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Elasto-Plastic Analysis and Field Studies on Coir Geotextile Reinforced Flexible Pavements

Aavani P.[1]* Priyanka Jawale[2], Amruta Kulkarni[3] and Mithun K. Sawant[4]

[1] Assistant Professor, Department of Civil Engineering, DYPIEMR, Akurdi, Pune, India

[2] Assistant Professor, Department of Civil Engineering, DYPIEMR, Akurdi, Pune, India

[3] Assistant Professor (HOD), Department of Civil Engineering, DYPIEMR, Akurdi, Pune, India

[4] Assistant Professor, Department of Civil Engineering, DYPIEMR, Akurdi, Pune, India

Abstract – Finite element analysis software, ABAQUS was used effectively in analyzing the stress – strain behavior under the application of static wheel load in the modeled flexible pavement structure. A series of 30 pavement response models were analyzed. In elasto – plastic analysis, rutting values were used to find the Traffic Benefit Ratio (TBR) for reinforced sections. TBR value ranges from 1.01 to 2.16. Multiple linear regression models were developed with acceptable degree of accuracy. Field studies were conducted on unreinforced and coir geotextile reinforced sections to evaluate the benefits of coir geotextiles in flexible pavements.

Index Terms— ABAQUS, Coir Geotextile, Finite Element Analysis, Rutting, Traffic Benefit Ratio

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I. INTRODUCTION

Accurate traffic loading estimates and analysis of the impact of heavy traffic on pavement performance are important issues for pavement designers. Hence a computational model that can be used to perform a pavement service life prediction based on a mechanistic analysis using a finite element method has to be developed. Finite element analysis is well suited in analyzing pavement systems subjected to various conditions due to its versatility. The method is capable of simulating pavement responses subjected to different axle load, tire pressure, axle configurations and loads moving at different speeds. Various material constitutive models such as linear elastic, nonlinear elastic and linear viscoelastic can be used to describe the material behavior. Moreover finite element method is best suited to analyze geosynthetic reinforced flexible pavements. The finite element procedure of solving the system is computationally demanding and results are highly dependent upon the mesh size and convergence criteria. In this study finite element analyses of coir geotextile reinforced flexible pavement were carried out to meet the objectives.

II. COIR GEOTEXTILES

Coir geotextile is made from coconut fiber extracted from the husk of the coconut fruit. It is available in different mesh matting with international trade names and is of different types and is classified according to varying degree of color, length and thickness. Coir has the highest tensile strength of any natural fiber and retains much of its tensile strength when wet. It is also very long lasting, with infield service life of 4 to 10 years. The reason for the greater strength of coir is its high lignin content. The physical and engineering properties of various coir geotextiles are tabulated below in table 1

Table 1: Physical and engineering properties of various coir geotextiles

Particulars	Woven Type Coir Geotextile		
	CCM 300	CCM 700	CCM 900
Mass/Unit Area (g/m^2)	390	800	820
Thickness (mm)	6.96	7.56	8.66
Tensile strength (kN/m)			
Warp	5.40	9.94	11.97
Weft	4.00	8.90	7.61
Failure Strain (%)			
Warp	24.16	28.70	27.06
Weft	21.30	30.06	27.63
TensileModulus (kN/m)	90	132	144

(Source: Central Coir Research Institute)

III. ELASTO PLASTIC MODELLING

For some practical analysis, hot-mix asphalt can be assumed to be linear elastic when it is solid and non-viscous. However, in reality, hot-mix asphalt materials are viscous at elevated temperatures, elastic at low temperatures and exhibit viscoelastic behaviour under intermediate conditions. Linear elastic analysis could not account for rutting criteria. In order to account rutting in flexible pavements elastoplatic analysis is carried out.

A. Geometry Model

Conventional kinematic boundary conditions have been successfully used by various researchers. The modeled domain must be large enough to avoid any edge error. Domain size analysis is carried out by various researchers to find out the optimum size of pavement response model yield desirable pavement responses with reasonable degree of accuracy. Accordingly pavement response model of 5 m length in horizontal direction and 7 m in height in vertical direction has been selected for axis symmetric elasto-plastic analysis. In elasto-plastic analysis pavement layers were modeled using four – noded quadratic plane strain elements, while quadratic axisymmetric membrane elements with plane strain thickness of 1 mm were used for the coir geotextile reinforcement.

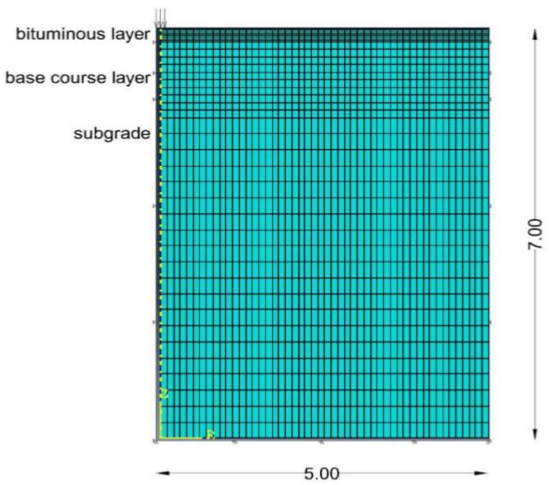

Figure 1: Ax symmetric elastoplastic model

B. Load Model

To model the surface load of the dual wheel the total load is transferred to the pavement surface through an average contact area of 200 mm radius. The stiffening effect of the tire wall is being neglected. The tire contact pressure on the road is equal to the tire inflation pressure with a circular tyre imprint. For performing the analysis axles loads are varied from 40 kN to 110 kN. Time period of loading is increased to arrive at permanent deformation profiles.

C. Asphalt Concrete Model

Stress and time dependency in the analysis of pavement rutting was accounted for using a creep model from the ABAQUS material library. Creep power law model in its time hardening form as described in ABAQUS can be represented as equation (1) shown below.

$$\varepsilon = A\sigma^n t^m \qquad (1)$$

ε = creep strain rate

σ = uniaxial equivalent deviatoric stress for isotropic

Behavior

t= total loading time

Researchers concluded that if a creep model is used to describe the time dependent material behavior, repeated loading and continuous loading will have the same effect on the predicted creep strain as long as the total loading times are the same. Table 2 summarizes the creep model parameters of asphalt material adopted for elastoplastic analysis.

Table 2: Creep Model material parameters for Asphalt Concrete

Material	Asphalt Concrete
Elastic Modulus (MPa)	2579
Poisson's Ratio	0.35
Unit Weight (kN/m^3)	22.8
A	0.8 x 10^{-4}
N	1.2
m	-0.5

D. Base Course and Subgrade Model

The focus is placed on elasto-plastic modeling as the most dominant framework for plastic modeling of soil. Table 3 summarizes the material parameters for base course layer and sub grade adopted for the elastoplastic analysis. Mohr-Coulomb failure criterion can be written as the equation for the line that represents the failure envelope. The general equation is

$$\tau_f = c + \sigma_f \tan \emptyset \qquad (2)$$

τ_f = shear stress on the failure plane

c = apparent cohesion

σ_f = normal stress on the failure plane

σ_f = angle of internal friction

E. Coir Geotextile Model

In this study the coir geotextile reinforcement membrane is considered as an isotropic elastic material. Material models which include components of plasticity creep, and directional dependency of the coir geotextile may be more realistic, however, these models require many parameters for numerical simulation. Therefore in this study the coir geotextile is assumed to act as a linear isotropic elastic material. Such a model proved to be efficient as used by other researchers; e.g.Ling and Liu (2003).

F. Pavement Composition

The pavement composition adopted for analyses for pavement sections with 100 mm asphalt layer are shown in Table 4. Similar composition of pavements was analyzed for sections with asphalt layer thickness of 75 mm and 50 mm.

Table 3: Elastoplastic material properties for base and subgrade layer

Material	Base course	Sub-grade
Thickness (mm)	480	6420
Elastic Modulus (MPa)	225	70
Poisson's Ratio	0.35	0.4
Unit Weight (kN/m^3)	21.2	19.6
Cohesion (kPa)	20	8
Friction Angle (°)	43	36
Dialation Angle (°)	13	6

Table 4: Pavement composition adopted for finite element analyses

Sections	Asphalt Layer Thickness (mm)	Type of Coir Geotextile	Location of Coir Geotextiles
A	100	Nil	Nil
B	100	CCM 900	Bottom
C	100	CCM 900	Middle
D	100	CCM 900	One –third
E	100	CCM 700	Bottom
F	100	CCM 700	Middle
G	100	CCM 700	One –third
H	100	CCM 400	Bottom
I	100	CCM 400	Middle
J	100	CCM 400	One –third

IV. ELASTO PLASTIC ANALYSIS

A. Traffic Benefit Ratio

Coir geotextiles were able to extend the service lives of the reinforced sections by reducing the amount of permanent deformation (rutting) in these sections. The increase in service life of pavement structure is usually evaluated by using the Traffic Benefit Ratio (TBR). The TBR is defined as the ratio of the number of load cycles to achieve a particular rut depth in the reinforced section to that of unreinforced section of identical thickness, material properties, and loading characteristics. The TBR values obtained at 20 mm rutting depth for the different sections studied in this research project were also calculated.

Traffic Benefit Ratio value ranges from 1.01 to 2.16. Decrease of the coir geotextile tensile modulus resulted in greater reduction in the permanent deformation of reinforced pavement system and hence increasing the number of load repetitions is needed to reach the 20 mm surface rutting.

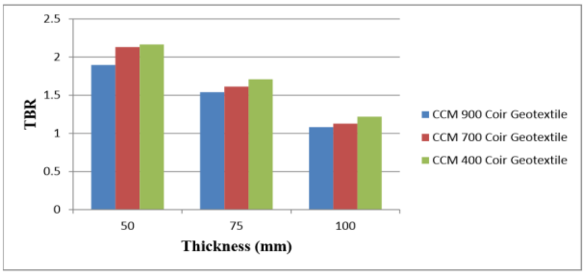

Figure 2: TBR of pavement section with coir geotextile reinforcement at the interface of AC layer and base course layer

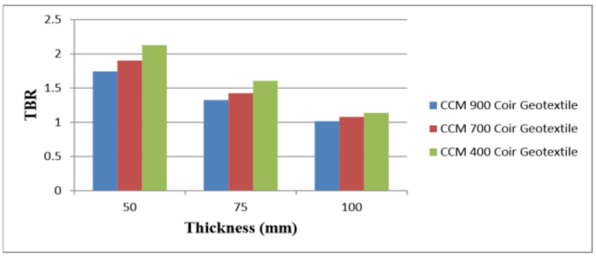

Figure 3: TBR of pavement section with coir geotextile reinforcement at one-third from bottom of AC layer

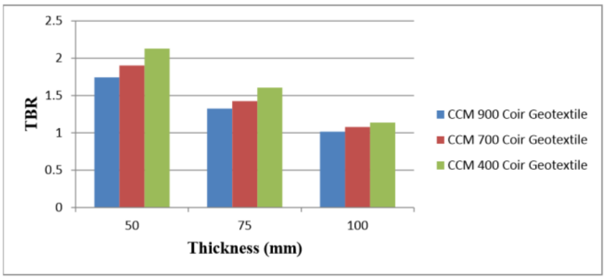

Figure 4: TBR of pavement section with coir geotextile reinforcement at middle of AC layer

Analysis shows the effect of modulus of coir geotextile and thickness of asphalt concrete layer when coir geotextile is placed at different locations. The results were consistent with the findings of finite element linear elastic analysis which showed that lower coir geotextile tensile modulus resulted in larger reduction in vertical strains. It also can be seen that the improvement provided by the reinforcement decreased with the increase of asphalt layer thickness for stiff subgrade.

B. Multiple Linear Regression Analysis

The general TBR model is given as:

$$TBR = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots \beta_n X_n \qquad (3)$$

In this analysis, there are two independent variables such as

X_1 = thickness of asphalt concrete layer

X_2 = normalized value of coir geotextile modulus used in finite element analyses

Based on the results of analysis, multiple regression analysis was conducted on finite element data to develop a TBR prediction model. The results showed that the final model has R^2 of 0.9.12 to 0.96, which suggested that the model well fits the data used. Equations below presented the final TBR model obtained from the statistical regression analysis

When Coir geotextile is placed at the interface of asphalt concrete and base course layer (R^2 = 0.912)

$$TBR = 3.346 - 0.018\, X_1 - 0.290\, X_2 \qquad (4)$$

When Coir geotextile placed at lower one-third of asphalt concrete layer R^2 = 0.966)

$$TBR = 3.220 - 0.017\, X_1 - 0.348\, X_2 \qquad (5)$$

When Coir geotextile is placed at middle of asphalt concrete layer (R^2 = 0.966)

$$TBR = 3.220 - 0.017\, X_1 - 0.348\, X_2 \qquad (6)$$

C. Validation of Regression Model

Additional cases of coir geotextile reinforced sections with 25 mm thick asphalt concrete layer were run using the finite element model and the corresponding TBR values for these cases were calculated using the mechanistic empirical method. These TBR values are used to verify the regression models developed. The TBR values of these cases calculated from the finite element analysis using mechanical-empirical method and those predicted from the statistical regression model were compared and summarized in Table.

The difference ranges from 0.37 % to 3.78 %, which suggest that the TBR values predicted by the regression model are within acceptable accuracy.

V. FIELD STUDIES

A. Benkelmam Beam Test

Pavement deflection is measured by the Benkelman Beam. For measuring pavement deflection the C.G.R.A. procedure which is based on testing under static load may be adopted. The road stretch is divided into sections of 10 m interval. Deflections measured by the Benkelman Beam are influenced by the pavement temperature and seasonal variations. But correction for temperature is not applicable since the road has only a thin bituminous surfacing. Since the pavement deflection is dependent upon change in the climatic season of the year, it is always desirable to take deflection measurements during the season when the pavement is in its weakest condition. Since, in India, this period occurs soon after monsoon, deflection measurements should be confined to this period as far as possible.

This field deflection study is carried out soon after the monsoon, climatic correction is not required. Characteristic deflection for unreinforced section is obtained as 1.363 mm and that of coir geotextile reinforced section is 1.0745 mm From the Benkelman Beam deflection test, it is observed that coir geotextile reinforcement decreased the deflection in pavement by an amount of 21.17 %. Hence from the results we can conclude that inclusion of coir geotextile reduces deflection in pavements.

VI. CONCLUSION

In elasto – plastic analysis vertical strain profiles were plotted for unreinforced and coir geotextile reinforced sections. The rutting values thus obtained were used to find the Traffic Benefit Ratio (TBR) for reinforced sections. TBR value ranges from 1.01 to 2.16. Multiple linear regression models were developed with acceptable degree of accuracy. The improvement provided by the reinforcement decreased with the increase of asphalt layer thickness. From both the analyses it is concluded that coir geotextiles with lower tensile modulus resulted in greater reduction in strain values. Also as asphalt layer thickness increases life of pavement increases. From the Benkelman Beam deflection test, it is observed that coir geotextile reinforcement decreased the deflection in pavement by an amount of 21.17 %. Hence from the results we can conclude that inclusion of coir geotextile reduces deflection in pavements.

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Corresponding Author

Aavani P.*

Assistant Professor, Department of Civil Engineering, DYPIEMR, Akurdi, Pune, India