low Volume Roads. He used An appropriate constitutive model representing the nonlinearity of a granular layer. i.e, Drucker-Prager model and made a analysis finally significant differences can be noted in the critical response obtained from the two approaches. The present study concludes that linear analysis results in unsafe designs for low volume roads where nonlinear analysis gives compared to linear analysis.

3) Behzad Ghadimi et.al (2013) carried out the Comparison between Effects of Linear and Non-linear mechanistic behaviour of materials on the Layered Flexible Pavement Response. The analysis is performed through a well-known program CIRCLY and KENLAYER. Two systems of layered flexible pavements have been constructed. The first model is analyzed through KENLAYER, CIRCLY and ABAQUS. Then the second model is constructed in ABAQUS and analyzed through linear elastic and nonlinear elastic assumptions.

Results show a larger deformation, larger tensile strain at the bottom of asphalt layer and larger vertical strain at the top of subgrade. The maximum of 33% difference has been calculated for the horizontal strain at the asphalt layer.

4) Nidhi. M (2013) carried out a study on A pplications of layered theory for the analysis of flexible pavements consideration of non-linearity in these layers is necessary for accurate estimation of the pavement responses of a flexible pavement structure. consideration of non-linearity in these layers is necessary for accurate estimation of the pavement responses of a flexible pavement structure. The data used in this study are collected from IRC-37-2012 i.e., Guidelines for the design of flexible pavements and CBR values are obtained from IRC guidelines. He compared linear and linear analysis and finally concluded that nonlinear coefficients of granular layers have more pronounced effect on tensile strain rather than on compressive strain.

5) Yusuf Mehta, et.al (2003) carried out the Evaluation of FWD Data for Determination of Layer Moduli of Pavements. Falling weight deflectometer FWD testing has been done extensively in the past to assess structural condition and determine the moduli of pavement layers. He compared measured and calculated deflection through BACKCALCULATION. And finally concluded that The values obtained any program give a good fit between the measured and computed deflections.

3. METHODOLOGY

Data Collection

The data used in this study are collected from IRC-37-2012 i.e., Guidelines for the design of flexible pavements and Pavement Analysis and Design by Yang. H. Huang. The multiple thicknesses, elastic modulus of pavement component layers and CBR values are obtained from IRC guidelines.

Method of Data Analysis

The method used in data analysis is mechanistic-empirical method. The mechanistic empirical software called KENLAYER is used to analyze the pavement responses. There are two method of analysis such as linear analysis and nonlinear analysis.

Linear Analysis

The stresses in linearly elastic materials are proportional to strain, with the proportionality constant equal to young s modulus (E). Material properties are constant, and deformations are covered by small deflection theory.

Nonlinear analysis

It is an iterative procedure First, an elastic modulus is assumed for each layer and the stresses are obtained from the layered theory. The stresses thus obtained, a new set of modulie is determined, and a new set of stresses is then computed. The process is repeated until the modulie between two consecutive iterations converge to a specified tolerance.

Three methods of nonlinear layers are investigated.

In method 1, the nonlinear granular layer is subdivided into a number of layers, and the stresses at the mid- depth of each layer are used to determine the modulus.

In method 2, the granular layer is considered as a single layer, and an appropriate stress point, usually between the upper quarter and upper third of the layer, is selected to compute the modulus.

In method 3, the granular layer is considered as a single layer with the stress point at the mid height of the layer.

Analysis of Deflection Bowls

Table 1: The variation of deflection for linear & Nonlinear analysis

CBR=3%, Traffic=30msa						
Vertical deflections	Radial distances					
	1a	2a	3a	4a	5a	6a
Linear	76.3	75.88	75.06	74.53	73.88	72.64
Non linear Method1	67.8	67.11	66.23	65.92	65.34	64.88
Non linear Method2	69.5	69	68.34	67.88	66.98	66.2
Non linear Method3	68.8	68.15	67.33	66.85	66.12	65.77

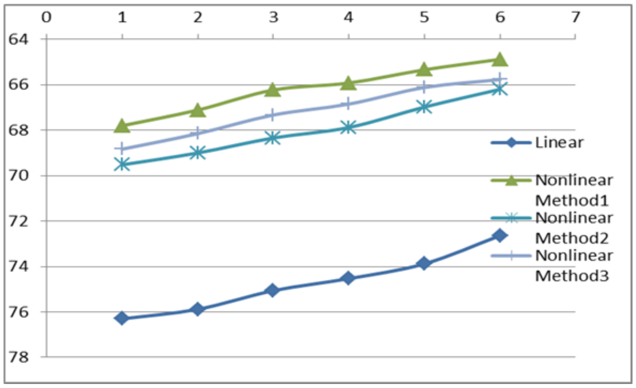

Fig. 1: Comparision of linear and nonlinear deflections.

Table 2: The variation of deflection for linear & Nonlinear analysis

CBR=3%, Traffic=50msa						
Vertical deflections	Radial distances					
	1a	2a	3a	4a	5a	6a
Linear	74	73.2	72.4	71.5	70.66	69.84
Non linear Method1	65.44	64.84	64	63.75	62.98	61.82
Non linear Method2	68.3	67.74	67	66.52	65.84	64.99
Non linear Method3	67	66.54	65.88	65.32	64.94	64

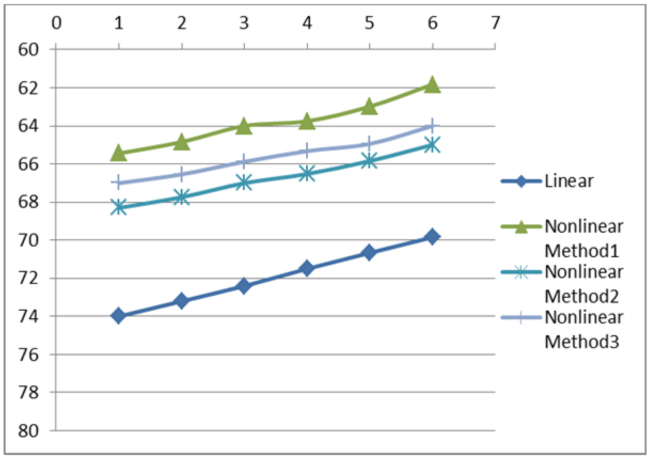

Fig. 2: Comparision of linear and nonlinear deflections.

The pavement cross section recommended in IRC 37-2012 catalogue for flexible pavements for different cumulative traffic (Traffic (30, 50, 100, 150msa) were taken. Tables and graphs shows the vertical deflection for various surface and granular layer thicknesses and various CBR values for linear and nonlinear granular case. For a nonlinear layer, The granular layer is subdivided into number of layers with the stress point at the mid-height of each layer E is the elastic modulus of first iteration and a convenient E is assumed on the basis of Thomson and Elliot and the properties of granular layers were revised iteratively by changing Witzack s constants K_1, $K_{2.}$ Three methods of nonlinear layers were investigated.

It is observed that Method1 gives better results compared to other two methods. This is due to material properties. With the increasing CBR, the thickness of the pavement increases and hence decreases in the vertical deflection. This analysis is carried out for different CBR (5%, 8%, 10% and 15%).

Analysis of Stress Strain Bowls

Comparison of Vertical stress, Normal X stress, horizontal tensile strains and Vertical compressive strains for pavements with linear and nonlinear granular layers is shown in the above table and figures.

Table 3: Variation of stress and strains for linear and nonlinear analysis

For CBR 3%, Traffic= 50msa							
sl.no	**Specification**	**Radial distances**					
1	Vertical stresses(kpa)	**1a**	**2a**	**3a**	**4a**	**5a**	**6a**
	Linear	72.26	70.2	67.4	62.8	59.4	56.2
	Nonlinear	39.4	37.5	33.2	30.9	28.5	25.4
2	Normal 'X' stress (kpa						
	Linear	915	912	907	904	901	897
	Nonlinear	784	781	777	774	771	769
3	Horizontal tensile						
	Linear	155	153	150	146	143	139
	Nonlinear	145	143	141	140	138	135
4	Vertical strain						
	Linear	306	304	299	297	294	291
	Nonlinear	298	295	292	289	287	285

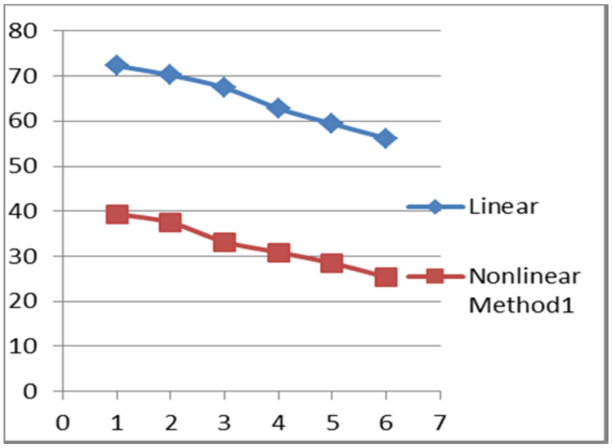

Fig. 3: Vertical stress Bowl

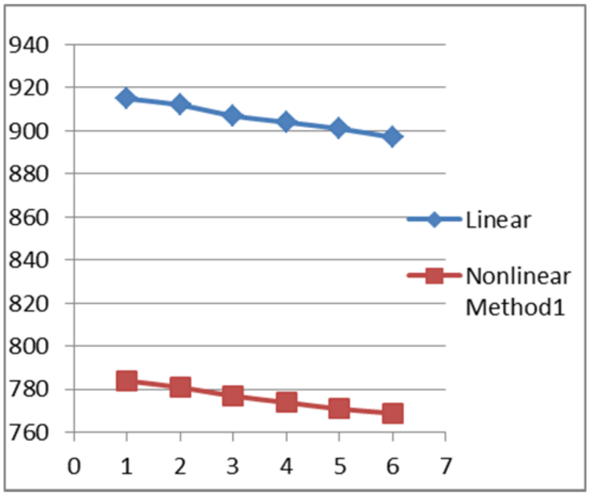

Fig. 4: Normal X stress bowl

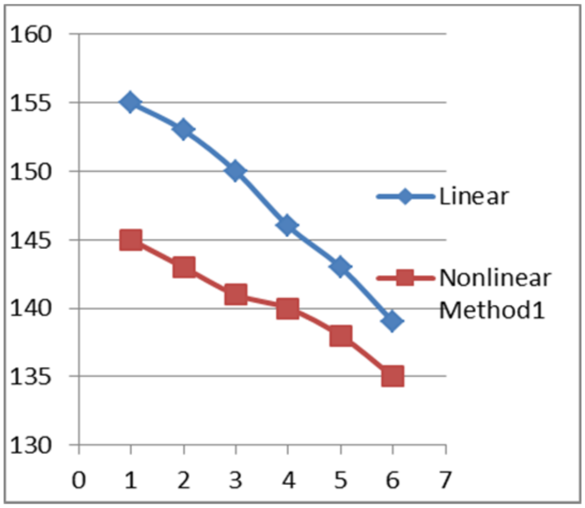

Fig. 5: Tensile strain bowl

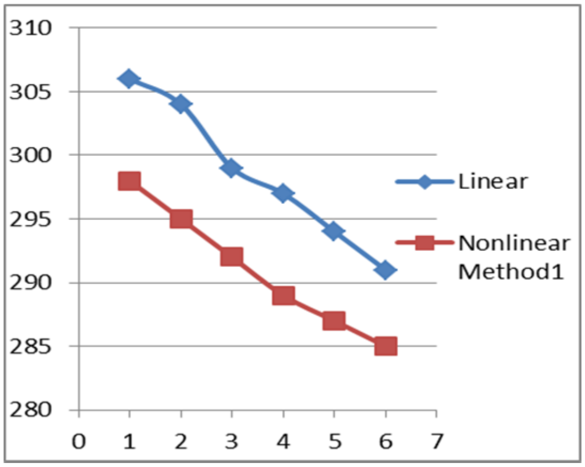

Fig. 6: Vertical Compressive strain

From the analysis it is observed that, The horizontal tensile strain at the bottom of bituminous layer decreases with an increase in surface thickness and decreases with an increase in elastic moduli of granular layer.

The vertical compressive strain on the top of the subgrade

decreases with an increase in granular thickness and decreases with an increase in CBR values.

The normal X stress at the Bottom of the Bituminous layer

decreases with an increase of surface thickness and decreases with an increase in elastic modulie of granular layer.

The vertical compressive stress on the top of the subgrade increases with an increase in CBR values and decreases with an increase in granular thickness.

With the increase of the CBR, the stress and strain gradually decrease due to material type, material quality, subgrade support, enviornmental factors and variability within the pavement structure. This analysis is carried out for different values of CBR (5%, 8% 10% and 15%) and different traffic (50, 100 and 150msa).

LIFE ESTIMATION AND PERFORMANCE

The mechanistic criteria adopted in the Indian Road Congress guidelines (IRC: 37-2012) for design of flexible pavements. For CBR 3-15%

Table 4: The fatique and rutting life of the pavement with different CBR

CBR(%)	Traffic in msa	Linear analysis		Nonlinear analysis	
		Fatigue life	Rutting life	Fatigue life	Rutting life
3	50	51	151	65.26	166
	100	106	158	119	180
	150	160	180	178	195
5	50	52.96	161	70.79	177
	100	119	166	132	190
	150	184	192	198	209
8	50	59	169	77	190
	100	132	174	140	203
	150	191	199	220	220
10	50	65.26	178	84	195
	100	140	183	155	213
	150	205	209	238	232
15	50	71	183	89	203
	100	161	193	178	224
	150	229	220	256	244

ANALYSIS OF DEFLECTIONS BASINS OBTAINED USING FWD

Deflection measurements were made using FWD on a national highway in the month of January. Based on the deflection data and other parameters such as subgrade strength and pavement layer thicknesses different homogeneous sections have identified. Deflections measured at different locations of the homogeneous section a normalised for 40 kN standard load and are given the following Table.

Table 5: Measured deflections

FWD Deflections								
Sl.no	Normalised FWD deflections at Radial distances(mm)							Pavement temperature(˚C)
	0	300	600	900	1200	1500	1800	
1	0.481	0.294	0.216	0.163	0.134	0.107	0.08	35
2	0.478	0.317	0.231	0.186	0.156	0.13	0.106	35
3	0.481	0.34	0.242	0.201	0.17	0.139	0.105	36
4	0.5	0.321	0.233	0.198	0.151	0.13	0.093	36
5	0.477	0.324	0.24	0.19	0.159	0.138	0.109	36
6	0.485	0.319	0.23	0.194	0.152	0.141	0.101	37
7	0.473	0.315	0.229	0.191	0.149	0.131	0.097	37
8	0.46	0.301	0.223	0.188	0.151	0.13	0.093	38
9	0.48	0.365	0.251	0.19	0.17	0.152	0.108	38
10	0.487	0.327	0.245	0.187	0.161	0.148	0.102	38

Layer moduli are back calculated using KGPBACK program. The pavement has been modeled as a three-layer system with bituminous layer, granular layer and subgrade.

The moduli values back calculated for all the ten test points of the homogeneous section are given in the following table

Table 6: Calculated deflections

Initial Bowls considering Initial E values							
Sl.no	Calculated deflections at Radial distances(mm)						
	0	300	600	900	1200	1500	1800
1	0.455	0.214	0.151	0.115	0.088	0.071	0.058
2	0.489	0.219	0.163	0.127	0.099	0.08	0.066
3	0.428	0.225	0.169	0.132	0.103	0.083	0.068
4	0.456	0.228	0.166	0.127	0.099	0.079	0.065
5	0.448	0.219	0.165	0.129	0.101	0.082	0.067
6	0.5	0.222	0.164	0.128	0.1	0.081	0.066
7	0.48	0.214	0.158	0.122	0.095	0.077	0.063
8	0.427	0.209	0.156	0.121	0.095	0.076	0.063
9	0.41	0.228	0.172	0.135	0.105	0.085	0.069
10	0.453	0.223	0.167	0.13	0.101	0.082	0.067

Bituminous layer moduli are corrected for a standard pavement temperature of 35°C and granular layers and subgrade moduli back calculated from deflections collected in Winter are corrected for monsoon season. The corrected moduli are given in the following table

Table 7: Corrected deflections

Final Bowls							
Sl.no	Calculated deflections at Radial distances(mm)						
	0	300	600	900	1200	1500	1800
1	0.489	0.244	0.175	0.133	0.103	0.083	0.067
2	0.529	0.255	0.193	0.151	0.119	0.096	0.079
3	0.458	0.26	0.2	0.157	0.124	0.1	0.082
4	0.483	0.26	0.194	0.15	0.117	0.094	0.077
5	0.478	0.253	0.195	0.154	0.121	0.098	0.08
6	0.516	0.254	0.193	0.151	0.119	0.096	0.079
7	0.494	0.244	0.183	0.143	0.112	0.091	0.075
8	0.433	0.236	0.18	0.142	0.111	0.09	0.074
9	0.424	0.26	0.202	0.16	0.126	0.102	0.084
10	0.462	0.254	0.195	0.153	0.12	0.097	0.08

The measured deflection bowl and corrected deflection bowl is as shown in the figure.

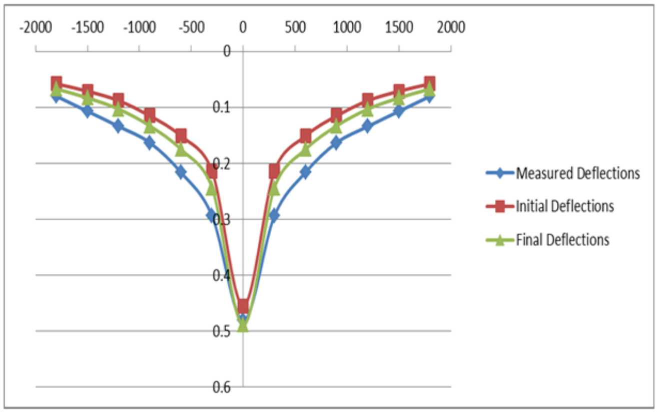

Fig. 7: Comparision of measured, calculated and corrected deflections

The values obtained from the back calculation program give a good fit between the measured and computed deflections. Selecting 15th Percentile moduli for the purpose of design, the design moduli of in-service layers are :- 1112, 173, 44.3 MPa respectively for bituminous, granular and subgrade layers. From the KENLAYER software, Tensile strain at the bottom of bituminous layer = 284.5 microstrains Vertical strain on top of subgrade = 439.6 microstrains

4. LIFE ESTIMATION AND PERFORMANCE

Life of the pavement obtained by using fatigue life and rutting life Equation in IRC 37-2012 as follows

1. Fatigue model,

$$N_f = 0.711 * 10^{-4} * \left[\frac{1}{\varepsilon_t}\right]^{3.89} * \left[\frac{1}{M_R}\right]^{0.854}$$

$N_f = 0.711 * 10^{-4} * \left[\frac{1}{284.5 * 10^{-6}}\right]^{3.89} * \left[\frac{1}{1112}\right]^{0.854}$

$N_f = 11.07$msa<100msa

2. Rutting Model,

N=1.41*$10^{-8} * \left[\frac{1}{\epsilon_v}\right]^{4.5337}$

N=1.41*$10^{-8} * \left[\frac{1}{439.6 * 10^{-6}}\right]^{4.5337}$

N=233.7msa>100msa

The existing pavement is inadequate to carry the design 100 msa traffic from fatigue consideration. So, there is a need to design the overlay thickness. The combination of existing pavement and overlay will be analysed as a four-layer system to ensure that fatigue and rutting criteria are satisfied for the assumed design traffic. Analysis of the pavement with a Bituminous Concrete overlay of 95 mm thickness yields a tensile strain of 159.8 microstrain and 208.3 vertical subgrade strain. Elastic modulus value of BC mix has been taken as 1695 MPa.

The fatigue life for this overlaid pavement will be 104.4 msa and rutting life will be 690.5 msa. Hence, design overlay thickness is 95 mm of Bituminous concrete.

5. CONCLUSION

An analytical study was conducted to evaluate the effect of nonlinearity in granular layers.

A comparison of linear and nonlinear analysis shows that nonlinear analysis shows better results for the determination of pavement response compared to linear analysis due to material properties can account for stress dependent.

The values obtained from the backcalculation program give a good fit between the measured and computed deflections.

In all the cases the computed rutting life is very much higher than the design life and is much more than the fatique life.

REFERENCES

[1] Yang.H.Huang, Pavement analysis and design , University of Kentucky, Prentice hall, Eaglewood cliffs, New Jersey, 2004.
[2] IRC-37:2012, Guidelines for design of flexible pavements
[3] Seong Wan Park and Robert L. Lytton, F, Effect of Stress dependent Modulus and Poisson s Ratio on Structural Response in Thin Asphalt Pavements , ASCE Journal, May 2004.
[4]Umesh Chandra Sahoo and Kusum Sudhakar Reddy Effect of Nonlinearity in Granular Layer on Critical Pavement Response of Low Volume Roads , March 2010.
[5] Nidhi .M , M.S. Nagakumar, applications of layered theory for the analysis of flexible pavements , Nov 2013.