Performance Evaluation of Geocell Reinforced Granular Sub-Base Layers – A Numerical Study

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Abstract. In this study, finite element analyses are carried out using PLAXIS 3D software for realistic prediction of stress and deformation in granular sub-base layer of an unreinforced section as well as section reinforced with Geocell. The behaviour of sub-base and subgrade soil has been simulated using linear elastic model and Mohr-Coulomb yield criterion respectively. Geocell has been simulated as plate material and tyre pressure has been simulated using loading on circular plate. Slow cyclic testing in various stages has been performed with varying loads to study the resilient behaviour of reinforced and unreinforced granular layers and the Modulus Improvement Factor (MIF) are determined due the Geocell inclusion. The finite element model has been validated with the field test results of load and deforamation conducted on trial sections built near Dandeli Reserve forest in Karnataka state highway No 6 (Saride et al., 2016). This model has also been used to study the effect of Geocell reinforcement in the pavement sections given by IRC 37-2018 in their design catalogue. It has been observed that, the MIF values obtained by introducing the Geocell as a reinforcement in the base layer comes down when compared with various field studies and laboratory studies due to the restriction of minimum thickness of base layer to be maintained as per IRC guidelines.

Keywords: Finite element; Geocell; Resilient modulus, Reinforcement, Modulus improvement factor.

1 Introduction

In the present scenario, India is giving boost to its highways infrastructure throughout the country. Highways infrastructural growth programs face challenges in the form of poor soil condition, adverse weather condition and varied traffic condition. Indian Road Congress has given guidelines for design of pavement on various soil subgrade condi-

tion and also for various traffic loads. This guideline uses fatique and rutting performance criteria and provide the section with thickness of different pavement layers for different traffic load and different subgrade soil condition, however the guidelines do not include the effect geosynthetic material in pavement design.
The study aims to compare the pavement design of unreinforced section as per IRC guidelines with the pavement designed with geocell as a reinforcement in subbase layer. The geocells is a three-dimensional honeycombed geosynthetic material which provides confinement to the soil filled in it. The geocell confined soil acts like a semi-rigid mat in distributing the surface loads over a wide area of the foundation soil. In this study, geocell of height 150mm is used for analysis.
A number of researchers have investigated the fundamental properties of the soil reinforced with geocells (Bathurst and Rajagopal 1993, Rajagopal et al. 1999) and the performance of the geocell reinforced foundation bases (Bush et al. 1990, Madhavi Latha et al. 2008, Krishnaswamy et al. 2000) and in flexible pavements (Emersleben and Meyer 2008, Han et al. 2008 and 2010, Rajagopal and Kief 2008, Pokharel 2010, Pokharel et al. 2010 and 2011). Field study conducted by Kief and Rajagopal, (2008) showed that with the inclusion of Geocell in the pavement layer, bearing capacity of the pavement has increased to 2.5 times. Giroud and Han (2004) and Huang (2004) have discussed the design of flexible pavements with and without using the geosynthetic reinforcement layers. Empirical recommendations for the modulus of different layers in terms of the thickness of the layers and the CBR value were made by Huang (2004), IRC-37 (2012) and IRC-37 (2018). Thakur et al.,(2012) through his study found that stress distribution angle through the geocell and vertical stress transferred on the subgrade in reinforced case is directly proportional. With the model studies conducted by Rajagopal et al., (2012), he observed that geocell increases the structural stiffness of the pavement and thereby increases the service life of the pavement.

2 Methodology

2.1 Finite element modeling

Geocell being a three dimensional honey combed structure required a FEM package capable of doing 3-D analysis. PLAXIS 3D software was used to model the geocell. Unlike geogrid, geocell is not amongst the inbuilt structural material available in the package. Geocell was modeled as a plate element with the following properties given in Table 1 attributed to it.
A pavement section was modeled as per the field plate load test conducted by Saride et al., (2016). Geocell was modeled with the properties shown in Table 1 as a plate element as shown in Figure 1. The experimental section was modeled with the following properties as given in Table 2.

Table 1. Mechanical properties of Geocell

Properties	A/U	Value
Polymer Density	g/cm^3	0.935
Material	-	Polyethylene
Weld spacing	mm	330
Cell Depth	mm	150
Expanded cell dimensions	mm x mm	244 x 210

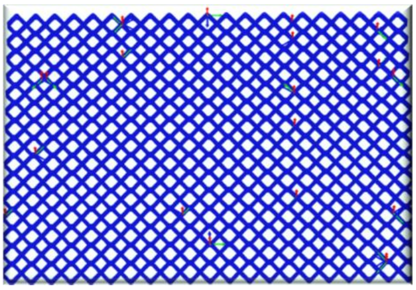


Fig. 1. Geocell modeled in PLAXIS 3D

Table 2. Property of Subgrade, Unreinforced and Geocell reinforced subbabse

	E MPa	G MPa	k_s kN/m^3	M_r MPa
Subgrade	9.7	3.9	44236	-
Unreinforced Bed	24	9.4	106798	29
Reinforced bed	32	12.7	143821	69

Note: Calculations based on μ=0.25, M_r=Resilience Modulus

Geocell reinforced section modeled in PLAXIS 3D is shown in Figure 2. A 15 noded model was considered for modeling the section in PLAXIS. Boundary condtion were considered normaly fixed laterally, free vertically and fixed at the bottom. For calculation purpose, mesh sensitivity analysis was done and very fine mesh was selected. The load was considered to be acting on the circular area and intensity of loading was altered for different stages and the validation was carried out.

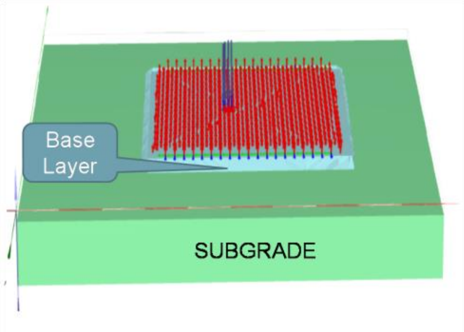
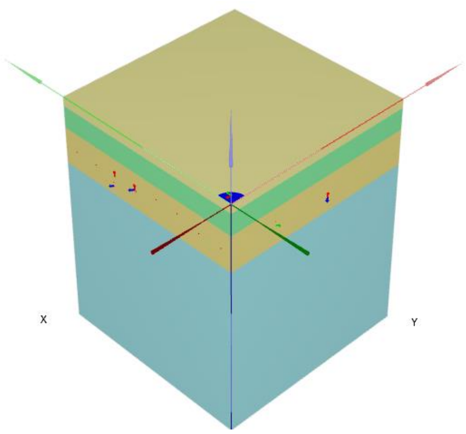


Fig. 2. Geocell reinforced test section

After the modeling of geocell was validated with the result of the field study, the same geocell model was used for analysis of unreinforced section with pavement configuration as per design catalogue of IRC 37-2018 for subgrade with CBR ranging from 3% to 12% for different traffic load (Figure 3). Taking the benefit of symmetry, 1/4th of the model was considered and loading was applied at the corner. As per the guidelines of IRC, a tyre pressure of 565 kPa over a circular area is replicated as a circular load. In this case, due to symmetry only 1/4th of the loading area was considered.



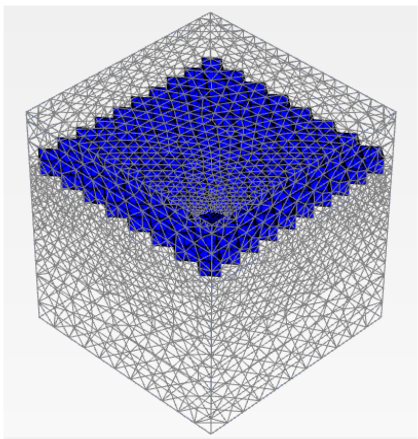


Fig. 3. Model of unreinforced and Geocell reinforced section

Vertical compressive strain on the subgrade was calculated. Geocell reinforced pavement was also modeled with the properties of geocell as shown in Table 1. Vertical compressive strain at the subgrade was calculated for this section also. Vertical compressive strain in case of geocell reinforced section was found to be much lower than unreinforced case. In order to increase the strain, thickness of base layer was reduced to such a value when strain in reinforced and unreinforced case becomes equal. The ratio of modulus of Reinforced base layer to the unreinforced base layer gives Modulus Improvement Factor (MIF).

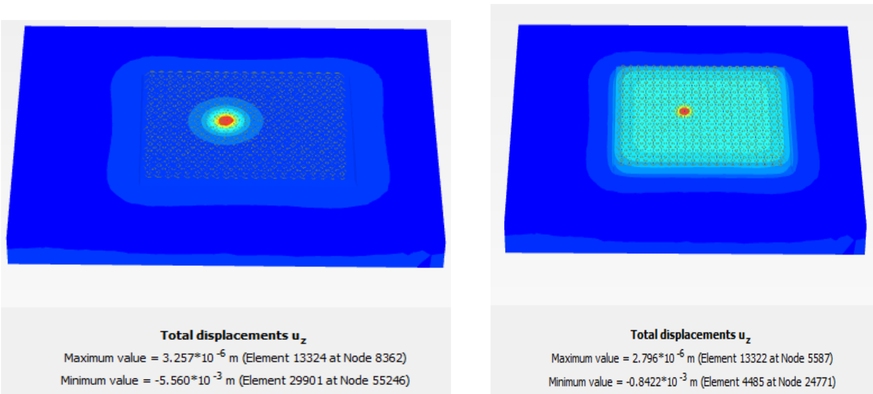
$$MIF = \frac{Modulus\ of\ reinforced\ base\ layer}{Modulus\ of\ unreinforced\ base\ layer} \tag{1}$$

Also the improvement in service life of the pavement is expressed by Service Life Ratio (SLR) which is given by equation

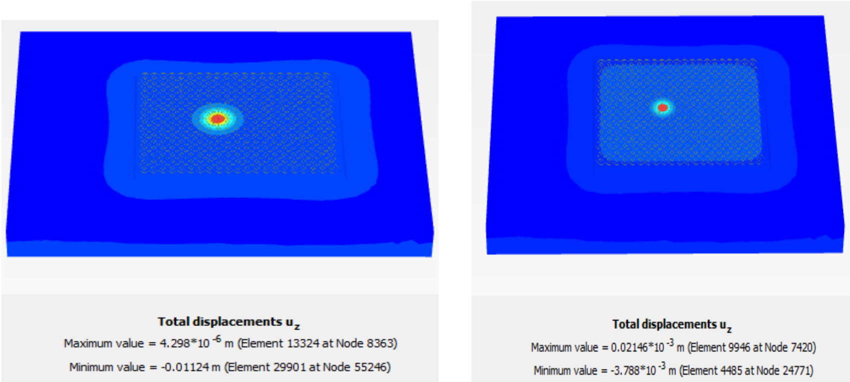
$$SLR = \frac{vertical\ compressive\ strain\ in\ unreinforced\ pavement}{vertical\ compressive\ strain\ in\ reinforced\ pavement} \tag{2}$$

2.2 Numerical Validation

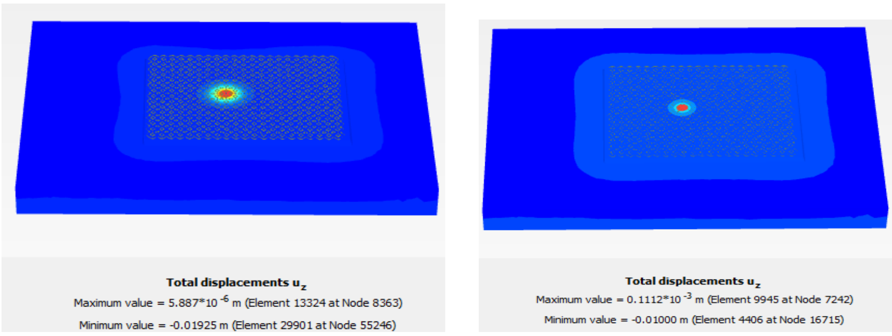
As the numerical modeling on PLAXIS for field load test were done both on unreinforced and reinforced sections. For reinforced section the loading was started from 400 kPa and then it was reduced to 0. This cycle was continued for a maximum load of 700 kPa, 1050 kPa and 1450 kPa. However in the case of unreinforced section, only two cycle of loading were performed. For reinforce case, following results as shown in Figure 4 were obtained.



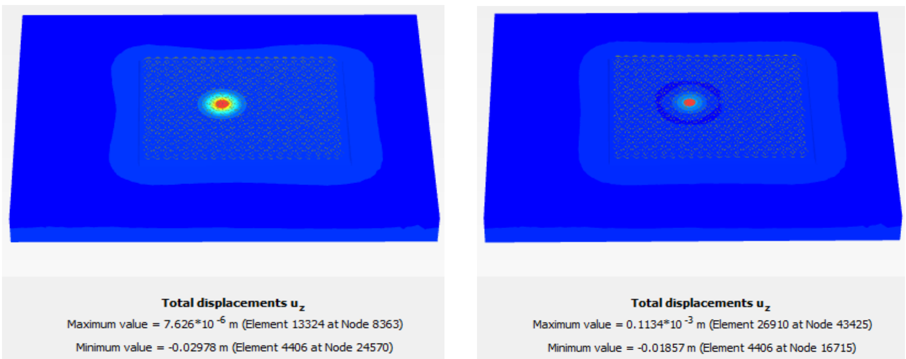
(a) Loading and unloading for 400 kPa



(b) Loading and unloading for 700 kPa



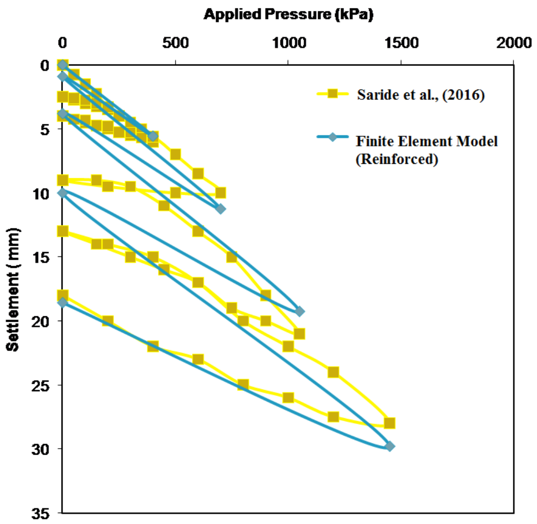
(c) Loading and unloading for 1050 kPa



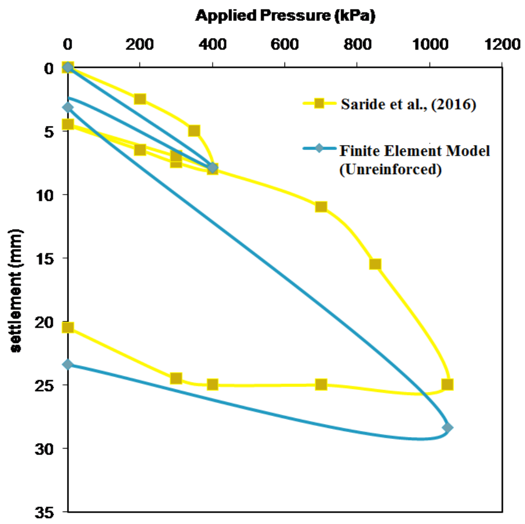
(d) Loading and unloading for 1450 kPa

Fig. 4. Loading and unloading cycle for different pressure

Figure 5 shows comparison between the results obtained from field test and FEM. It is clear from the results that there is only slight variation in the results from field test and FEM analysis, which clearly shows that the material and model taken for design of Geocell reinforced section in FEM can be considered acceptable.



(a)



(b)

Fig. 5. Comparison of results from field test and FEM study for reinforced and unreinforced section (a) Reinforced case; (b) Unreinforced case

3 Numerical analysis of geocell reinforced pavement

After the geocell model was found satisfactory, modeling was done for pavement section taken from IRC 37-2018 for CBR values of 3%, 5%, 8%, 10% and 12%. The same section was also modeled for geocell kept at subbase layer as shown in figure 3. Results obtained from the analysis are tabulated in below. Table 3 shows percentage reduction in vertical compressive strain when geocell is placed in subbase layer. Table 4 shows the modulus improvement factor and service life ratio when the pavement as recommended by IRC 37-2018 is reinforced with reinforced with geocell.

Table 3. Percentage reduction in vertical compressive strain

Traffic in msa	CBR (%)				
	3	5	8	10	12
5	22.50	22.87	21.00	21.24	21.22
10	21.58	21.67	21.31	21.34	21.05
20	23.44	24.15	21.83	22.31	21.79
30	22.86	22.19	22.74	21.51	22.49
50	22.35	24.07	21.30	20.78	23.61

Table 4. Variation of CBR with MIF and SLR values

CBR (%)	MIF	SLR
3	1.26	1.78
5	1.26	1.76
8	1.26	1.81
10	1.26	1.84
12	1.26	1.86

It was seen from various field studies and laboratory test in the past that MIF value for geocell reinforced pavement ranges from 2-4. In this study, when geocell was introduced as a reinforcing material in the in the pavement section recommended by IRC for various CBR values of subgrade, it was observed that there was considerable amount of vertical compressive strain reduction on the top of the subgrade, when compared with the unreinforced case, as shown in the Table 3. However, when the base thickness was reduced in order to increase the strain value to same as in the case of unreinforced case, it was observed that complete reversal of strain values were not possible due to restriction imposed by IRC guidelines of minimum thickness of bases layer i.e. 150mm. Hence the thickness of base layer could not be reduced below 150mm. therefore in this study, a low MIF of 1.26 is shown in Table 4.

However in the case of Service life improvement in form of SLR, it is observed in this study that service life of the pavement reinforced with geocell increases close to 2 times when compared with unreinforced pavement section. The values are shown in Table 4. It is also observed that as the CBR value of the subgrade soil is increased, inclusion of geocell in form of reinforcing material increases the service life of the pavement.

4 Conclusions

From this study it was observed that geocell can be modeled on PLAXIS 3D as plate element by using the specification given in datasheet of any standard geocell manufacture. With geocell being modeled on PLAXIS 3D, various studies on critical parameters of geocell reinforced pavement may be carried out which may prove efficient and economical to study the geocell and granular layer interaction. During this study, it was also observed that geocell improves the stiffness and service life of pavement. By reinforcing the granular layer with geocell, vertical compressive strain on the top of subgrade is reduced significantly up to a maximum reduction value of 24.07%, however due to limitation of minimum thicknesses of pavement layers as given in guidelines of IRC 37-2018, reduction in vertical compressive strain cannot be fully translated into reduction in thickness of pavement layer and maximum Modulus Improvement Factor that could be achieved was 1.26. Hence we can conclude that in spite of significant reduction in vertical compressive strain on top of subgrade, Geocell remains underutilized in layer thickness reduction and hence may not be recommended as it may prove to be uneconomical.

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