Prediction of Geogrid-Reinforced Flexible Pavement Performance using Numerical Analysis

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Abstract. The finite element (FE) software PLAXIS 2D is used in this study to perform a numerical analysis for the prediction of deformation in the surface layer of geogrid reinforced flexible pavements for various California bearing ratios (CBR) of subgrade and traffic volume. A linear elastic model was used to simulate the behaviour of base, sub-base, and subgrade soil, whereas geogrid was modelled as a linear elastic geogrid element. The accuracy of the FE analysis was verified by comparison of the outcomes of numerical studies to the findings of the experimental study reported by Correia, 2014. Using the validated FE model, this work has been extended to include geogrid into the base course of flexible pavement. A significant improvement in base layer modulus value was observed for geogrid reinforced pavement when compared to an unreinforced case. Furthermore, the modulus improvement factor (MIF) for geogrid has been calculated based on the improved modulus value of the reinforced base layer. A comparison between two different types of geogrids i.e. stiffness of 400 kN/m and 800 kN/m, is also analyzed on the basis of MIF value.

Keywords: California bearing ratio; Flexible Pavement; Geogrid; Traffic load; Modulus Improvement Factor, Numerical Analysis

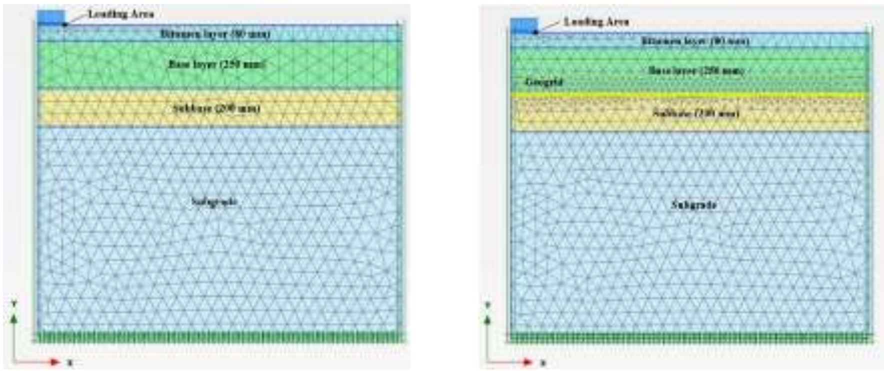
1. Introduction

Flexible pavement is a load-bearing structure that consists of different granular materials layered above the subgrade. The main purpose of flexible pavement is to provide a safe riding surface without causing discomfort to passengers or vehicles. The stability of flexible pavement is affected by factors such as the thickness of layers, pavement material quality, and environmental conditions. However, the primary concerns with flexible pavements are fatigue and rutting caused by large traffic volumes [1, 2]. Geosynthetics are utilized as reinforcement in flexible pavements worldwide when the foundation soil has a very poor load-bearing capability [3-5]. Geogrid has been widely employed in pavements since the early 1970s, particularly for strengthening the pavement layer or enhancing a poor subgrade soil [6]. Geogrid at the base-subgrade interface has been proven to increase the efficiency of flexible pavements by increasing the pavement service life or minimizing the thickness of the pavement while keeping similar performances in both laboratory and field studies [7-10]. Raymond and Ismail [11] showed experimentally that incorporating geogrid onto railway tracks and highways on loose material may significantly improve the load-carrying capacity and efficiency of transportation systems. Perkins et al. [12] conducted triaxial testing on granular base materials unreinforced and reinforced with geogrids. These results indicated that when test specimens were reinforced with geogrid, the rutting depth was significantly reduced.

In this investigation, numerical studies on geogrid reinforced (GR) and the unreinforced (UR) pavements were performed using finite element (FE) software PLAXIS 2D [13]. In the numerical analysis, the geogrid was incorporated into the base course of the pavement. The numerical study was performed using validated numerical models to predict the deformation in the surface layer and afterward, the modulus value of the base course was determined for UR and GR pavements. Furthermore, the MIF of the base course is evaluated as per IRC: SP:59 [14] by comparing the GR and UR flexible pavement. In addition, MIF is compared between two distinct categories of geogrids (i.e., stiffness 400 kN/m and 800 kN/m).

2. Numerical Modelling

The 2D FE analyses are performed on both UR and GR flexible pavements using PLAXIS 2D, and the various pavement layer thicknesses are taken from the design catalogues specified in IRC 37 [15] for the CBR value and traffic volume. The model developed for both unreinforced and reinforced case with a 10% CBR and a 10 msa traffic load is presented in Fig. 1a and b respectively. A standard fixity boundary condition has been adopted, i.e., horizontal displacement restriction at all vertical boundaries and fully fixed at the bottom boundary.



(a) (b)

Figure 1. Numerical model for 10% CBR and a 10 msa traffic volume:
(a) Unreinforced flexible pavement; (b) reinforced flexible pavement for geogrid stiffness of 400 kN/m.

The mesh was discretized using 15-noded triangular elements. Analyses have been conducted using a mesh with a relative element size of 0.333. Additional mesh refinement was performed at the interfaces of the different pavement layers, as well as adjacent to the geogrid. The pavement was modelled as a multi-layer structure under static loading. A circular tyre imprint of 150 mm radius was used to apply a uniform loading of 565 kPa.

For both UR and GR cases, the axisymmetric linear elastic model was adopted as it was capable of simulating circular loading [16-19]. The 15-noded structural solid element was used to model the various pavement layers used in the investigation. The modulus value and thickness of various layers have been computed for the flexible pavement using IRC 37-2018 guidelines. For example, Table 1 shows the important parameters for a 10% CBR value and a 10 msa traffic volume. Geogrid was modelled by introducing biaxial elastic geogrid elements in the base layer of the pavement and the parameter used in numerical analysis are shown in Table 1.

Table 1 Material properties of pavement and geogrid for 10% CBR and 10 msa traffic load

Parameters	Bituminous layer	Base	Subbase	Subgrade	Geogrid
Layer Thickness (mm)	80	250	200	1000	-
Resilient modulus (MPa)	3000	300	200	80	-
Poison’s ratio	0.35	0.35	0.35	0.35	-
Stiffness (kN/m)	-	-	-	-	400, 800

3. Validation

3.1 Validation of 2D-numerical unreinforced pavement model

The UR pavement is modelled and analyzed using FE software with similar input parameters as IITPAVE (i.e., layer thickness, modulus value, Poisson's ratio, wheel load and tyre pressure). The modulus values and thicknesses of various layers were estimated for the flexible pavement using IRC: 37-2018 guidelines. The vertical subgrade strain values derived from FE analyses are compared to those determined from IITPAVE software for an 8% CBR value and traffic volume varying from 5 to 50 msa, as illustrated in Table 2. Additionally, the vertical strain values on the subgrade derived from FE analysis are compared to the allowable vertical strain values (*i.e.*, estimated from the equation provided in IRC 37) for an 8% CBR value and a traffic volume of 5 to 50 msa, as shown in Table 2.

Table 2 Comparative study on the subgrade strain values for different traffic loads and subgrade CBR of 8%

Traffic volume (msa)	Strain (As per IRC 37)	Strain (Obtained from IITPAVE)	Strain (Obtained from FE analysis)
5	7.84×10^{-4}	6.39×10^{-4}	6.43×10^{-4}
10	6.73×10^{-4}	4.96×10^{-4}	5.02×10^{-4}
20	5.77×10^{-4}	4.21×10^{-4}	4.26×10^{-4}
30	4.16×10^{-4}	3.58×10^{-4}	3.64×10^{-4}
50	3.90×10^{-4}	3.19×10^{-4}	3.24×10^{-4}

It can be seen in Table 2 that the vertical subgrade strain values derived in the current FE study are within the allowed range, indicating that the pavement section is not problematic. Additionally, as shown in Table 2, the 2D numerical finding for the vertical subgrade strain values was in excellent agreement with the IITPAVE software results, with an average deviation of 5.2 percent. Hence, the numerical study for the unreinforced case was performed using the same validated FE model.

3.2 Validation of 2D-numerical geogrid reinforced pavement model

The accuracy of the FE analysis was verified by comparison of the outcomes of numerical studies to the findings of the experimental study reported by Correia [20]. Correia [20] investigated a large-scale model testing on a GR paved road, with the model loaded using a wheel monitoring system, to assess the significant impact of geogrid-reinforcement. In this investigation, the parameters chosen for the experimental study were the same as those chosen for the numerical simulation.

Table 3 Comparison of the maximum surface deflection determined by the experimental and numerical investigation.

Parameter	Correia [45]	Present study
Maximum Displacement	-2	-2.17

Table 3 shows the comparison of the numerical results with that obtained through an experimental study. It can be seen from Table 3 that the 2D numerical finding for the maximum displacement value on the surface layer is in good agreement with the experimental data, with an average deviation of 0.085 percent. Thus, a numerical study for the reinforced case was performed using the same validated FE model.

4. Results and discussion

To analyze the effectiveness of geogrid reinforcement, two scenarios were studied: unreinforced pavement and the pavement reinforced with geogrid. Additionally, this section discusses the comparative analysis of two categories of GR (i.e., 400 kN/m and 800 kN/m stiffness) pavements based on MIF.

In the first scenario, the analysis was conducted using geogrid with a stiffness of 400 kN/m. The surface deflection values for geogrid reinforced and unreinforced pavements were determined using numerical analysis for various combinations of traffic volume and subgrade CBR values according to IRC 37: 2018. Then, as mentioned in IRC 37, the modulus values of the supportive layer are determined using the derived deflection values. Then, using the derived modulus value of the supporting layer, the modulus values of both UR and GR base layers are computed again. Furthermore, the MIF is calculated using the formula given below:

$$\text{MIF} = \frac{\text{Modulus value of reinforced base layer}}{\text{Modulus value of unreinforced base layer}}$$

Table 4 contains the modulus improvement factor. As seen in Table 4, the modulus values of the GR base layer are approximately 1.042 times greater than the modulus values of the UR case. The same modulus improvement value was reported by several researchers [21-22].

Table 4 Effect of geogrid 1 (400 kN/m) reinforcement on MIF values for various CBR values

Traffic volume (msa)	Parameter	CBR values		
		3%	8%	10%
5	MIF	1.05	1.05	1.05
10	MIF	1.04	1.04	1.04
20	MIF	1.04	1.04	1.04
30	MIF	1.04	1.04	1.04
50	MIF	1.04	1.04	1.04

In the second scenario, an analysis was performed for geogrid with a stiffness of 800 kN/m. As described in the first case, the modulus improvement factor is computed for this study. The modulus improvement factors are given in Table 5. It can be seen from Table 5 that the modulus values of the GR base layer are about 1.162 times greater than the modulus values of the UR case.

Table 5 Effect of geogrid 2 (800 kN/m) reinforcement on MIF values for various CBR values

Traffic volume (msa)	Parameter	CBR values		
		3%	8%	10%
5	MIF	1.17	1.17	1.17
10	MIF	1.16	1.16	1.16
20	MIF	1.16	1.16	1.16
30	MIF	1.16	1.16	1.16
50	MIF	1.16	1.16	1.16

Additionally, Fig. 2 illustrates a comparison of two categories of GR pavements (i.e., stiffness 400 kN/m and 800 kN/m) based on MIF. As seen in Fig. 2, the MIF values are increased as a result of the addition of geogrid with a greater stiffness value. Tables 4 and 5 show MIF for various categories of GR pavement for different CBR values. From the comparisons in Fig. 2, it is noticeable that geogrid reinforced pavements with a greater stiffness shows better performance as compared to the geogrid reinforced pavements with lower stiffness.

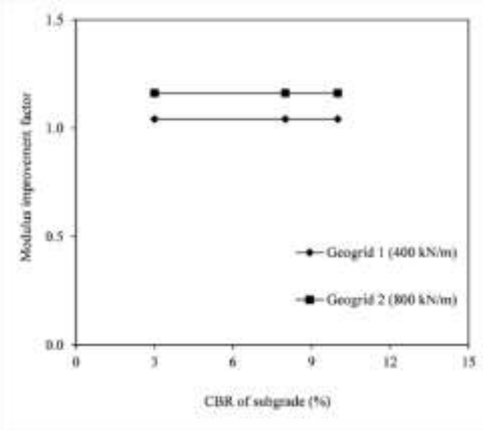


Fig. 2 Comparison of geogrids of different stiffness values based on modulus improvement factor (MIF)

5. Conclusions

The purpose of this study is to evaluate the advantageous effect of geogrid reinforced flexible pavements following IRC 37 recommendations by numerical study. The analysis outlined above yields the following conclusions:

1. The numerical study revealed that the incorporation of geogrid in the base layer enhanced the modulus value of the pavement base course by about 1.042 to 1.162 times when compared to unreinforced pavement.
2. By including geogrid into the base course, the deformation value on the surface layer is significantly reduced.
3. As the stiffness of the geogrid improves, the modulus value of the base course increases significantly.
4. The outcomes of this study also indicate that when the stiffness of the geogrid material increases, the MIF of the pavement increases as well. In comparison to geogrid with a stiffness of 400 kN/m, the MIF value for geogrid with a stiffness of 800 kN/m is increased by approximately 0.115 times.

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