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Stabilization of Steep Slopes on Soft Foundation using Geocells

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Abstract. Geocells are three-dimensional honeycomb shaped geosynthetic material used for ground improvement. It is mainly used for strengthening foundation beds, flexible pavements and for erosion control. In the case of steep and high slopes, it is necessary to provide reinforcements to ensure the stability of structures. In places where foundation is made up of soft soil, foundation reinforcement becomes necessary. Geocells are usually provided in the form of basal reinforcement. Geocells can provide confinement and tensile strength which can help in increasing the factor of safety of slopes. Present study indicates the efficacy of geocell in the stabilization of a lateritic steep slope resting on a clay foundation. Numerical modelling was conducted using a commercially available software PLAXIS 3D. An attempt of modelling of the curvilinear geometry of geocells was done and validated. Slope stabilization using geocell in the form of slope reinforcement and also as a foundation reinforcement was presented in this study. The slope was found to be stable when geocell was provided both as foundation reinforcement as well as along the slope (GCFS) owing to the site conditions, slope geometry and soil properties.

Keywords: Geocells, PLAXIS 3D, Ground improvement, Slope stabilization; Reinforced soil

1 Introduction

As a result of urbanization, there is a rapid increase in land requirement for the construction of various transportation infrastructures. It is thus becoming a necessity to find land with suitable engineering properties. Replacement of unsuitable land is not always feasible. Thus, it is important to enhance the properties of existing ground and utilize it efficiently. There are different ways for improving the existing land and soil reinforcement is very well-known technique. Earlier, soil reinforcement was provided in the form of metallic strips, which has given way to synthetic reinforcements. Geosynthetic reinforcements are being used in the field for several years. Geogrid, which is in planar form, is the most commonly used geosynthetic reinforcement. These days, Geocells which are in three-dimensional form, are also increasingly used in practice. They provide three-dimensional confinement and thus help to prevent lateral spreading of soil (Wu and Austin, 1992; Cowland and Wong, 1993; Zhao et al., 1997; Dash et al., 2003;

Krishnswamy et al., 2000; Leshchinsky and Ling, 2013). They have inter-linked pockets/cells which can be filled with infills. Granular infills are usually provided.

Geocells are mainly used for strengthening foundation beds, flexible pavements and for erosion control ((Bush et al., 1990; Wu and Austin, 1992; Bathurst and Crowe, 1992; Bathurst and Rajagopal, 1993; Rajagopal et al., 1999; Madhavi Latha et al., 2008; Rajagopal and Kief, 2008; Han et al., 2010; Dash et al., 2003; Pokharel 2010; Pokharel et al., 2010 and 2018). Formation of geocells using connected geogrids was reported in literature (Krishnaswamy et al., 2000), which was utilised in reinforcing embankment foundations over soft soils and marine structure foundations. Another type is welded polymer sheet strips to form inter-linked cells which can be used in road bases and ballast tracks for reinforcement purposes, channel protection, slope protection and retaining walls using geocell (Bathurst and Crowe, 1994). The latest development is Novel Polymeric Alloy (NPA) geocells. NPA is consisting of a polyethylene matrix with polyester/ polyamide nano-fibers dispersed, which is a nano-composite alloy with better stiffness compared to high density polyethylene geocells (Pokharel et al., 2018).

The three-dimensional structure of geocells provide confinement effect. When a geocell is loaded, active earth pressure is developed from the loaded cell. In the adjacent cells, a passive earth pressure will be developed. Hoop tension will be mobilized in the geocell wall. Confinement imparts a pseudo-cohesion to the infill material and thus shear strength and stiffness increases.

Geocell layer functions can be reviewed in three different aspects in embankments with geocell reinforced layers: vertical stress-dispersion, lateral resistance-effect and membrane-effect (Zhang et al., 2010). It can be observed from literature that geocell mattress transmits the pressure from footing to soil layer underlying the footing similar to a slab action redistributing the footing pressure over a wider width (Dash, 2010). Geocell system has high stiffness which redistributes the stress from pavement subgrade more uniformly. Also, it promotes uniform settlements by acting as a stiff rigid base to embankment. It increases the factor of safety of the slope since additional component of tensile force is acting as a restoring force. As the cells are perforated, lateral cell to cell drainage is facilitated for excessive ground water and these perforations and its textured surface increase the friction between infill and the pocket wall and lock the infill better, leading to greater overall load distribution.

Bathurst and Crowe (1994) explain utilizing geocell in the construction of flexible gravity structures and facia of steep slopes and reinforced retaining wall structures with geosynthetics. Geocell is preferred due to the variability of infill material, three-dimensional confinement, transportation convenience in unexpanded form, complete system solution including connection, anchoring and load transfer.

Very limited studies are available in the literature regarding the application of geocells for slope stabilization. Few investigators attempted to model geocell system as an equivalent soil composite layer by considering geocell- soil system as a soil layer with improved cohesion and same angle of internal friction in two-dimensional modelling. Commercial geocells are having a curved shape and thus modelling it as a square or diamond shaped structure can lead to stress concentrations.

This study mainly focuses on utilizing geocells for the stabilization of a lateritic steep slope resting on a clay foundation. Performance of the slope with and without geocell reinforcement was numerically investigated using PLAXIS 3D software. This study involves modelling of the geocell reinforced soil considering the realistic geometry of geocells and understand the reinforcement mechanism.

2 Site conditions

The slope under consideration is a part of highway embankment at Kannur district in Kerala. The soil strata consist of clay up to 5m depth beyond which hard strata is available. Foundation soil was classified as low compressibility clay (CL) and the effective cohesion and angle of internal friction of the soil were 15 kPa and 22° respectively. The undrained cohesion of the clay was 22.5 KPa. The slope was 10 m high and was inclined at an angle of 63°. Lateritic soil with effective friction angle of 32° and unit weight of 17.5 kN/m^3 was used as the embankment fill. The soil was classified as sandy silt. Unreinforced soil slopes were not found to be stable with a lower factor of safety of 0.76. It was required to stabilize the embankment slope and foundation soil. The present study investigates the application of geocell in stabilizing the slope and foundation soil through numerical modelling.

3 Modelling and Validation of geocells

An attempt was made to model the geocell considering its realistic geometry. The properties of geocell were taken from an experimental study reported in literature by Yang et al. 2010. Lateral cell dimension of a single cell is 240 x 200 mm with 150 mm cell depth (Fig. 1). Young's modulus was 200 MPa. Geogrid elements were used for modelling geocells.

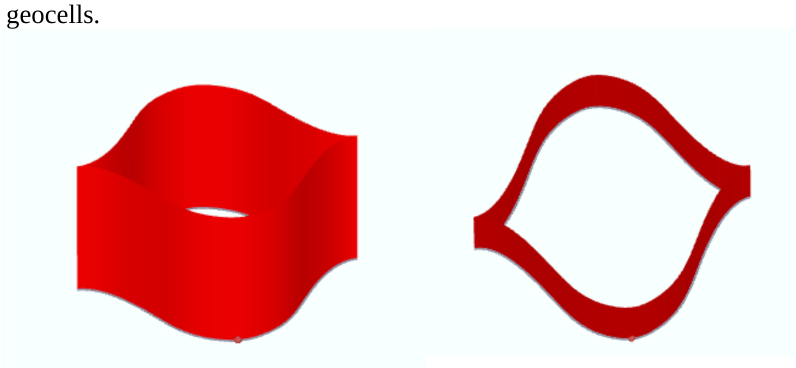


Fig. 1. Shape of the geocell modelled in the present study

For validation of the geocell, the experimental study reported by the same author was numerically modelled as shown in Fig. 2. Foundation soil considered is poorly graded sand having friction angle of 40.9° and cohesion of 1 kPa with minimum and maximum unit weight of 16.4 kN/m^3 and 19.5 kN/m^3 respectively. Specific gravity of the sand is 2.65, the coefficient of curvature is 0.98 and coefficient of uniformity is 2.73. Infill soil is considered same as the foundation soil. The interface friction angle is 34.7^0 and the interface cohesion is 0.8 kPa. Modelling of geocell was done using isotropic geogrid material which is elastic and the foundation soil is modelled using Hardening soil model. Loading was provided in different phases from 0 kPa to 150 kPa with an incremental loading of 10 kPa using a circular steel plate of 15 cm diameter. The bottom boundary of the model is restricted against vertical movement and the side boundaries are restricted against horizontal movement. Fine meshing with enhanced mesh refinement for geocell was provided.

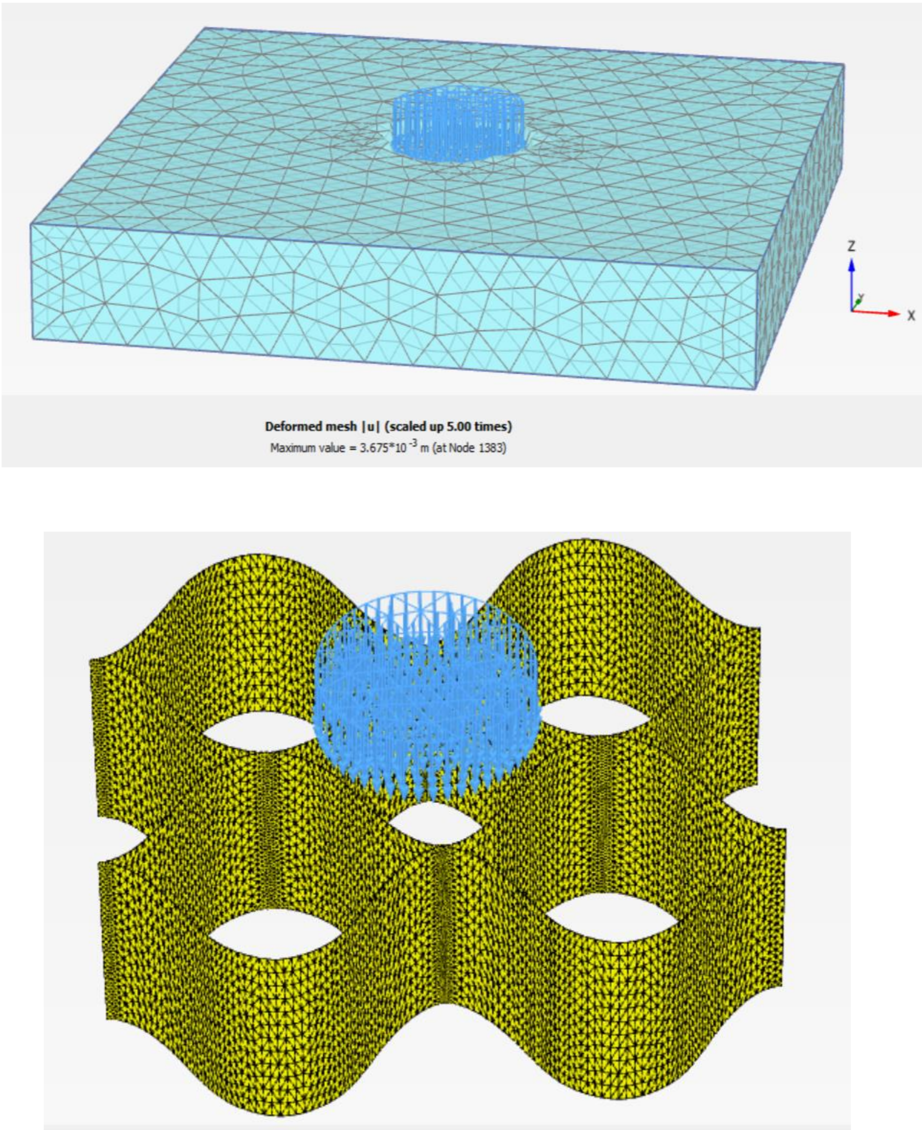


Fig. 2. Validation model

As the loading is directly above the centre geocell, more deformation is expected to be at the centre geocell and the infill soil. Fig. 3 shows the deformation pattern of the geocell mat and centre geocell.

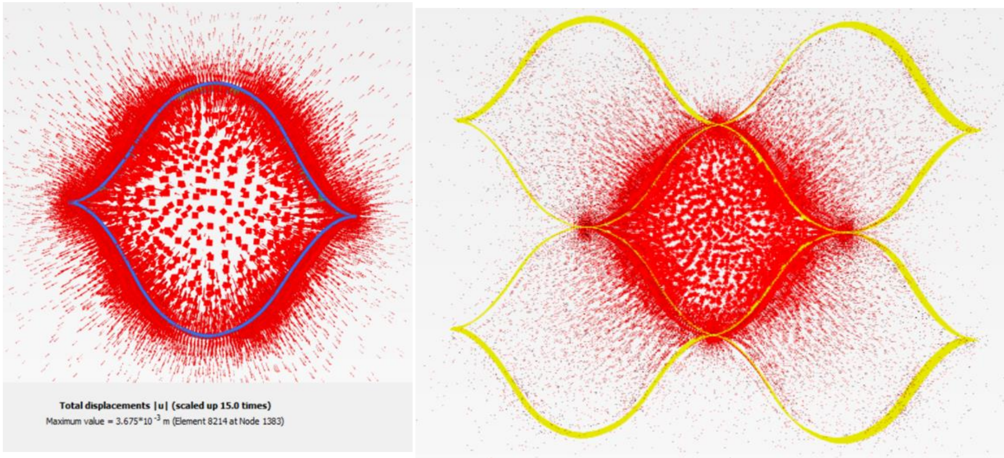


Fig. 3. Deformation pattern of geocell mat and centre geocell

Deformation pattern clearly indicates the radial displacement of geocell wall under the application of loading. The deformation of geocell on the application of loading of 10 kPa and 150 kPa are shown in Fig. 4.

From the deformation pattern, it can be observed that higher deformation is at the cell wall of the centre geocell as it is loaded above the centre geocell. Deformation increases as loading increased from 0 to 150 kPa. Figure 5 shows the variation of settlement as the loading increases from 0 to 150 kPa. As can be seen from the graphs, the present numerical model is able to predict the experimental behavior of geocell reinforced soil.

Active earth pressure is developed from within the loaded cell. From the adjacent cells, passive earth pressure will be developed. Under the application of loading, hoop tension will be mobilized in the geocell wall. Hoop tension developed in the geocell under circular loading is shown in Fig. 6.

Hoop tension is found to be increasing with the increase in loading. Value of hoop tension varied up to 1.2 kN/m under different stages of loading. Maximum hoop tension is developed within the loaded cell compared to the other cells. Variation of hoop tensile strain developed in geocell wall at different stages of loading as obtained from the experimental results and the present numerical study are plotted in Fig. 7.

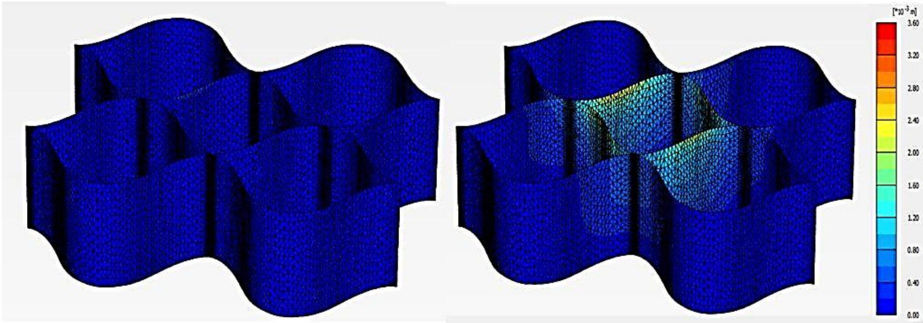


Fig. 4. Deformation of geocell at 10kPa and 150 kPa

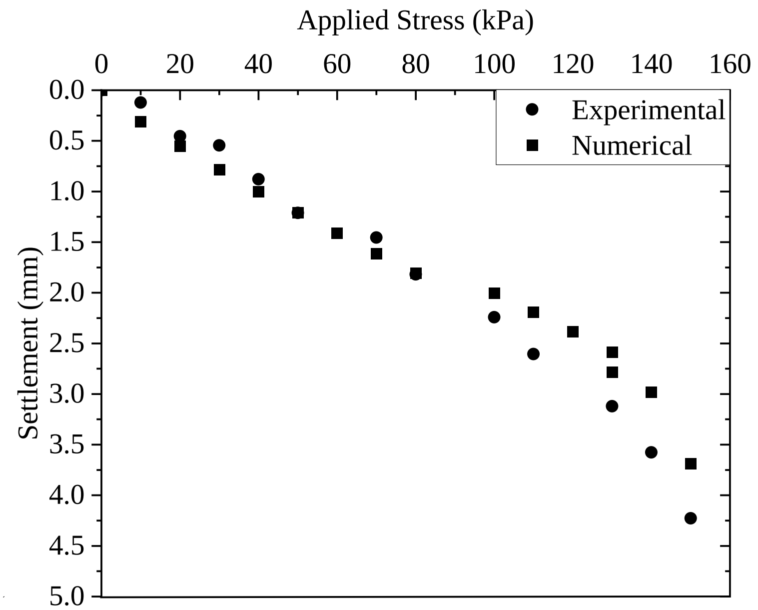


Fig. 5. Applied stress-settlement variation of geocell reinforced foundation

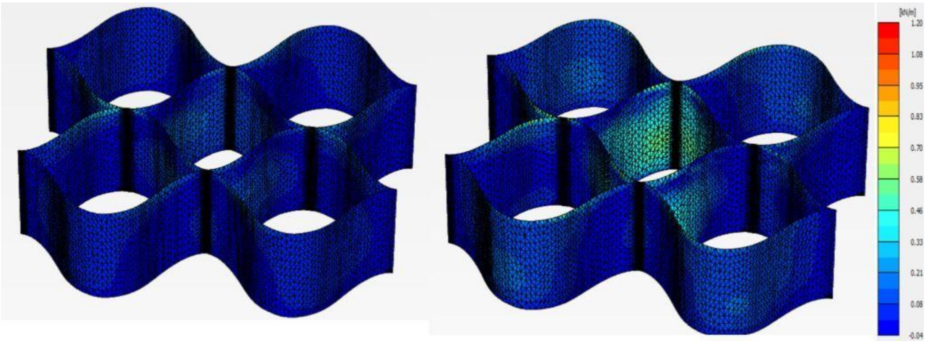


Fig. 6. Hoop tension variation in geocell mat loaded above central cell

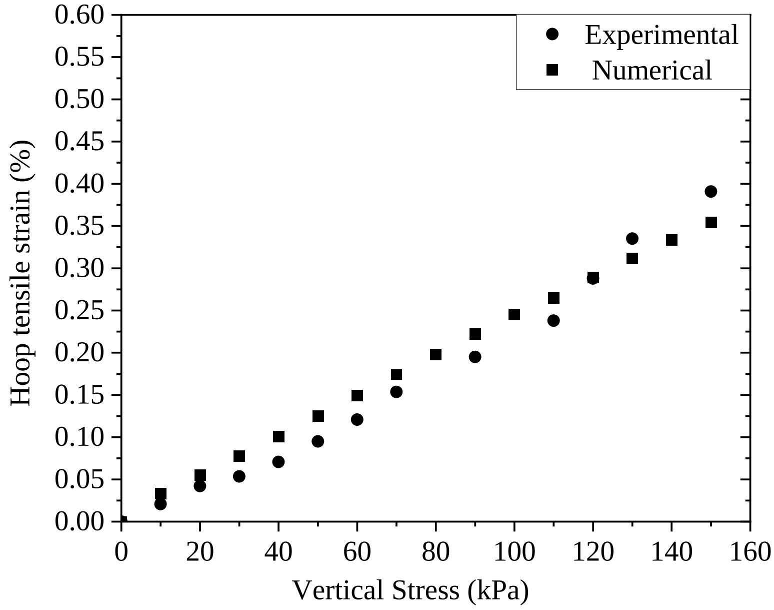


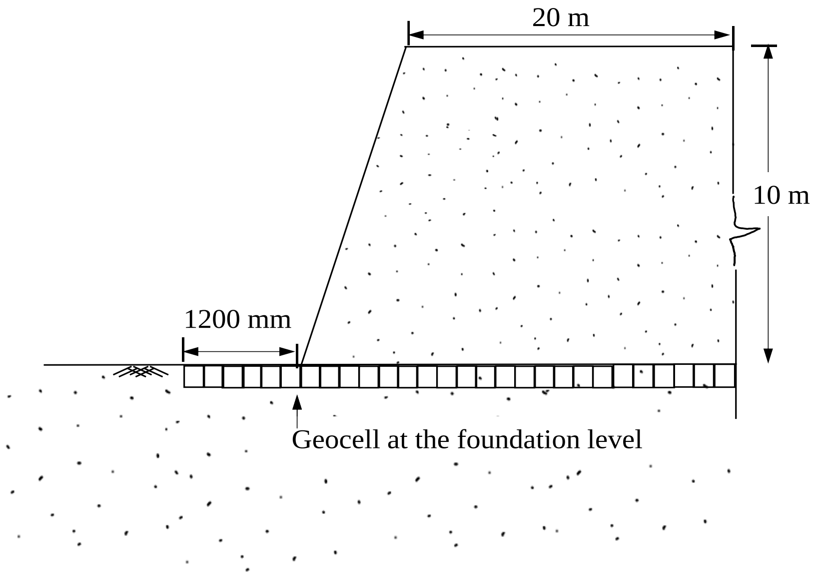
Fig. 7. Applied vertical stress versus hoop tensile strain curve

Present numerical results are in good agreement with the experimental data. Thus, it can be concluded that the geocell modelled in the present study is able to simulate the field behavior. Thus, the same geocell model was used for further modelling studies presented here.

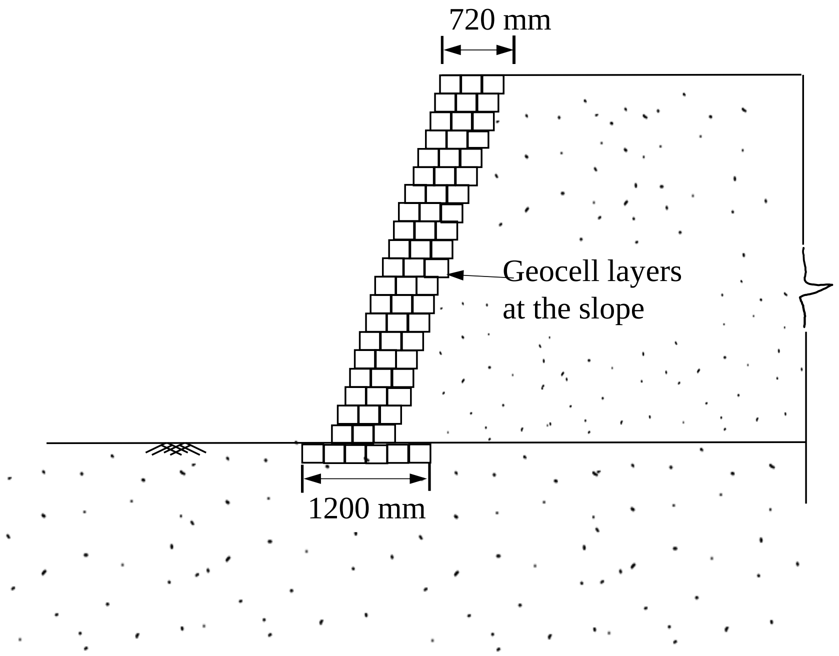
4 Stabilization of the slope using geocells

Soft clay foundations can cause excessive settlement problems, bearing capacity issues etc. As the foundation is weak soil layer, it can be reinforced with a geocell mat at the base. Three different configurations were modelled in the present study. In first configuration, geocell mat was laid at the foundation clay layer as basal reinforcement as shown in Fig. 8a. This configuration with geocell layer provided only at the foundation level is labelled herein as GCF. In second configuration, the slope was constructed with facing layers of geocell mat of 720 mm width as shown in Fig. 8b. The geocell layers can help in effectively confine the soil infilled and act like a facia system to protect the steep slope. This configuration with geocell mat provided only at the slope was labelled herein as GCS. In third configuration, geocell mat was provided both at the foundation and slope. This configuration with layers of geocell mat provided as shown in Fig. 8c was labelled herein as GCFS. Here, four geocell layers at 2.5 m intervals were extended in to the slope beyond the facing system as marked in Fig. 8c.

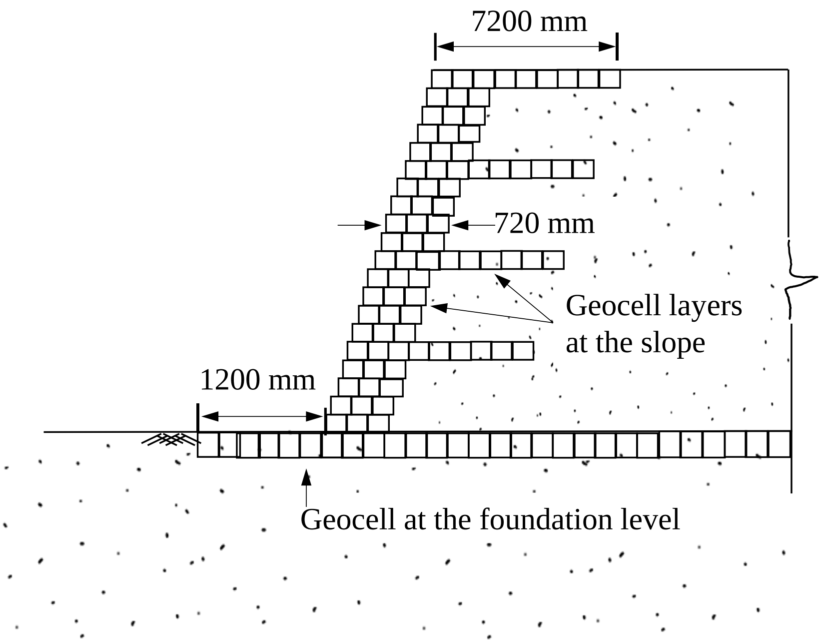
The geocell mat used for reinforcing the foundation is shown in Fig. 9a. From the base layer, 300 mm thick clay layer was replaced with geocell layer infilled with poorly graded sand as shown in Fig. 9b. Properties used for modelling poorly graded sand were considered to be same as that of validation study presented in section 3. The slope was constructed in four stages of 2.5m height increment with alternate construction and consolidation stages, though in actual scenario, consolidation can also occur simultaneously during construction. The excess pore water pressure generated during undrained construction phase starts dissipating during subsequent consolidation phase. The slope was constructed in 108 days. Safety analysis indicated that the slope is not stable with a factor of safety less than 1, indicating the need for stabilization of embankment slope. Further, the slope configuration with geocell layers only at the slope (GCS) was also not stable with a factor of safety value less than 1. Figure 10 shows the comparison of factor of safety value for various configurations. Unreinforced slope (UR), GCF and GCS was not found to be stable with factor of safety value less than 1 (0.76,0.9 and 0.99 respectively).



a. Geocell layer provided at the foundation level (GCF)

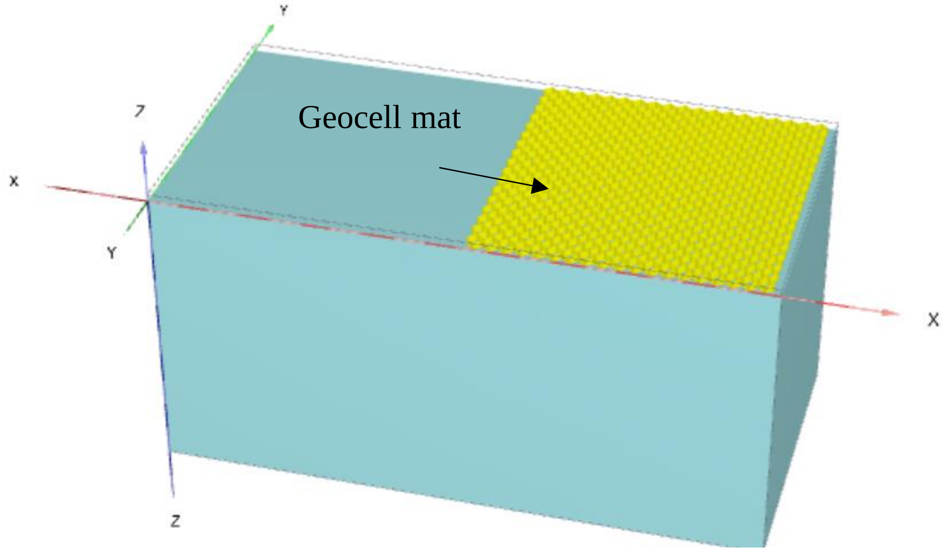


b. Geocell layers provided at the slope (GCS)

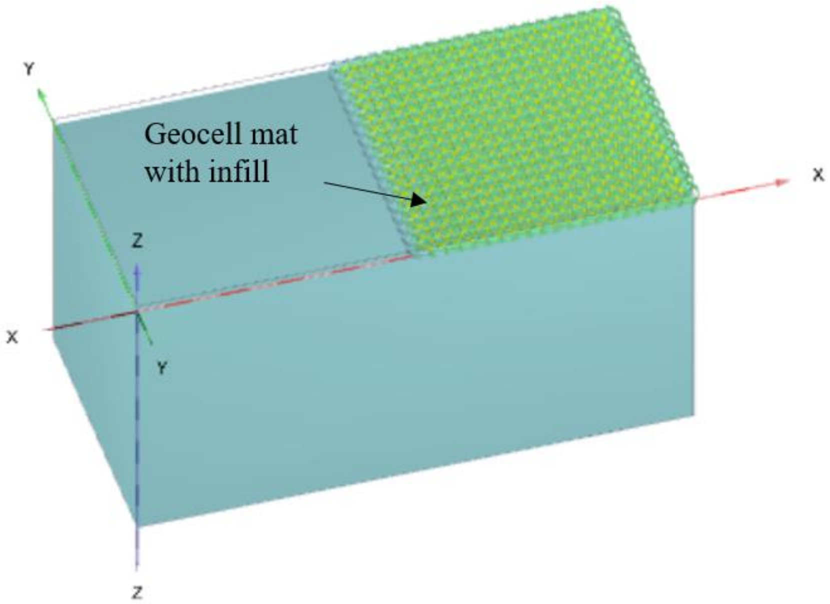


c. Geocell layers provided both at the foundation and at the slope (GCFS)

Fig. 8. Schematic configurations of geocell reinforced slope considered in the present study



a. Geocell mat placed at the foundation level



b. Geocell mat infilled with poorly graded sand

Fig. 9. Geocell mat provided at the base with infill

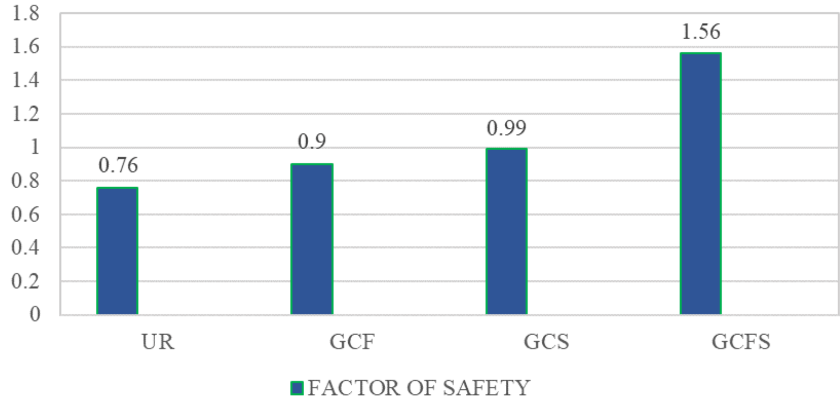


Fig. 10. Variation of factor of safety for different configurations of the slope

The slope was found to be stable with a factor of safety of 1.56, when geocell was provided both as foundation reinforcement as well as along the slope (GCFS) owing to the site conditions, slope geometry and soil properties. The geocell layer provided at the foundation or base of the embankment can provide a working-platform for constructing the embankment, in addition to the benefits of increased bearing capacity and resistance to lateral deformation and differential settlements. The geocell layers of 720 mm width along the slope help in confining the soil infilled and act like an effective facia system preventing the erosion, raveling or sloughing of the steep slope. In addition, the geocell layers of 7200 mm in length extended in to the slope act like internal reinforcements, providing increased resistance to slope shear failure.

5 Conclusions

Present study indicates the efficacy of geocell in the stabilization of a lateritic steep slope resting on a clay foundation. Numerical modelling was conducted using a commercially available software PLAXIS 3D. An attempt of modelling of the curvilinear geometry of geocells was done. Validation study indicated that the geocell model is able to capture the experimental behavior. The settlement behavior and hoop tension developed in the geocell was found to match with the experimental data. Unreinforced slope (UR) was not found to be stable with factor of safety value less than 1. As the foundation is soft soil, geocell reinforcement was provided at the foundation (GCF). GCF is having a factor of safety of 0.9 which is unsafe indicating the need for stabilization of steep embankment slope. The slope was also unstable with a factor of safety of 0.99 when geocell layers were provided only at the slope without foundation reinforcements. The slope was found to be stable when geocell was provided both as foundation reinforcement as well as along the slope (GCFS) owing to the site conditions, slope geometry and soil properties.

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