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Numerical Study of Multi-Layered Geocell Confined Pavement Subgrade

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Abstract. Geocell is a honeycombing interconnected cellular confinement system made of, in general, different types of geosynthetics. It encapsulates infill-material within its pockets (restricts from shearing off) and acts like a composite mattress to redistribute the incoming load to the underlying soil with lesser intensity. Thus it improves the overall bearing capacity and stability of geo-structures. Its wide application includes foundations, railway and highway sub-structures, embankments etc. In highways, geocell-reinforced pavements have exhibited notable improvement in respect of carrying capacity, stability, and durability. For pavements, mostly the base and/or sub-base layers are reinforced with geocells overlying the weak subgrades. In this study, responses of geocell-reinforced flexible pavements are investigated using Plaxis-3D, a FE based software for geotechnical issues. The study compared the effectiveness and performance optimization of pavement structures with a single and multiple-layer of geocell systems. The outcome has depicted considerable betterment with respect to reduction in deformation, increase in bearing capacity, and improvement in material consumption. The objective envisaged would be a viable method to mitigate the scarcity of competent sub-structures for construction of road network, fulfilling the demand of ever increasing urbanization.

Keywords: Geocell; Multi-layer; Subgrade; Pavement; Bearing capacity.

1 Introduction

Competent subgrade is the primary need and has been a critical issue for ever increasing road-networks. Thus, it has enforced designers/practitioners to consider different ground improvement techniques/alternatives based on availability, feasibility, economics, and importantly different environmental issues for its durability. Amongst the few, geocell has complied most of the issues and thus, preferred the most over other methods/alternatives.

Considerable researches are performed on the application of geocell in pavement structure. A brief is presented by Sarkar and Biswas [1] which may be a good read in this regard. Critically, it can be concluded that most of the studies have assumed geocell in the base or sub-base layer, whereas, the less reckoned weak subgrade may be the cause of failure. In this regard, except very few, studies/applications have used single layer geocell system regardless of thickness required in laboratory and/or in-practice. Recently, researchers have identified few critical issues of such adaptation, namely, buckling of geocell-walls at the top-array/top part just under the loading, difficulties in achieving desired degree of compaction at the bottom of geocell-soil matrix and non-utilization of a large portion of geocell-mattress beyond the load-dispersion [2-4]. In such condition, provision of multiple layers of geocell reinforcements would be a practicable way out to overcome the drawbacks with greater performance [5-8]. In this regard, Tafreshi et al. [7] have confirmed the improved performance of multi-layered-geocell using a cyclic plate load tests; whereas, Li et al. [8] have reported an increasing bearing capacity with the increase in number of reinforced layers. Such research outcomes have encouraged authors to envisaged the objectives of present study

In the present work, geocell layers are applied over the weak subgrade to check the benefits of multi-layer geocell in pavement applications, as compared to conventional single-layer of geocell and unreinforced pavement sections. The analysis is done in Plaxis-3D with dynamic analysis. It is found that multi-layer geocell system performs better in terms of greater stress distribution to the subgrades and reduced settlement of the overall geo-structure.

2 Materials and Methodology

In this study, clay, sand (for infilling, and, as cushion between geocell layers), and geocell properties are adopted from the laboratory test performed by Biswas [9, 10]. The stiffness and modulus parameters of geocell-soil matrix are calculated according to Latha and Rajagopal [11]. The summarized material properties, including the base and asphaltic layer [12], used in the numerical simulation are presented in Table 1.

Table 1. Material properties for numerical analysis

Material/Layer	Material Properties				
	E (kPa)	c_u (kPa)	φ (°)	υ	γ (kN/m^3)
Subgrade Clay	18000	30	0	0.45	17.3
*Base	414000	0	38	0.30	22.0
*Asphalt Layer	4134693	-	-	0.30	23.0
Geocell-Sand matrix	92719	93	38	0.30	16.4
Sand	13000	0	40	0.30	16.4

*Source: *Saad et al.* [12]

3 Numerical Simulation

Evaluation of performance of reinforced flexible pavement on clay subgrade, with special attention to multiple layer geocell configuration, is the objective of this study. A three-layered (subgrade, base and asphalt layer) pavement section configuration

(Fig. 1) is considered for the purpose and studied for different conditions, such as, unreinforced (Fig. 1), with single layer geocell (Fig. 2a) and multiple-layer-geocells over the subgrade (Fig. 2b).

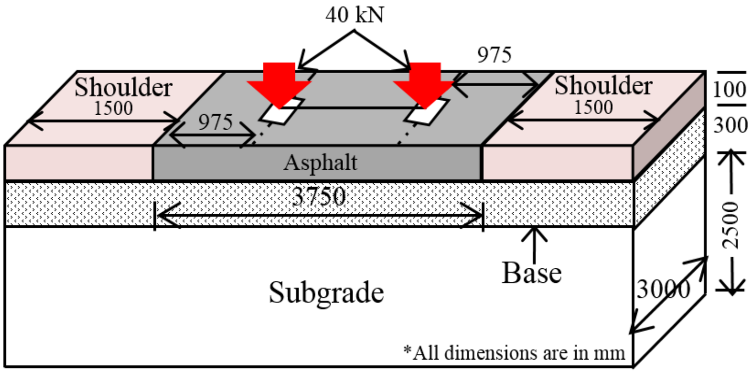

Fig. 1. Schematic diagram of the three-layer flexible pavement system considered

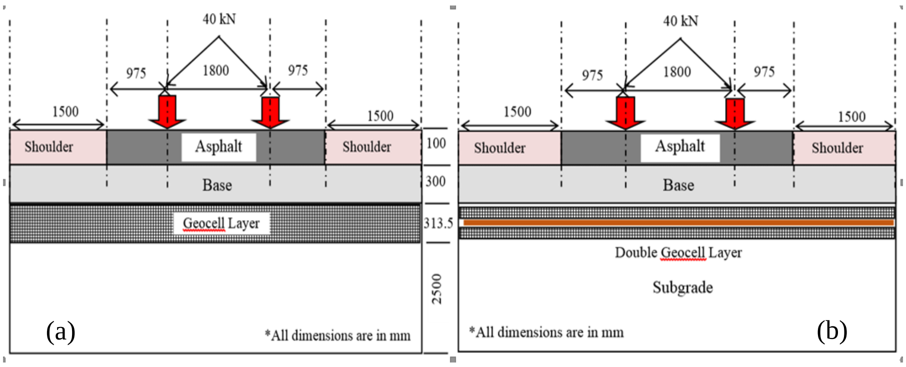

Fig. 2. Pavement structure with (a) single and (b) double layer geocell reinforcement

Present study has referred the reported data-set of Saad et al. [12] for the base and asphaltic layer properties. Saad et al. [12] have reported the results of a series of FE analysis, through finite element programme ADINA having implicit solution scheme for flexible pavement. In present study, the properties, such as tire impact dimension (406×178 mm^2) and load-time relationship (a triangular 0.1s load cycle with maximum 40 kN wheel load intensity at half of the cycle time) were validated in Plaxis. The result, as compared to Saad et al. [12], has satisfied the authors (Fig. 3) to adopt the parametric values in the present study.

It is referred that the Mohr-Coulomb and Drucker-Prager model are better in representing the soil nonlinearity. Hence, in the analysis, the subgrade and base is modeled using Mohr-Coulomb criteria; whereas, the asphalt layer is modeled as linear-elastic material. The Rayleigh coefficient, for considering damping effect of soil and asphalt layers, are adopted as per Ju and Ni [13] Al-Qadi [14], and Hasheminejad et al. [15].

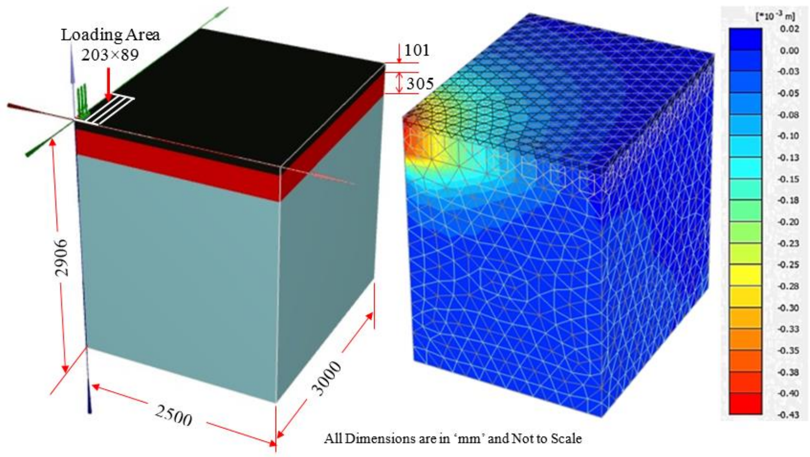

Fig. 3. Validation of Saad et al. [12] using Plaxis3D

4 Result and Analysis

The study has compared the behavior of three different pavement sections as unreinforced, single layer geocell-sand and double-layer geocell-sand matrix overlying the weak clay subgrade. In reinforced section, the subgrade was overlain by a 315 mm thick (single layer configuration) and two nos. 150 mm thick geocell-mattresses (double layer configuration with a 15 mm thick sand cushion in between layers) in-filled with sand [5, 10]. In all the cases, an axle load of 80 kN, with each wheel load of 40 kN, is applied. The subgrade clay strength (c_u) was kept 30 kPa for all the cases.

The unreinforced pavement section showed considerable surface deflection, about 2 mm, under the load. Such deformation has significantly reduced with single and double layer of geocells (about 1.2 and 0.7 mm respectively). As per the reinforced-section performance, about 2-fold improvement in performance is achieved with double layer configuration of similar material-consumption (Table 2).

Table 2. Improvement in surface deformation of different pavement sections

Sl. No	Subgrade Condition	Surface Deflection (mm)	Improvement (%)
1	Unreinforced	1.97 mm	-
2	Single layer geocell reinforcement	1.19 mm	40
3	Double layer geocell reinforcement	0.73 mm	63

Typical pavement behavior with unreinforced and reinforced sections are presented in Fig. 4 (a-c). Responses demonstrate reduction in deformation with a greater load dispersion for reinforced sections. Besides, a reduced stress overlapping is also observed in case of higher degree of reinforcements. In addition, the reinforced pavements depicted considerable improvement in terms of dynamic time-displacement response and showed reduction in deflection under the load (Fig. 5).

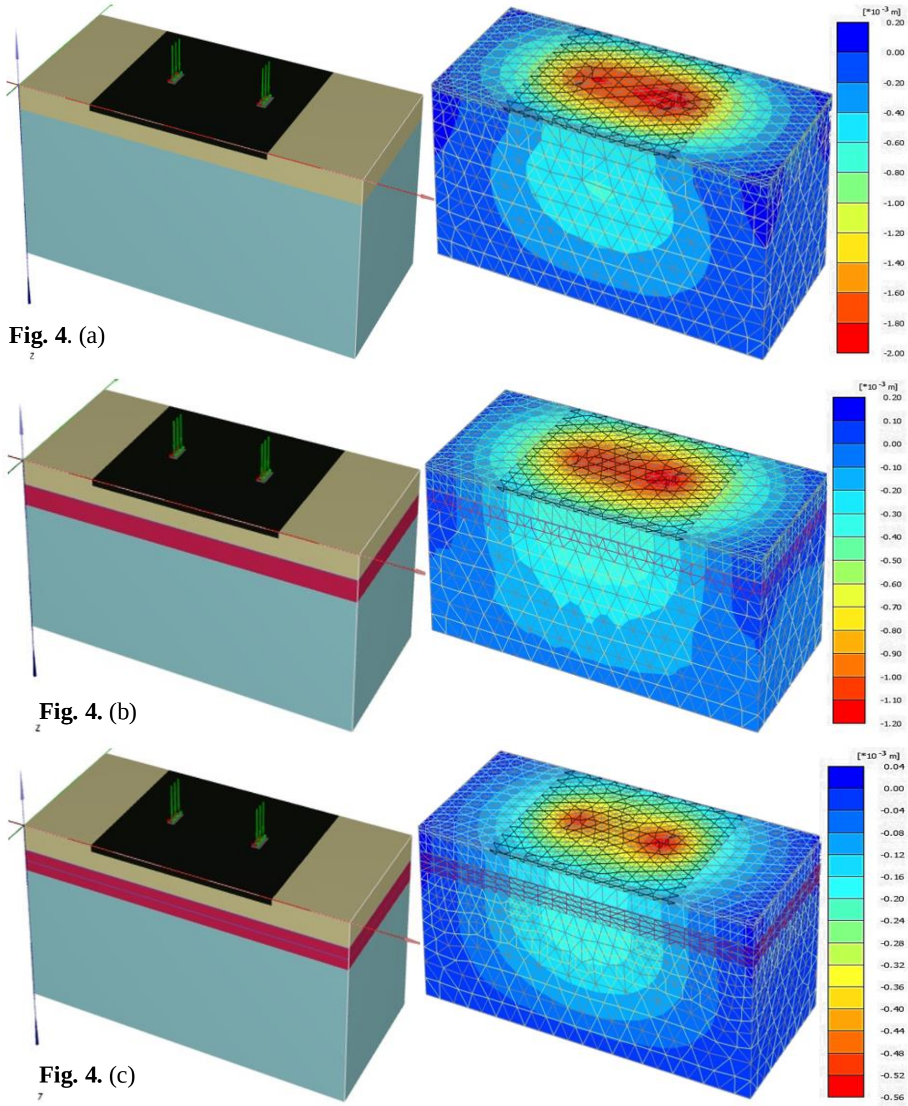

Fig. 4. Typical responses (a) unreinforced, (b) single-layer, and (c) double-layer geocell reinforced pavement sections

The analysis indicated that response of multi-layer geocell reinforced pavement systems are better compared to other two configurations (Fig. 5). A deflection profile, along the centerline of loads, presented in Fig. 6, depicting the effect of wheel-loads in the transverse direction of pavement sections. It reflects influence of wheel load diminishes with the distance with a maximum deformation at and in between the wheels. Further, it is also noticeable that, with geocells, the pavement sections between the wheels have behaved more elastically and showed deep beam actions compared to the unreinforced section.

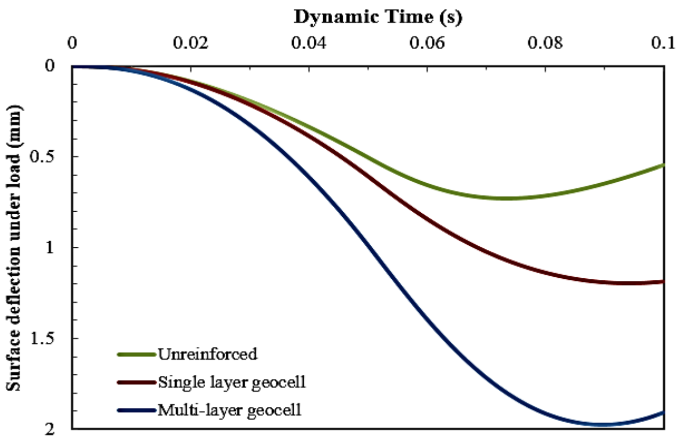

Fig. 5. Dynamic time vs. surface deflection under the wheel load

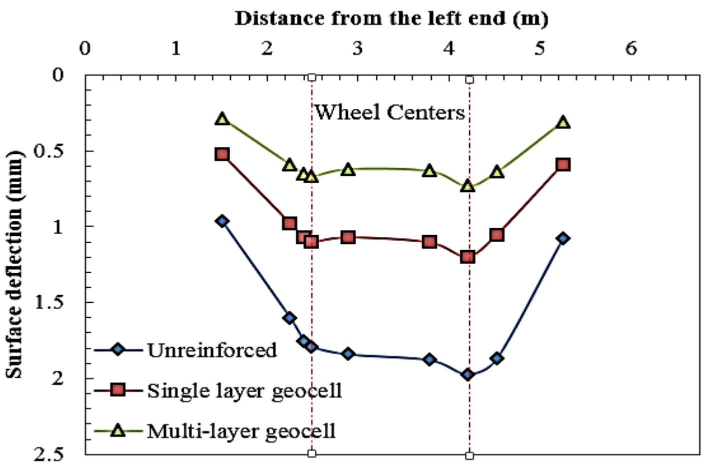

Fig. 6. Deflection at different locations of the pavement sections

5 Conclusion

The present study shows that flexible pavement confined with geocell layers gives considerably higher performance with geocell and enhances with the multi-layer of geocell system. It behaved much more elastically under the dynamic wheel load in terms of reduction and regain of deflections. This study also confirms the improved benefits in terms of reduction in material consumption when used in layers (geocell-mattress). The analytical outcome has encouraged and explored the scope of laboratory physical test. The authors admit the limitation of the article with respect to validation which was planned to be done through physical modelling in the laboratory; however, has not been possible yet due to unforeseen situation arose and restrictions imposed therefore.

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