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Investigation on Mechanical Behavior of Embedded Geocell in Geocell-Reinforced Railway Embankment

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ABSTRACT

Increasing axle load and speed of travel on existing railway tracks is one of the approaches that is taken by the industry to improve rail transportation system. In this regard, improvement of railway embankments as an important part of railway infrastructure is increasingly appearing as a necessity. In this study, the application of geocell layers in railway embankment body as an improvement technique for geotechnical issues is surveyed. A numerical model is developed that resembles an embankment of 10-meter height on a scale 1:20 in the laboratory setup. The sensitivity analysis is carried out on the adhesion and elastic modulus of the embankment, geocell elastic modulus, and the embankment length. Loading is carried out on each reinforced and non-reinforced embankments until failure. The results indicate an increase in the loading capacity of the embankment and reduction of the crest settlement proportional to the increase in the number of geocell layers. Monitoring the geocell behavior indicates that stress inside the embedded geocell under loading is low in comparison with the tensile test result of the geocell.

1. Introduction

Improvement and renovation of existing railway tracks with the aim of increasing speed of travel and axle load of rail vehicles are vital issues for the efficiency of railway transportation industry. For increasing axle load or train speed the settlement and bearing capacity of existing railway tracks need to be enhanced by using stabilization techniques. Special geotechnical conditions of some areas create challenges in the construction of new railway tracks. It is needed to find suitable resources of high quality materials conforming to the geotechnical standards. To solve the problem a variety of methods of soil improvement techniques such as condensation, slurry injection, deep mixing injection, high-pressure injection (jet grouting), geosynthetic materials especially geocell, and the geometric correction of slopes, etc. can be highlighted.

In what follows, a wide range of studies related to the use of geocell to improve mechanical properties of soils are examined.

Geocells are widely used in construction for erosion control, soil stabilization, channel protection, and structural reinforcement for load support and earth retention. Because of special physical structure and the confining features, geocell can keep soil in the integrated state without spearing. Increasing the soils bearing capacity and its settlement reduction in comparison with non-geocell soil are main advantages of geocells, which can utilize poor soil materials within the geocell [1]. The stability of geocell-reinforced soil was investigated by Mandal et al. [2]. The results indicated that load-settlement characteristics were improved by using of geocell reinforcement. Mahdavi et al.

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[3] studied the geocell-reinforced foundations by performing laboratory model tests. They finally proposed a simple method based on slope stability analysis for preliminary design of embankments over geocell layers. Zhang [4] carried out an analytical study in order to calculate the bearing capacity of the geocell reinforced soft subgrade of the road embankment. The calculated results from their method were so close to the experimental results obtained by Koerner's method. Moreover, they found that placing the geocell layer in crushed stone cushion increased the bearing capacity of soft subgrade. Dash and Shivadas [5] reported that using geocells can decrease the dispersion of ballast particles and make the maintenance interval longer by performing a series experiments. Furthermore, the results indicated that the maximum improvement can be met when the pocket size of geocell is about twice the average size of ballasts. The results of numerical simulations of Leshchinsky and Ling [1] showed that the confinement of ballast aggregates by geocell is quite effective to reduce vertical deformations under railway loading, when low-quality ballast particles were used. In addition, using the geocell layer made subgrade stress distribution more uniform. The laboratory and numerical investigations on geocell-reinforced sub-ballast under cyclic loading was carried out by Biabani et al. [6]. They achieved some conclusions including a decrease in sub-ballast deformity with increasing geocell stiffness and a minimizing lateral displacement up to a sub-ballast stiffness of 10 Mpa. Biabani et al. [6] claimed that using geocell and sub-ballast with relatively low compressive strength has proper performance considering concurrent economic issues. The cell surface and the lateral pressure are the factors affecting geocell strips. Numerical results showed that with the increase of geocell hardness, the mobilized tensile strength of the geocell increases while the inactive resistance decreases [7]. Mehdipour et al. [8] performed a numerical study on geocell reinforced slopes considering the bending effect. The results show that by using geocells, the safety factor of slopes increases and the related lateral displacement detracts. Findings present that geocells prevent surface failure and redistributes the load on a wider surface. Geocell parametric studies were carried out with changing its layer locations in depth, the number of geocell layers, vertical spacing between reinforced layers, length, thickness, and the Yung modulus of the geocell. The effects of slope geometry, shear strength characteristics, and soil density on the behavior of reinforced slopes were also discussed [8]. Krishnaswamy et al. [9] investigated geocell supported embankments on soft foundations. They found that using a geocell layer, improved bearing capacity and settlement of the embankments and also tensile stiffness had an important influence on the performance of the geocell-supported embankment. Dai et al. [10] adopted particle image velocimetry (PVI) method to investigate performance of reinforced embankments with geocell under static and cyclic loading. The main results indicated that cumulative displacement reduced by using geocell and with increasing embedded depth, the improvement effect of geocell gradually decreased.

A review on the technical literature shows that the mechanical behavior of the embedded geocell layers in geocell-reinforced embankment has not been studied, yet. Therefore, this research aims at finding a solution for increasing bearing capacity and minimizing crest settlement of the existing railway tracks. Moreover, the mechanical behavior of geocell material is investigated. In the laboratory model, the influence of geocell layers number on bearing capacity and settlement is surveyed by constructing six laboratory embankment models including non-geocell embankments (ELM0), ELM1, ELM2, ELM3, ELM4 and ELM5. It should be noted that the ELM1 to ELM5 refers to reinforced embankments by 1, 2, 3, 4, and 5 geocell layers, respectively. Furthermore, by developing a finite element (FE) model by using ABAQUS engineering software the laboratory and numerical results are compared. The stress-displacement curve extracted for each embedded geocell layer is checked. The state of stress inside geocells with tensile test results of geocells are examined.

2. FEM Model Validation

A series of 6 laboratory railway embankments including 5 geocell-reinforced embankments containing 1, 2, 3, 4 and 5 geocell layers respectively and one non-reinforced embankment are constructed and loaded [11]. Based on the Iranian railway standards' requirements, a 10 m height embankment with a crest width of 4.6 m and slope angle of 45 degrees is selected. The scale factor of 1:20 is adopted [12]. All real embankment dimensions are converted into scaled laboratory model. All laboratory and real dimensions of the selected railway embankment are provided in details in Table 1. A variety of laboratory embankment sections are presented in Figure 1. It also indicates that geocell layers are placed consecutively at the top of the embankment. The geocell that is used in the experimental models is made of a geomembrane sheet with the stiffness of 70 MPa and dimensions of 0.16×200×1500 cm. The handmade geocell layers with cell dimensions of 5×5×5 cm, wall thickness of 0.15 cm, and lengths of 23, 33, 43, 53, and 63 cm are prepared to reinforce the laboratory embankments. The mechanical properties of the embankment body soil, subgrade soil and geocell which are determined through a variety of material tests and are addressed in Table 2. In order to validate the laboratory results a finite element (FE) model is developed that is based on ABAQUS engineering software [13].

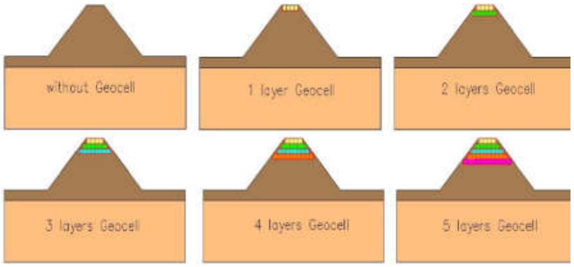


Figure 1. A schematic illustration of geocell layers in the laboratory embankments

Table 1. Full-scale and laboratory railway embankment dimensions (scale factor 1:20)

Parameter	Scaled model	Real embankment
Embankment height	0.5 m	10 m
Embankment length	2.4 m	48 m
Slope angle	45°	45°
Slope length	0.71 m	14.2m
Crest width	0.23 m	4.6 m
Subgrade depth	0.6 m	12 m
Modified subgrade depth	0.1 m	2 m
Bedside width	0.56 m	11.2 m

Table 2. Specifications of subgrade and embankment soils of laboratory models

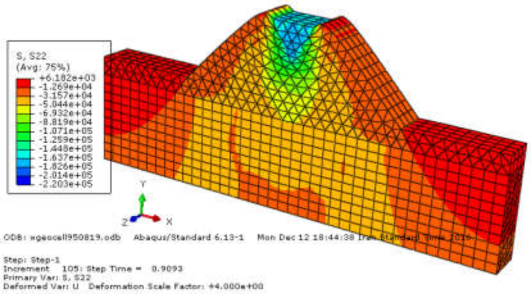
Soil parameters		Subgrade	Embankment
Soil type		SP	SW
ϕ	(Degree)	38	29
C	$(\mathrm{kN/m^2})$	1.8	21
E	$(\mathrm{kN/m^2})$	14900	6000
γ	$(\mathrm{kN/m^3})$	15.7	17.1
D_r	(%)	70	91
C_u	-	1.45	8.33
C_c	-	1.08	1.001

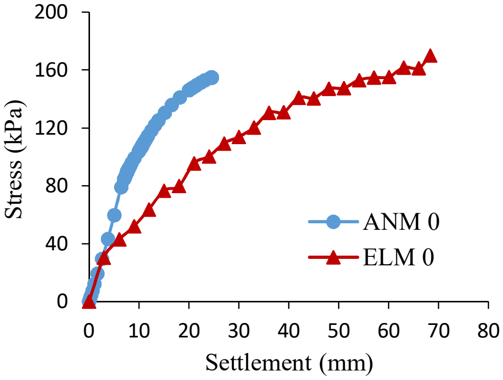
It is to facilitate simulating the laboratory models in 3-dimensions (3D).

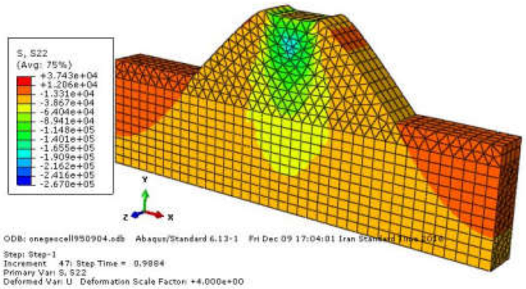
For the simulations a 15-node quadratic triangular prism (C3D15), with 8-node quadrilateral membrane, reduced integration (M3D8R) and a 20-node quadratic brick, reduced integration (C3D20R) elements are selected for soil, subgrade, geocell, and the loading plates, respectively. In the numerical embankment models, the imposed boundary conditions are the same as the experimental embankment.

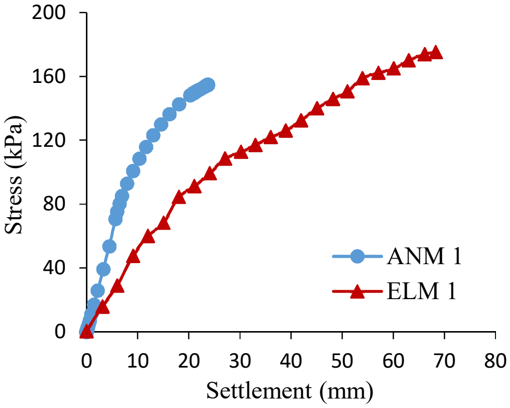
To validate the numerical results, they are compared with the laboratory experimental results in terms of stress-settlement. The names that are associated with the numerical ABAQUS models are related to the corresponding laboratory models. In this regard, ANM0 refers to non-geocelled embankment, ANM1 to ANM5 refer to the reinforced embankments with one to five layers of geocell, respectively. Figure 2 presents the mechanical behavior of the numerical and laboratory models in terms of stress-settlement. From the numerical results, it becomes cleat that using more geocell layers leads to the increased bearing capacity of the embankment models, the same as laboratory results. Comparing numerical and laboratory results indicate that the numerical models behave with more rigidity while the numerical models exhibit less settlement in comparison with laboratory ones.

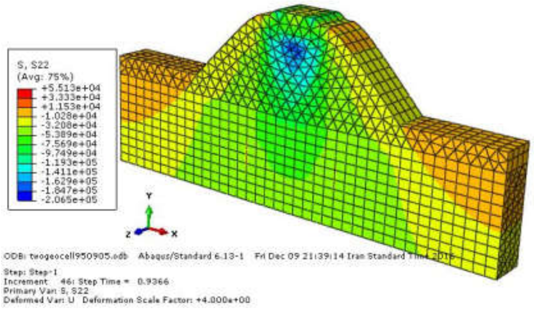
The main difference between the laboratory and numerical results come from the fact that the handmade geocells had non-integrated connections and did not contain adequate stiffness, not the same as the commercial geocells. Therefore, they did not encompass enough integrity against displacement during loading process. Hence, the laboratory results showed less bearing capacity and more crest settlement compared with the FE models.

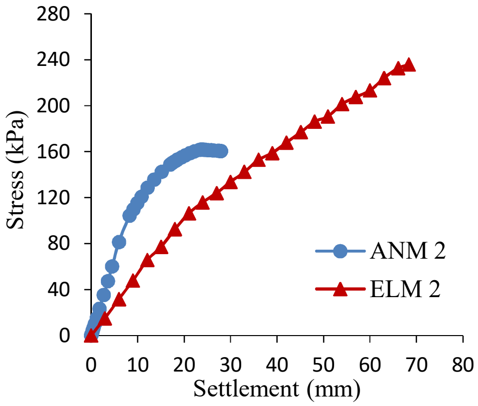


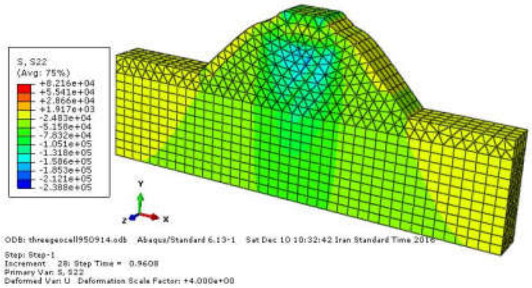


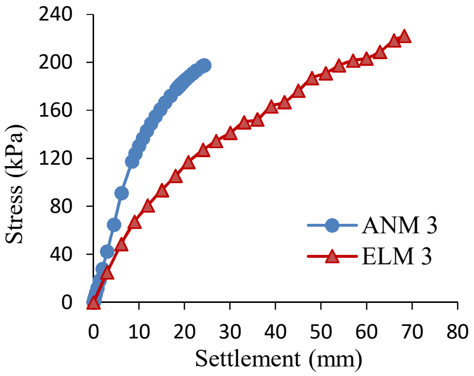












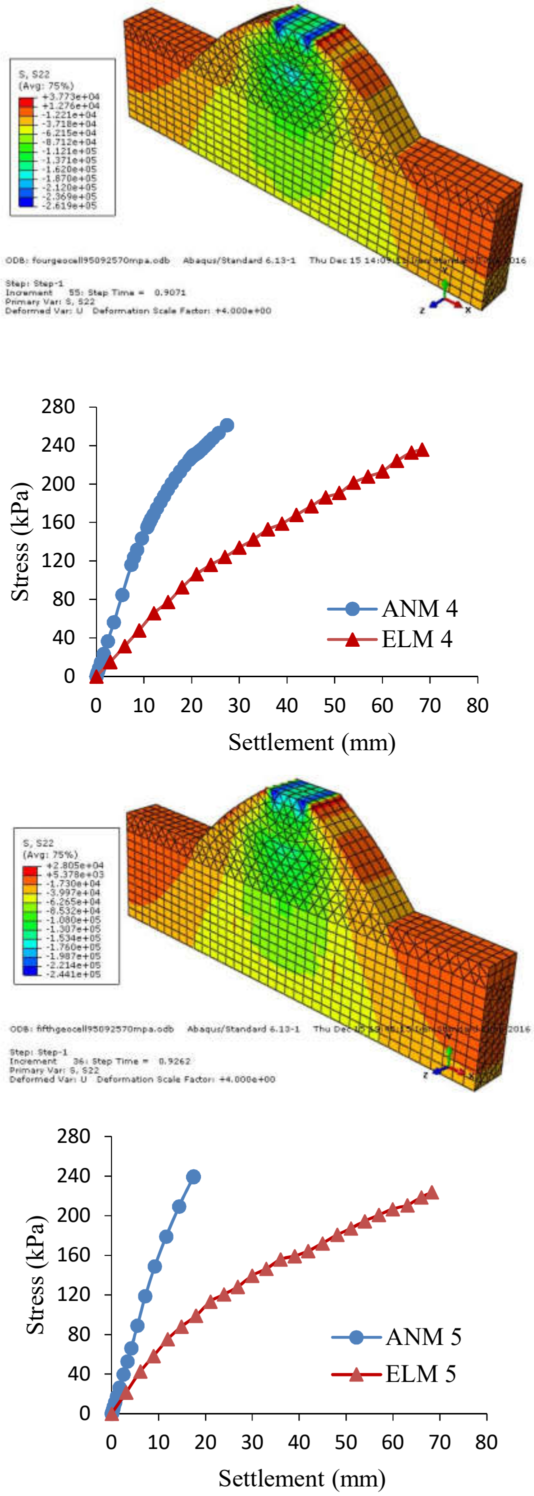


Figure 2. Stress-settlement curve of laboratory and numerical embankments

3. Investigation of Embedded Geocell Layers in Geocell Reinforced-Embankment

The laboratory embankments are modeled by using ABAQUS engineering software that is based on the finite elements method. This facilitates surveying the mechanical behavior of embedded geocell in embankment body. The mechanical behavior of the embedded geocell layers are studied based on the results from the previous step where the modeling processes were validated by comparing with the experimental output. The displacement-stress curves are extracted for each embedded geocell layer in five aforementioned reinforced embankments.

4. Results and Discussion

In this section the mechanical behavior of embedded geocells for each reinforced embankment are examined. To serve the purpose, the stress present within each geocell layer under its designated loading is extracted. The aim is to determine whether the geocell material has entered its plastic zone or not. For this reason, for each embankment the stress-settlement curve for a middle point and a critical point in geocell layers are examined. Moreover, the geocell laboratory tensile test results are performed and are presented in Figure 3. It should be noted that the geocell layer midpoint is the central point on the upper surface of the geocell layer, and its critical point is the blue parts in Figure 3 that indicate the maximum stress in the geocell. The diagrams indicate that the predictions by the numerical model for the stresses within the geocell are less than the predictions from the tensile test results. It clearly means that the geocell layer has not crossed into its plastic margin based on the numerical predictions. Moreover, by increasing the number of geocell layers the lower layers experience less stress and deformation.

5. Conclusions

This research set out to investigate the mechanical behavior of embedded geocell in geocell-reinforced railway embankment. Six laboratory embankments including 5 reinforced embankments with 1, 2, 3 and 4 geocell layers and a non-reinforced embankment were constructed in the laboratory setup. Also, a Finite Elements modeling by using ABAQUS engineering software was developed to validate the laboratory results and to survey the

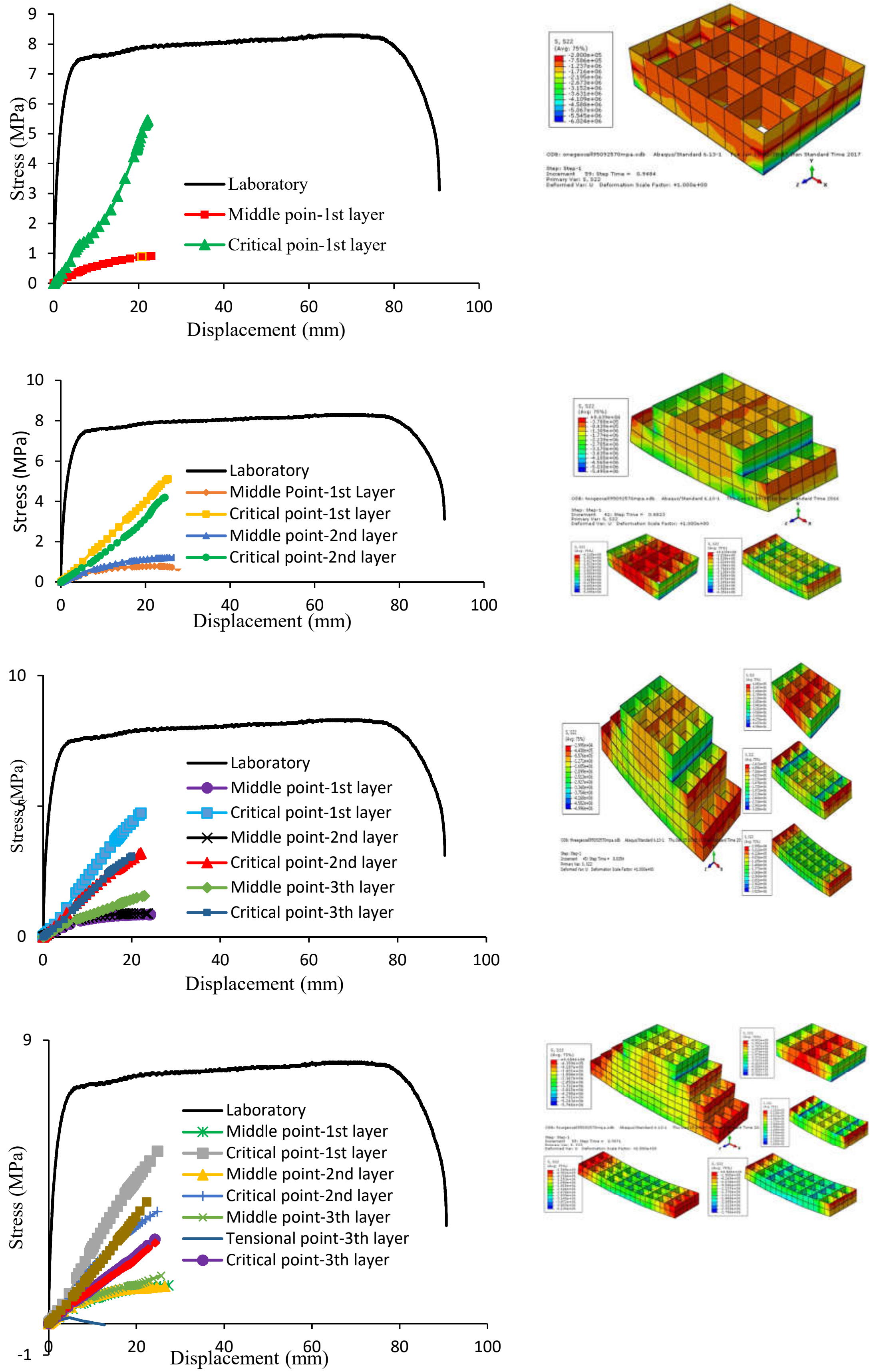


Figure 3. Mechanical behavior of embedded geocell layers against tensile test result of geocell

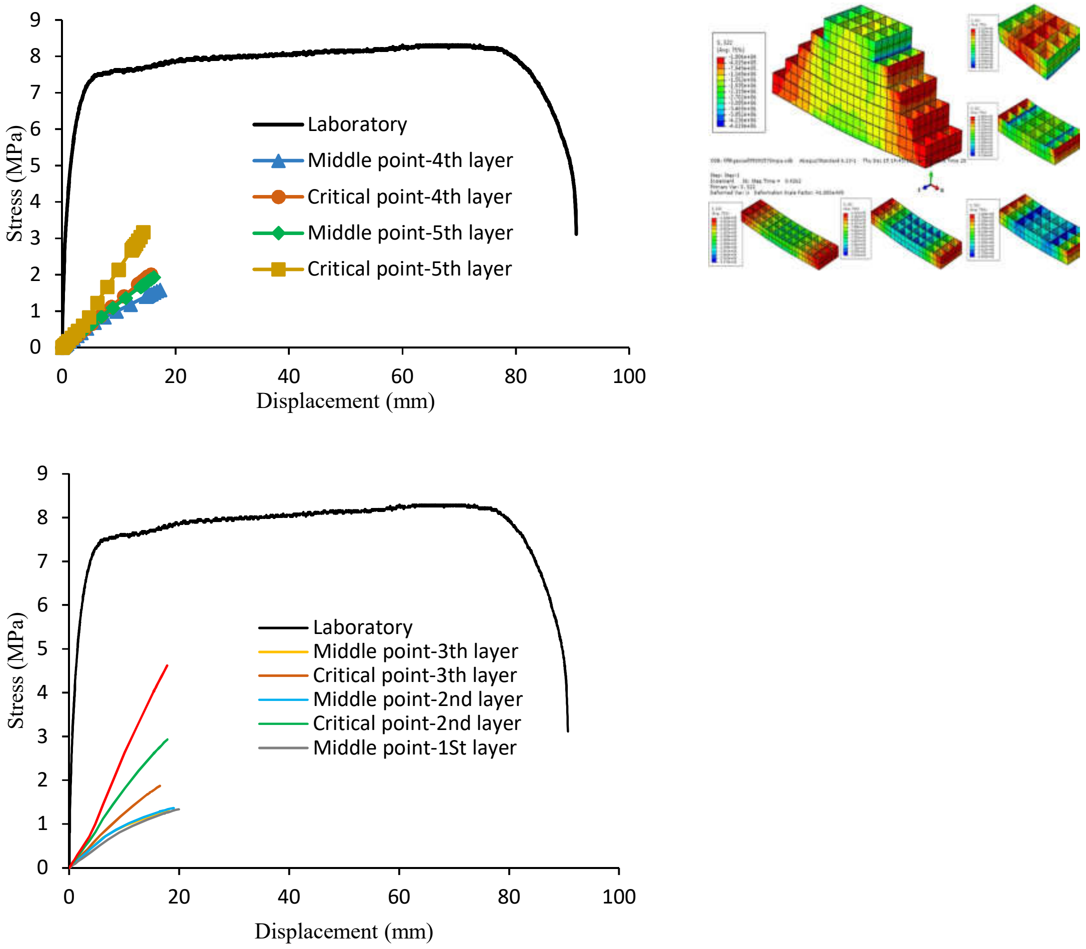


Figure 3. Mechanical behavior of embedded geocell layers against tensile test result of geocell (continued)

mechanical behavior of embedded geocell layers. The mains results can be summarized as:

The reinforced embankments demonstrate more bearing capacity and less settlement in comparison with non-reinforced ones. Moreover, by increasing the number of the geocell layers the reinforced embankments exhibit more rigid response under the railroad loading. Furthermore, increasing the number of geocell layers led to improving the bearing capacity of the embankments up to 4 layers.

The embedded geocell layer's tensile capacity did not reach to its ultimate strength based on the geocell tensile test data. Therefore, its maximum capacity has not been used. Thus, in order to optimally utilize its capacity, the geocell need to be used with less tensile strength.

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