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Numerical Modelling Based Assessment on Performance Evaluation of Geocell-Reinforced Base Layer over Soft Subgrade

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ABSTRACT: Pavement structures supported on weak subgrade are susceptible to significant deformation or even failure due to truck passage. Presently, Geocells, which are expandable three-dimensional cellular mats, are being utilized to increase the strength of weak subgrade. In this study, numerical analysis is conducted using PLAXIS 3D to simulate the impact of geocell reinforcement on the behavior of soft subgrade. In order to first verify the precision of the finite element (FE) analysis, the results of numerical studies are compared to those of the experimental and numerical findings available in the literature. Afterward, the validated numerical model is used to conduct parametric investigations to determine the effect of geocell height and base layer thickness on the performance of the geocell-reinforced base layer above the soft subgrade. The findings of the research are analysed in terms of the pressure-settlement response and subgrade stress ratio (SSR) and compared with the unreinforced section. The numerical results demonstrated that the geocell reinforcement improved the performance of the weak subgrade by increasing the load-carrying capacity of the soil as compared with the unreinforced section.

Keywords: Geocell, Pavement, Reinforcement, Soft subgrade, Numerical modelling

1 INTRODUCTION

Pavement design, construction and performance are significantly influenced by subgrade soils. Inadequate subgrade conditions can affect the construction of different layers (i.e., subbase and a base layer) above it, as well as the provision of adequate support for subsequent paving operations. When pavement construction has been carried out over a poor subgrade, it is a common procedure in engineering to extract the weak soil to a specific depth and replace it with a layer of material that has appropriate support strength. This methodology is not assumed to be the most sustainable because it requires high-quality materials, which is not a cost-effective solution. Therefore, the researchers investigated cost-effective solutions that can reduce the overall settlement and vertical stresses above the subgrade layer, ultimately enhancing the performance and stability of the pavement. For more than 40 years, one of the effective procedures for base reinforcement and subgrade improvement has been geosynthetic reinforcement (Giroud and Han, 2004). The application of geosynthetics has been shown to extend the service life of pavements, reduce the thickness of a base for a given design life and prevent the formation of the rutting (Bush et al., 1990; Hufenus et al., 2006; Latha et al., 2009; Mamatha and Dinesh, 2019). Geocell, a recently developed three-dimensional geosynthetic material, has been used to reinforce the base layer of weak subgrade soil. It is a three-dimensional honeycomb structure constructed of polymeric strips, and each cell is connected with the cells that surround it. The photograph of geocell material is shown in Figure 1.

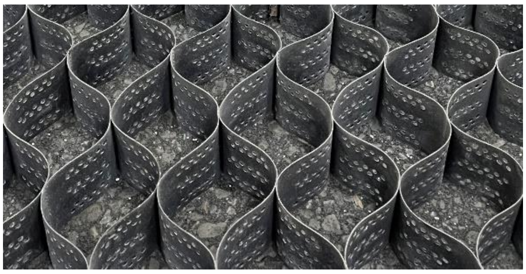


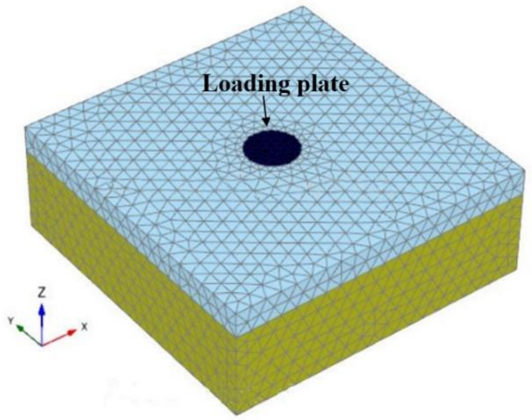
Figure 1. Photograph of Three-dimensional expanded Geocell material

It has been determined that the incorporation of geocell material as soil reinforcement is beneficial because it provides all-around confinement to the infill soil and tension membrane action, hence increasing the overall stiffness of the soil bed and enhancing its performance. Numerous laboratory and field experiments conducted over the past three decades by different researchers have demonstrated the major advantages of geocells in soil reinforcing techniques (Bathurst and Karpurapu, 1993; Pokharel et al., 2010; Venkateswarlu and Hegde, 2019; Gedela and Karpurapu, 2021 a,b). Though there are some limitations in both laboratory and field studies, numerical modelling is one of the best ways to evaluate the effectiveness of geocells. However, relatively few numerical analyses have been performed by researchers considering the real curvature of the geocell due to its distinct three-dimensional honeycomb shape.

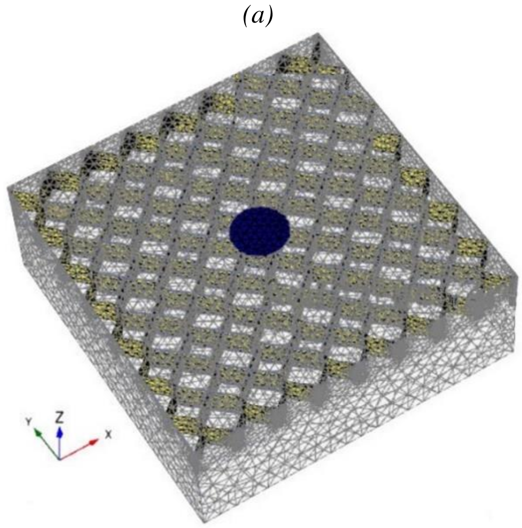
In the present study, a numerical analysis has been done using PLAXIS 3D by considering the actual curvature of the geocell to evaluate the influence of geocell reinforcement on the behaviour of soft subgrade. In addition, a parametric study was conducted to assess the impact of geocell height (125 mm and 200 mm) and base layer thickness (225 mm and 250 mm) on the performance of the geocell-reinforced base layer over the soft subgrade. The study findings are analysed in terms of the pressure-settlement response and subgrade stress ratio (SSR) and compared with an unreinforced section.

2 NUMERICAL MODELLING

In the present study, the numerical analysis of both reinforced and unreinforced pavement has been carried out using finite element method (FEM) based software, PLAXIS 3D (Plaxis, 2019), as depicted in Figures 2(a) and (b).



(a)



(b)

Figure 2. Three-dimensional FE model (a) Unreinforced section; (b) Geocell reinforced section

The lateral boundaries of the model are constrained to lateral movement, whereas the bottom boundaries are constrained to both horizontal and vertical movement. In order to get a more accurate result, a 'fine' mesh was used in this analysis with a relative element size of 0.70. Additional mesh refinement is performed at the loading plate as well as adjacent to the geocell wall.

The subgrade soil behaviour is represented in both the reinforced and unreinforced cases using the Mohr-Coulomb constitutive model. Furthermore, the Mohr-Coulomb model is used to represent the base and infill soil layers for the unreinforced and reinforced cases respectively. The behaviour of the geocell is simulated using the linear elastic model and the only parameter of axial stiffness (EA) is 160 kN/m, which is provided as an input parameter. Figure 3 depicts the stress strain response of geocell material. Previous research (Gedela and Karpurapu, 2021a) has shown that during the loading phase, the geocell experiences the least amount of strain and the strain responses are within the elastic limit. The geocell layers are modelled using the Geogrid structural elements, a built-in PLAXIS 3D feature.

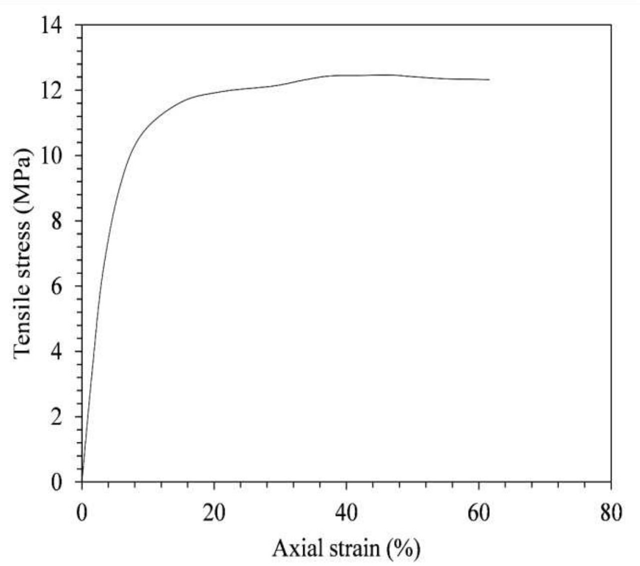


Figure 3. Stress strain plot of geocell material (figure reproduced from Gedela and Karpurapu, 2021a).

The geotechnical parameters of various soil layers and geocell material employed in the analysis are derived from previous research (Gedela and Karpurapu, 2021b). For the subgrade layer, the reported values for Young's modulus (E), Poisson's ratio (μ), Friction angle (ϕ), cohesion (C) and Density (γ) are 3.996 MPa,0.11, 2º, 37.5 kPa and 0.196 kN/m^3 respectively. Furthermore, for the base layer, Young's modulus (E), Poisson's ratio (μ), Friction angle (ϕ), Dilation angle (ψ) and Density (γ) values are reported as 35 MPa, 0.35, 44º, 11º and 17.21 kN/m^3 respectively.

The stage construction technique is adopted for the construction of reinforced and unreinforced sections. The various pavement layers are activated in separate phases, and the load is applied over the base layer in the final step. In this analysis, the monotonic load was transmitted through a circular plate with a 0.30 m diameter until the plate deflection reached 100 mm.

3 VALIDATION

Firstly, the numerical FE model of both reinforced and unreinforced sections was validated using the experimental and numerical results given in the prior literature (Gedela and Karpurapu, 2021b). The dimensions and material attributes of the model used in the current investigation are identical to those described in the literature.

The results obtained in terms of maximum pressure response at 100 mm settlement values for reinforced and unreinforced cases were compared to experimental and numerical findings by Gedela and Karpurapu, 2021b. Tables 1 and 2 show a comparison between the results of the current investigation and those reported in the literature for the unreinforced and reinforced cases, respectively.

Table 1. Comparative results of the present study and those reported in the literature for the unreinforced case

Parameters	Settlement (mm)	Maximum pressure response (kPa)
Present study	100	263.21
Experimental study (Gedela and Karpurapu, 2021b)	100	249.70
Numerical study (Gedela and Karpurapu, 2021b)	100	261.92

From Tables 1 and 2, it can be seen that the obtained maximum pressure at a specific settlement value for both the reinforced and unreinforced cases closely matches the prior literature results. Consequently, the validated FE model is employed to conduct parametric investigations to determine the effect of geocell height and base layer thickness on the performance of the geocell-reinforced base layer above the soft subgrade.

Table 2. Comparative results of the present study and those reported in the literature for the Geocell reinforced case

Parameters	Settlement (mm)	Maximum pressure response (kPa)
Present study	100	546.34
Experimental study (Gedela and Karpurapu, 2021b)	100	533.03
Numerical study (Gedela and Karpurapu, 2021b)	100	554.88

4 RESULTS AND DISCUSSION

4.1 *Effect of Geocell height*

Two different geocell heights of 125 mm and 200 mm are studied to determine the effect of geocell height on the performance of the reinforced section and these results are compared with the unreinforced section. Figure 4 shows the pressure-settlement responses of unreinforced and reinforced sections with varying geocell heights.

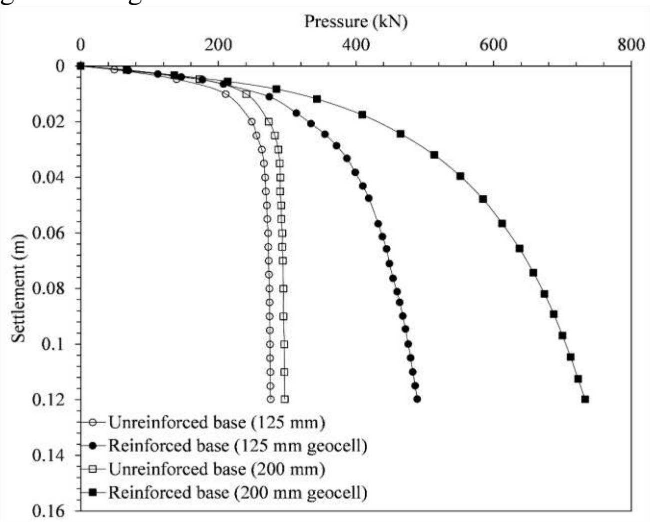


Figure 4. Pressure-settlement responses of unreinforced and reinforced sections

As illustrated in Figure 4, the geocell layer increases the bearing capacity of the pavement layer in comparison to the unreinforced case. In addition, it can be observed that the higher geocell height enhances the bearing capacity of the pavement layer. The overall frictional resistance on the cell walls improves with increasing geocell height. This improvement enhanced the confinement effect of the reinforced section, thereby improving the stiffness and bearing capacity of the pavement layer.

The present study also evaluates the effects of geocell height on the stress ratio at the subgrade (SSR) layer. Several studies (Gedela and Karpurapu, 2021b) have utilized the SSR value to describe the amount of stress transmitted to the subgrade layer relative to the surface layer. The SSR is computed by dividing the subgrade stress by the surface stress. The impact of geocell height over SSR value is shown in Figure 5.

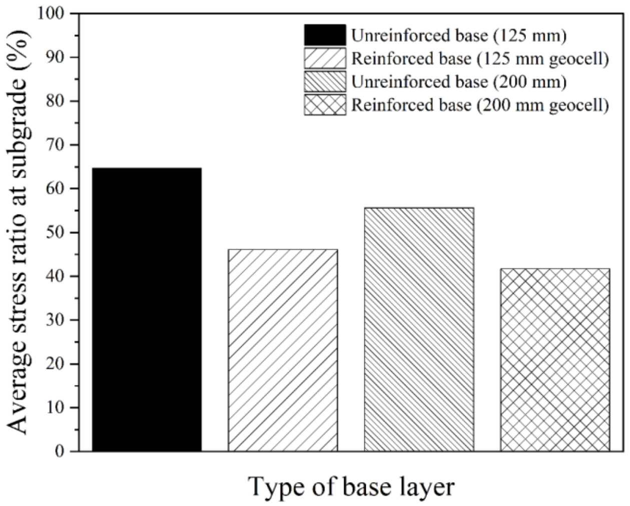


Figure 5. Average stress ratio at the subgrade layer for both reinforced and unreinforced sections

As shown in Figure 5, the SSR value decreases due to the inclusion of geocell layer when compared to the unreinforced case. Additionally, it can be shown that the increased geocell height decreased the SSR value of the pavement. When a load is applied across a reinforced section, the geocell layer behaves as a stiff mat, and only minimal stress is transmitted to the subgrade layer, hence decreasing the SSR value of the pavement.

4.2 *Effect of base layer thickness*

To understand the influence of the base layer thickness, two different base thicknesses of 225 mm and 250 mm with a geocell height of 200 mm were investigated and these results are compared with the unreinforced section. Figure 6 shows the pressure-settlement responses of unreinforced and reinforced sections with varying base layer thicknesses. The geocell layer enhances the bearing capacity of the pavement layer compared to the unreinforced case, as depicted in Figure 6. It can be observed from Figure 6 that the effect of the base layer thickness on the pressure-settlement response for both reinforced and unreinforced sections is very minimal. For reinforced sections, the interaction between the infill soil and geocell layer plays a significant role in enhancing the bearing capacity of pavement. However, when the geocell height remains constant for different base thicknesses, the interaction effect is similar for all base layers, and as a result, the bearing capacity of reinforced sections does not increase much with base thickness.

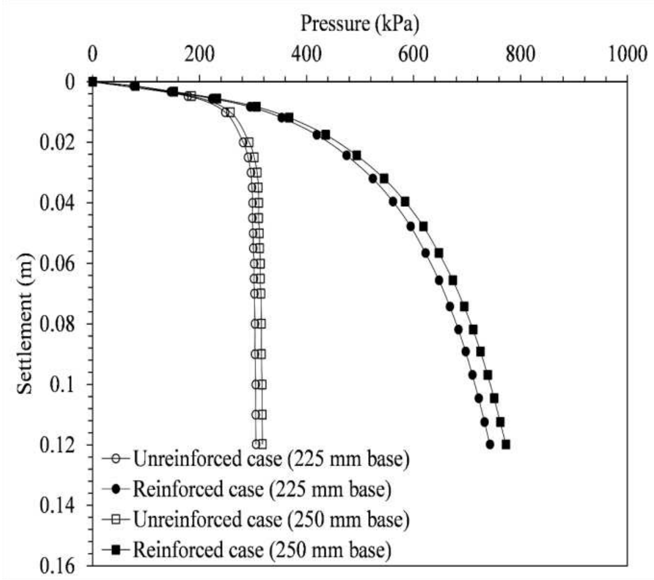


Figure 6. Pressure-settlement responses of unreinforced and reinforced sections

The effects of base thickness on the stress ratio at the subgrade (SSR) layer are also evaluated for both reinforced and unreinforced sections, as shown in Figure 7. Figure 7 demonstrates that the inclusion of the geocell layer reduces the SSR values compared to the unreinforced case. From Figure 7, it can be shown that the increased base layer thickness for both reinforced and unreinforced cases decreased the SSR value of the pavement. Due to the increased base thickness, the redistribution of applied force occurs more uniformly and with lesser intensity to the underlying subgrade layer. As a result, SSR values for both reinforced and unreinforced sections are reduced.

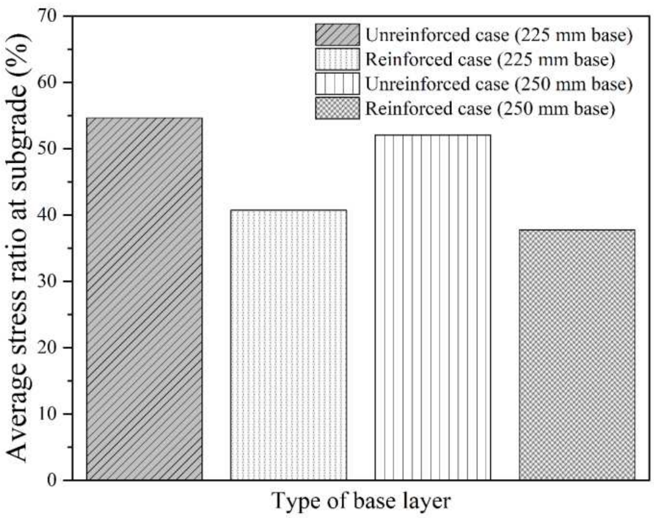


Figure 7. Average stress ratio at the subgrade layer for both reinforced and unreinforced sections

5 CONCLUSIONS

The purpose of this study is to evaluate the advantageous effect of geocell reinforcement on the behavior of soft subgrade. The analysis outlined above yields the following conclusions:

1. The geocell reinforcement considerably improved the bearing capacity of the pavement as compared to the unreinforced case. The current study demonstrates that the bearing capacity of the reinforced pavements with a 125 mm and 200 mm high geocell layer was increased by around 1.77 to 2.47 times in comparison to the unreinforced pavements.
2. Owing to the higher geocell height, the bearing capacity of the reinforced sections has enhanced, however, there has been no notable improvement in bearing capacity due to the increased base thickness. For reinforced sections, the interaction between the infill soil and geocell layer plays a significant role in enhancing the bearing capacity of pavement. However, when the geocell height remains constant for different base thicknesses, the interaction effect is similar for all base layers, and as a result, the bearing capacity of reinforced sections does not increase much with base thickness.
3. Only 37% to 46% of the vertical stress has been transmitted to the subgrade layer for reinforced pavement, compared to 52% to 64% for unreinforced pavement. When a load is applied across a reinforced section, the geocell layer behaves as a stiff mat, and only minimal stress is transmitted to the subgrade layer, hence decreasing the vertical stress value at the subgrade layer of the pavement.
4. The SSR value of the pavement decreased as the thickness of the base layer increased for both reinforced and unreinforced cases. Due to the higher base thickness, the redistribution of applied force on the subgrade layer occurs more uniformly and with less intensity. As a result, SSR values are reduced for both reinforced and unreinforced sections.

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