Response of Multi-layered-Stepped Geocell Reinforcement in Soil Structures

Haradhan Sarkar[1] and Dr. Arghadeep Biswas[2][0000-0002-3094-6361]

[1]Ghani Khan Choudhury Institute of Engineering & Technology, Malda, India, 732141
[2]Jalpaiguri Govt. Engineering College, Jalpaiguri, India, 735102

hsce2006@gmail.com, arghadeep.biswas@gmail.com

Abstract. The conventional single layer of geocell reinforcement, as a measure of ground improvement technique, has widely been accepted to strengthen weak soil into a competent foundation layer. Since its inception, several researches are performed with such layer configuration and successfully applied in field. The performance factors of geocell-systems have been improved with various laboratory/in-house investigations and their critical appraisals on parametric influences. However, it is noticed that most of the reinforcement volume (about one-third of the total with respect to loading size when full load transmission up to the geocell-bottom is allowed) remain unused in case of the single layer geocell system. Besides, compaction of soil at a greater depth of geocell experiences a great deal of difficulties. In addition, the thicker layers undergo considerable buckling at the top of geocell-walls (situated just under the load) affecting localized settlement without any appreciated improvement. Therefore, replacing the single layer, with a multi-layered stepped configuration, would mitigate this issue with an additional benefit in terms of material optimization. As of now, the mechanism of multi-layered structure has not been developed explicitly which thrusts more emphasis on this issue to be addressed. In this study, the performance of multi-layered system is envisaged to investigate through numerical simulation in Plaxis^{2D}. In doing so, initially, the work reported in Biswas (2019) is validated to confirm the parametric considerations. Being successful, it has further been used and extended for the present objective. A comparative performance of single with multi-layered configuration is presented to confirm the usefulness of the proposed concept.

Keywords: *Geocell, Multi-layer, Stepped configuration, Bearing Capacity, Improvement.*

1 Introduction

Geocell is one of the several types of ground improvement techniques favored by most of the geotechnical engineers of modern age. It has several advantages over conventional ground improvement techniques in terms of cost effectiveness, eco-friendly and ease of use etc. Initiated through pavement application [1-5], several investigations are executed to find out the working mechanism of geocell by varying different parameters controlling the performance of geocell-reinforced structures associated in various civil engineering applications, such as embankments [6-10]; railways [11-12], footing/foundations [13-15] etc. However, such studies were focused on single layer of geocell system; while, a multi-layered system would be a viable option mitigating different difficulties identified [16]. Unfortunately, very few attempts (mentioned hereunder), so far, are reported on this configurations and thus, the success and mechanism of multilayer geocell system has yet not explored properly.

Li et al. [17] has conducted a series of model experiments to compare the performance of reinforced embankment with multiple geocell layers and other parametric variations. They have noticed and concluded that the bearing capacity of embankment has increased with the number of reinforcement layers, and accordingly, the vertical and lateral displacements were decreased. Similar observation has also been reported by Tafreshi et al. [18]. They have reported the performance of a series of cyclic plate load tests on unreinforced and reinforced beds by multiple-layers of geocell. The result indicated the performance, in terms of load-settlement behavior, improved with the number of geocell layers [18]. Sarkar and Biswas [19] have reported an analytical study with multi-layered geocell system and observed that multi-layer of geocell system performs better in terms of reduced stress and settlement [20]. In present study, the authors have extended their previous work [19] with respect to effectiveness of multilayered geocell reinforcement.

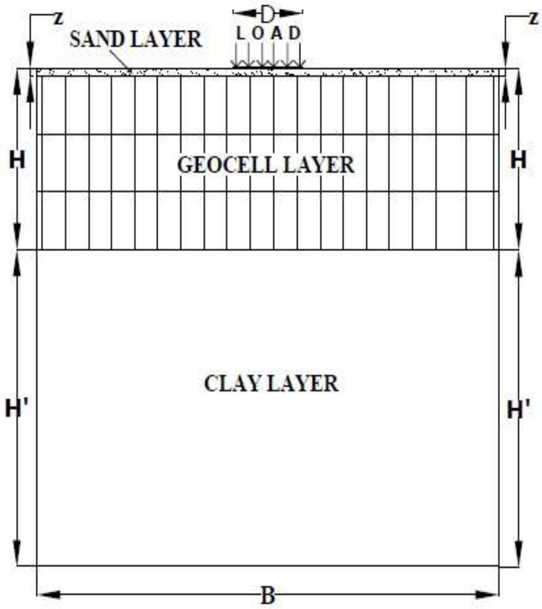

Fig. 1. Schematic Diagram of the model test set-up adopted by Biswas [16]

2 Material Characterization and Methodology

Biswas [16] addressed the various issues regarding single layer geocell-reinforced systems and presented a comparison for different reinforcements on varying foundation configurations. Model tests were performed with a circular footing rested over unreinforced and reinforced sand layers overlying clay subgrades of different strengths (c_u = 7, 15, 30, and 60 kPa). The properties of materials used in the test programme are reproduced in Table 1 along with calculated geocell-properties used for present numerical analysis as per Latha and Rajagopal [10]. In the experimental study geocells were assembled in chevron pattern with the help of bodkin joint. The geocell materials showed the maximum tensile strength as 20 kN/m at 11% of axial strain.

Table 1. Material Properties

Material	Material Properties	Values
Clay (CL)[#]	Max unit weight (kN/m^3)	17.3
	OMC (%)	19.7
Sand (SP)[#]	Max unit weight (kN/m^3)	16.43
	Friction angle (from triaxial test)(°)	40
Geocell*	Equivalent Diameter (mm)	120
	Modulus of elasticity E_g (kPa)	92719
	Poisson's ratio	0.3
	C_g (kPa)	92.73

*[#]From Biswas [16]; *Derived as per Latha and Rajagopal [10]*

Table 2. Details of test series and parameters considered in Biswas [16]

Foundation types	Test parameters
Homogeneous clay and sand bed	c_u = 7, 15, 30 and 60 kPa D_r = 80 %
Unreinforced sand layers on clay subgrades	c_u =7, 15, 30 and 60 kPa; D_r = 80 % *H/D* = 0.63, 1.15, 1.67, 2.19
Geocell-reinforced sand layers on clay subgrades	c_u = 7, 15, 30 and 60 kPa; D_r = 80 % *H/D* = 0.63, 1.15, 1.67, 2.19; *Z* = 0.1*D*; *d/D* = 0.8

3 Multilayer stepped geocell System

Till now, single layer of geocell is used in most of the soil reinforcing systems. But studies have revealed that difficulties in filling arises where thickness of the geocell layer is high. As per the authors, it can be addressed if multilayer of geocell system can be used (Fig. 2a). Therefore, in this study, geocell reinforced sand, having *H/D* = 2.19, overlaying clay subgrades is considered (as Biswas [16] has reported all the difficulties were prominently found for this configuration). In this study two layers of geocell is placed and a sand cushion of thickness *z* is considered in between the layers.

The conventional consideration in geocell reinforcing system is that the geoell is placed for full width of the area concern, instead as per the applied loading dimension only. Therefore, it has been found that in such configuration most of the portion of geocell remain unused. Hence, it could be an effective measure if the geocell length is curtailed as per the load transmission. To address this issue and to find out the effective mechanism to provide multi-layer stepped geocell, the configuration of geo-structure having *H/D* = 2.19, is splited into two and top-layer of the geocell is cut at its 1/4th width from the edge (from both ends; Fig. 2b).

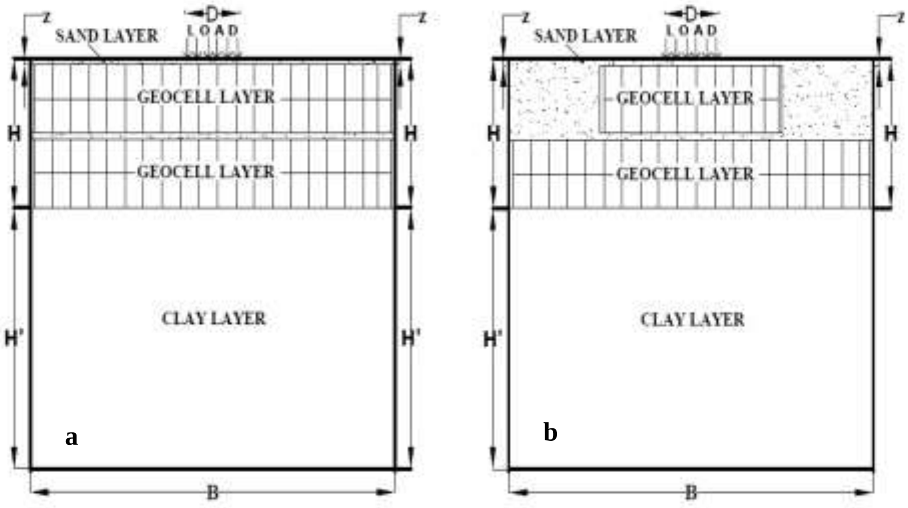

Fig. 2. Proposed configuration (a) Multi-layer Geocell, (b) Multi-layer stepped Geocell

4 Simulation and Validation

4.1 Composite Geocell-Soil Layer

All the finite element analysis reported in this paper are performed using the PLAXIS^{2D}. In the analysis, axi-symmetric model is used where soils are modelled using a nonlinear elastic-plastic constitutive model following Mohr-Coulomb yield criteria and non-associated flow rule (as per Wulandari and Tjandra [20]). The Geocell layers are modelled as an equivalent composite layer as proposed by Latha and Rajagopal [10]. In this method, the geocell-soil layer is simulated as a composite-soil having higher cohesion with unaltered internal friction angle. The geocell-induced cohesion is termed as apparent cohesion (c_r) and calculated as Eq. 1. With the modified shear parameters, the equivalent stiffness of geocell (E_g) layer is calculated (Eq. 1-3); where, '$\Delta\sigma_3$' is the additional confining pressure due to membrane stress, 'ε_a' is the axial strain at failure, 'D_o' is the initial diameter, 'M' is secant modulus of membrane, 'K_p' is coefficient of passive earth pressure and 'K_u' is the dimensionless modulus for the unreinforced sand.

$$c_r = \frac{\Delta\sigma_3}{2}\sqrt{K_p} \text{ .... (1)}$$

$$\Delta\sigma_3 = \frac{2M}{D_0}\left(\frac{1-\sqrt{1-\varepsilon_a}}{1-\varepsilon_a}\right) \text{ .... (2)}$$

$$E_g = 4(\Delta\sigma_3)^{0.7}(K_u + 200M^{0.16}) \text{ .... (3)}$$

A sample calculation for the input parameters are shown hereunder.

Let, ε_a is the axial strain at failure = 0.125, D_o is the initial diameter = 0.12 m, M = Secant Modulus at failure = 75 kN/m,

Hence, $\Delta\sigma_3 = \frac{2M}{D_0}\left(\frac{1-\sqrt{1-\varepsilon_a}}{1-\varepsilon_a}\right) = \frac{2\ x\ 75}{0.120}\left(\frac{1-\sqrt{1-0.125}}{1-0.125}\right) = 86.9\ kPa$

$c_r = \frac{\Delta\sigma_3}{2}\sqrt{K_p} = \frac{86.90}{2}\sqrt{4.56} =$ 92.78 kPa

$c_g = c_r + c$ = 92.78 kPa, and,

$E_g = 4\sigma_3^{0.7}(K_u + 200M^{0.16}) = 4\times86.9^{0.7} \times (550 + 200\times380^{0.16})$ = 92719 kPa

Thus, following are the parameters used in the analysis to define the materials.

Table 3. Material Properties and Parameters

Material	**Poisson's ratio**	**Undrained Cohession (kPa)**	**Modulus of Elasticity (kPa)**
Clay	0.45	7, 15, 30 ,15	$600c_u$
Sand	0.3	0	13000
Geocell	0.3	92.78	92719

4.2 Validation

Biswas [16] presented a comparative report of laboratory tests performed with circular plate (footing) rested on different surface foundations. The foundations are configured with unreinforced and reinforced sand (D_r = 80%) layers of varied thicknesses overlying a wide range of clay subgrade, from very soft (c_u = 7) to stiff (c_u = 60 kPa). The reinforced layers are comprised of an interface geogrid, geocell and combinations of geocell-geogrid of different thickness. It is reported that the performance of foundations improves with reinforcement superiority. However the reinforcement benefits were reduced with an increase in clay stiffness and thickness of overlying sand layers. In this study, initially, the work of Biswas [16] is validated using PLAXIS^{2D} to get the confidence on the parameters to be considered in the numerical analysis. On getting the comparable agreements between the experimental and numerical results (Figs. 3-6) for the soil parameters, they are further used for present objectives. In modelling the geocell-soil layers, it is considered as a composite soil layer with modified shear parameters [10]. In Fig. 6, it may be noticed that responses of numerical and experimental observations are deferring in a considerable margin for geocell-systems. However, as the present objective is to compare the performance of single and multi-layer (with and without stepped configuration) geocell-reinforced system, thus, this disagreement is neglected (as the performance will be evaluated through the ratios of bearing capacity and settlement levels).

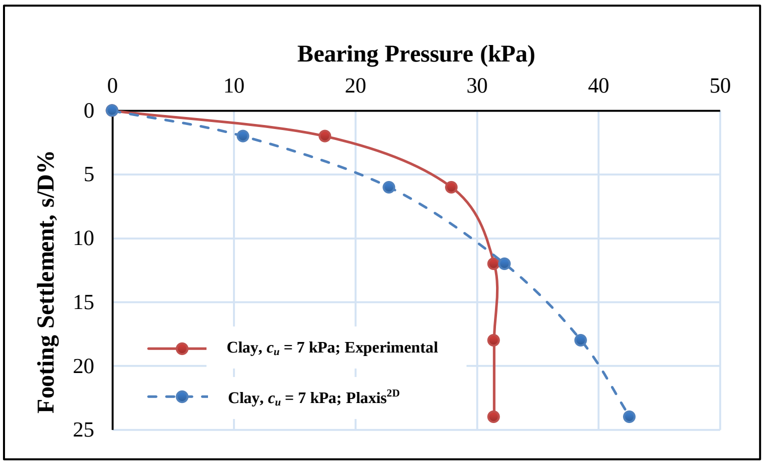

Fig. 3. Comparison between Experimental (Biswas [16]) and Numerical result (for Homogeneous clay bed having c_u = 7 kPa)

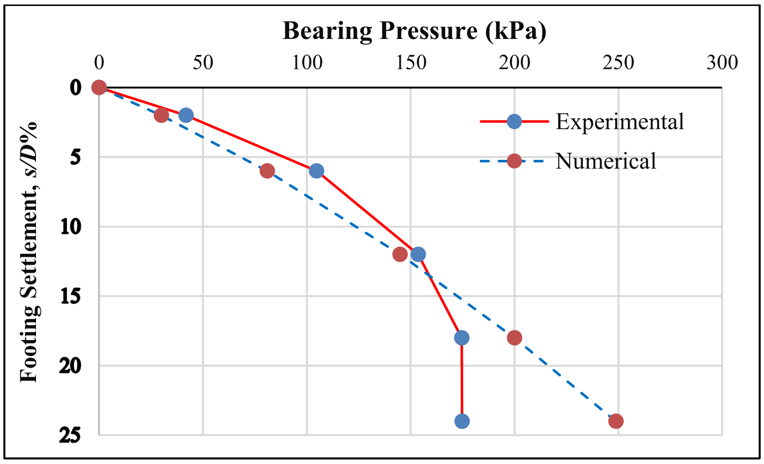

Fig. 4. Comparison between Experimental (Biswas [16]) and Numerical result (for Homogeneous sand bed with 80% relative density

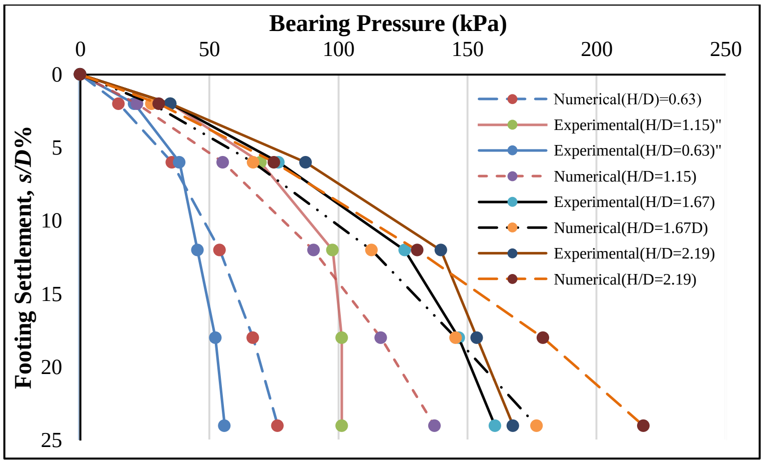

Fig. 5. Comparison between Experimental (Biswas [16]) and Numerical result (for Unreinforced layered configuration for c_u = 7 kPa)

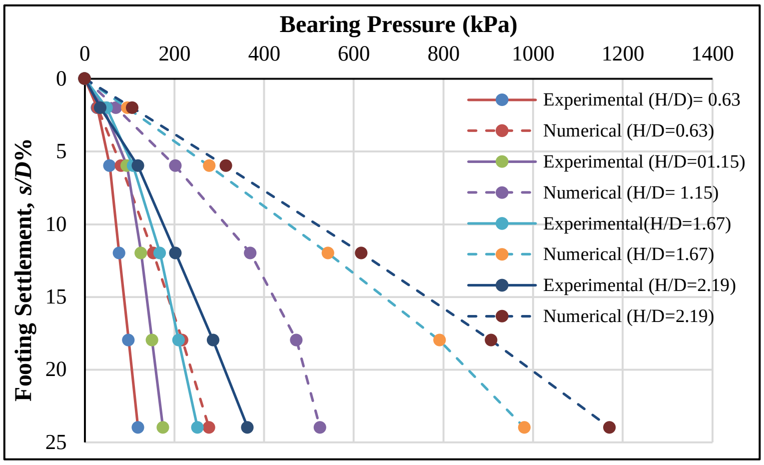

Fig. 6. Comparison between Experimental (Biswas [19]) and Numerical result for geocell reinforced layer of different thicknesses for c_u = 7 kPa

5 Numerical Analysis for Multi-Layer Geocell System

On successful validation for soil parameters, the study has considered the geocell reinforced foundation for multi-layered systems. Numerically, not much variation with respect to bearing pressure-settlement responses (for c_u = 7 and 15 kPa) is found (Fig. 7-8) for a single and multi-layer geocell system. This indicates that, practically, the multi-layered geocell system should be fruitful for thicker geocells where compaction and buckling is a defining factor. Besides, it may also be noticed that the stepped geocell system have performed as good as the other two; whereas, due to the curtailment, a huge savings on the material consumption is made. Thus, as per the objective of this study, it may be concluded that the stepped configuration would be much more effective than a conventional use of single layer geocell without compromising the benefits (laboratory experiments, as the companion, are planned to be conducted as future scope of this study).

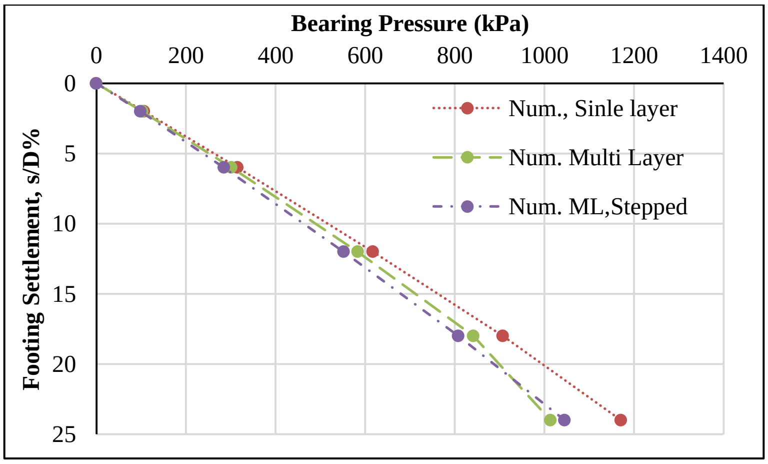

Fig. 7. Comparison between Single Layer of Geocell System, Multilayer of Geocell System and Multi-layer stepped geocell (c_u = 7 kPa)

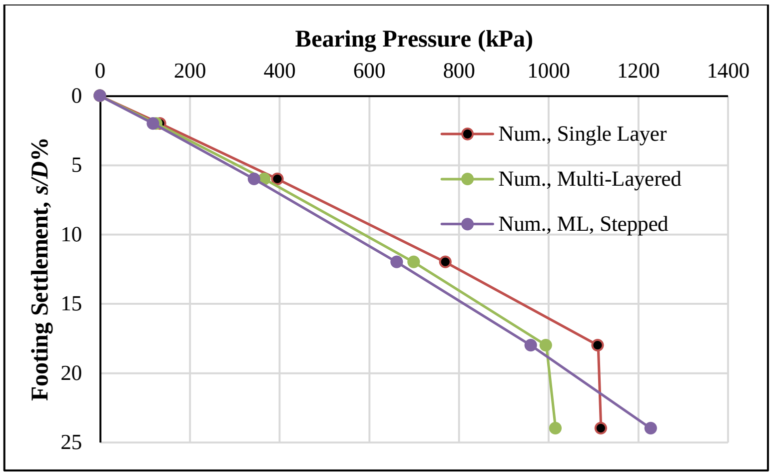

Fig. 8. Comparison between Single Layer of Geocell System, Multilayer of Geocell System and Multi-layer stepped geocell (c_u = 15 kPa)

6 Conclusion

This study has numerically investigated the comparative performance of single and multi-layer geocell systems. Though, the study is in primary stage, however, a clear indication is noticed that a multi-layer geocell system, with stepped configuration, would be a better consideration as compared to conventional single layer geocell systems (Fig. 8). It is observed that for the selected configuration at higher deformation (settlement level), soil system collapses for a single-layer system; while for multi-layer stepped geocell system, this phenomena has not been observed. However, a concrete conclusion can only be drawn after a validation programme can be performed through physical laboratory investigation.

References

1. Webster SL, Watkins JE (1977) Investigation of construction techniques for tactical bridge aproach roads accross soft ground. Technical Report S-77-1, United States Army Corps of Engineers, Waterways Experiment Station, Mississippi, USA.
2. Hausmann MR (1987) Geotextiles for unpaved roads-a review of design procedures. Geotextiles and Geomembranes, 5, 201-233.
3. Koerner RM (1997) Designing with geosynthetics, 3rd edn. Prentice Hall Inc., New Jersey.
4. Emersleben A and Meyer N (2008) The use of geocells in road constructions over soft soil: vertical stress and falling weight deflectometer measurments. EuroGeo4, Paper no. 132
5. Prasath SB, Krishna AM (2017) Design of geocell reinforced unpaved pavement for low traffic volume. Indian Geotechnical Conference, IIT Guwahati, India.
6. Humphrey DN, Holtz RD (1986) Reinforced embankments-a review of case histories. Geotextiles and Geomembranes, 4, 129-144.
7. Bush DI, Jenner CG, Bassett RH (1990) The design and construction of geocell foundationmattresses supporting embankments over soft ground. Geotextiles and Geomembranes, 9, 83-98.
8. Cowland JW, Wong SCK (1993) Performance of a road embankment on soft clay supported on a geocell mattress foundation. Geotextiles and Geomembranes, 12, 687-705.
9. Krishnaswamy NR, Rajagopal K, Latha GM (2000) Model studies on geocell supported embankments constructed over a soft clay foundation. Geotechnical Testing Journal, ASTM, 23,45-54.
10. Latha GM, Rajagopal K (2007) Parametric finite element analyses of geocell supported embankments. Canadian Geotechnical Journal, 44, 917-927.
11. Dash SK, Shivadas AS (2012) Performance improvement of railway ballast using geocell. Indian Geotechnical Journal, 42 (3), 186-193
12. Indraratna B, Biabani MM, and Nimbalkar S (2015) Behavior of geocell-reinforced subballast subjected to cyclic loading in plane-strain condition. Journal of Geotechnical and Geoenvironmental Engineering, 141(1),: DOI: 10.1061/(ASCE)GT.1943-5606.0001199.
13. Biswas A, Krishna AM, and Dash SK (2013) Influence of subgrade strength on the performance of geocell-reinforced foundation systems. Geosynthetic International, 20(6), 376-388.

14. Biswas A, Krishna AM, Dash SK (2016) Behavior of geosynthetic reinforced Soil foundation systems supported on stiff clay subgrade. International Journal of Geomechanics. ASCE, DOI: 10.1061/ (ASCE) GM.1943-5622.0000559.
15. Biswas A, Krishna AM (2017) Geocell-reinforced foundation systems: a critical review. International Journal of Geosynthetics and Ground Engineering, DOI 10.1007/s40891-017-0093-7.
16. Biswas, A (2019) Comparative performance of different geosynthetics on sandy soil overlying clay subgrades of varying strength. Innovative Infrastructure Solutions, Springer.
17. Li L, Cui F, Xiao H (2018) Experimental study on the properties of geocell-reinforced embankments. In: China-Europe Conference on Geotechnical Engineering, 1160-1163.
18. Tafreshi SNM, Khalaj O, Dowson AR (2013) Pilot scale load tests of a combined multi-layered geocell and rubber- reinforced foundation. Geosynthetic International, 20(3), pp. 143-161.
19. Sarkar H, Biswas A (2019) Behavior of multi-layer-geocell reinforced soil embankment. In: 7IYGEC 2019, NIT Silchar, pp. 48-51.
20. Wulandari PS, Tjandra D (2015) Analysis of geotextile reinforced road embankment using PLAXIS 2D. Procedia Engineering, pp. 358-362.