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Application of Geosynthetics For Geotechnical Challenges

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Abstract. Construction over soft soil has always been a challenge for geotechnical engineers. Soft soils are characterized by low shear strength, high compressibility and low bearing capacity. Such factors make construction of embankment on these soils challenging. If not addressed correctly, soft subsoil can pose serious problems. In this paper, a project site at Kochi Refinery (Kerala) considered, the existing subsoil stratum at the site location was incompetent to satisfy the bearing pressure requirement for the operations of the cranes which were planned for the erection of heavy columns/components. This paper provides the overview of the bearing capacity of the soil at the location of the project site and also to improve the bearing capacity of the soil stratum at proposed site by adopting suitable ground improvement techniques. Technical aspects of the past research studies in this area of ground improvement are highlighted. Finite element analysis software Plaxis 3D was performed to validate the bearing capacity and settlements of stratified soil deposit and reinforced soil stratum. The results from numerical studies are presented and discussed in detail.

Keywords: Bearing capacity, Settlement, hardstand, cellular mattress, geogrid

1 Introduction

Construction over soft soil has always been a challenge for geotechnical engineers. The low shear strength, high compressibility and low bearing potential characterize soft soils and these factors makes the embankment construction difficult on those soils. Weak subsoil may pose serious problems if not treated correctly. The nature of the soil was lateritic and was observed to be incapable to satisfy with the bearing pressure requirement for operations of the cranes which will be employed for the erection of heavy columns. Hence, there was a need to build a heavy-duty working platform or a hardstand area for the purpose to be solved.

Hardstand area is a paved area or place where machinery and equipment are stationed to work for the project which is being executed. The paving is usually designed to be thicker and more durable to support the weight of heavy vehicles such as large cranes or heavy trucks. To obtain the required hardstand area, a suitable ground improvement technique must be adopted as a solution for improving the bearing capacity and controlling the settlements at that particular location.

Depending upon the sub soil strata and bearing capacity requirement ground improvement using cellular mattress and Mechanically Stabilized Layers are incorporated at different locations as optimal foundation solution. Geogrids used in stabilization of soil layers known as Mechanically Stabilized Layers and geocell mattress is proposed as solution for stiffening granular layers to increase load distribution, control total settlements and minimize differential settlements over low strength and variable foundation soils.

Ong, Richard et al.,2011[1] discussed the use of geocell mattress with mechanically stabilized layer (MSL) for the construction of a heavy-duty working platform for an offshore facilities fabrication yard over the soft soil. The geocell mattress with thickness of 1 m was constructed using stiff geogrids to form honeycomb structure and filled with aggregates. Subsequently, the MSL with thickness of 2 m was constructed on top of the geocell mattress to form a stiff and stable working platform by maximizing the pressure distribution of applied loading onto the soft foundation soils effectively. This paper also discussed on design and construction of the geocell mattress combined with mechanical stabilized layers and presented the results from a large-scale plate bearing test conducted to verify the performance of the foundation system constructed. The result from the plate bearing test showed minimal settlement when the maximum load applied was 60 t/m². This indicates the geocell mattress with MSL had been constructed successfully to meet its design requirements.

Dobie et al., 2019 [2] proposed guidelines for the design, construction, operation and maintenance of working platforms and these are very important for many projects to support cranes or piling rigs. Finite element analysis was performed to check the mechanical behavior of working platforms. The results from parametric analysis were validated by full scale testing subjected to bearing capacity failure. From the results it is observed that there is significant increase in bearing capacity with the inclusion of geogrid resulting in stabilization of the granular material. Ooi,TA et al., 2013 [3] discussed on the use of different types of geogrid applications in soft ground in Malaysia.

Rakowski and Kawalec, 2009 [4] discussed on mechanical stabilization of granular material provided by geogrid. By including one or more layers of geogrid in a granular layer, a composite material with better properties and performance are created and this is often described as Mechanically Stabilized Layer (MSL). Fig. 1 shows the interlocking mechanism, which restrains the movement of aggregate particles within the geogrid aperture, is identified as the lateral confinement effect that can be mobilized from a stiff geogrid. Through the interlocking mechanism and lateral confinement, the aggregate layer can be stabilized without excessive deformation of the surface.

Fig. 1. Interlocking mechanism of stiff geogrid providing lateral confinement.

The cellular foundation mattress is open top, continuous and honeycombed structure formed from a series of interlocking cells (BSI,2010) [5]. The use of cellular foundation mattress or stratum was proposed as it maximizes pressure distribution of applied load onto the low bearing capacity of the soft foundation soils. It also forms a firm, stiff, stable working platform enabling safe construction plant travels and enables faster construction as compared to RC foundation construction.

Latha GM, 2011[6] presented the methods of design available for geocell-supported embankments. Two of the earlier methods are considered in this paper and a third method is proposed and compared with earlier methods. In the first method called slip line method, plastic bearing failure of the soil was assumed and the additional resistance due to geocell layer is calculated using a non-symmetric slip line field in the soft foundation soil. In the second method based on slope stability analysis, general-purpose slope stability program was used to design the geocell mattress of required strength for embankment. In the third method, geocell reinforcement is designed based on the plane strain finite element analysis of embankments. The geocell layer is modelled as an equivalent composite layer with modified strength and stiffness values. The strength and dimensions of geocell layer is estimated for the required bearing capacity or permissible deformations. These three design methods are compared through a design example. It is observed that the design method based on finite element simulations is most comprehensive because it addresses the issue of permissible deformations and also gives complete stress, deformation and strain behavior of the embankment under given loading condition.

Majority of the researchers have successfully predicted the ultimate bearing capacity of shallow footing resting on horizontal surface of ground (Terzaghi and Peck, 1948 [7], Meyerhof, 1953[8], Hansen, 1970[9] and Vesic, 1975[10] and the predictions are based on the laboratory investigation of undisturbed and disturbed soil samples. In the present study, conventional methods have been used to determine the bearing capacity of a stratified soil deposit. Ground improvement scheme was proposed to enhance the bearing capacity of the soil, limit post construction long term settlements to tolerable limits for the given loading conditions of the proposed foundation and is validated through the numerical studies.

2 Materials and Methods

Field tests were conducted to find the properties of soil stratum at the location of project site. Table 1 shows the properties of stratified soil deposit considered for the present study. SBC of the existing stratified deposit of soil was calculated by considering the weighted average of shear strength parameters up to the influence zone of the footing (5 m) respectively. The angle of internal friction of the soil deposit is 0º and cohesion of the soil as 24 kPa. The ultimate bearing capacity of the original soil stratum as per IS code 6403-1981 was calculated as 165.62 kPa and this is the optimum value of bearing capacity compare to the bearing capacity calculated using other conventional methods (Bowles LE, 1996) [11].

Table 1. Properties of stratified soil deposit

Soil Description	Thickness of the layer (m)	C (kPa)	ϕ (deg)	ϒ (kN/m^3)	Observed standard penetration number
Clayey soil	0-4	12	0	15	4
Clayey silt	4 - 8.5	36	0	15	8
Sandy soil	8.5 - 10.7	0	34	18	50

3 Finite Element Analysis

3D Finite Element Analysis was performed instead of 2D analysis due to the rectangular shape of the loaded area considered. Separate models were developed for the layered deposit of original soil stratum and proposed reinforced soil stratum but were identical in all respects apart from the geometry of the MSL, cellular mattress and geometry of loaded area. Based on the available data, the footing area of size 13.5 m × 5.5 m ×10.7 m was considered for the analysis and crane contact area at the location is 13.5 m × 5.5 m and the depth of soil profile is 10.7 m. Trials were carried out to select suitable ground improvement scheme to be adopted for the proposed project to meet the requirements and to satisfy the permissible settlements. Ground improvement scheme adopted for the particular area consists of three layers of MSL using three layers of triaxial geogrids underlain by 0.65 m thick cellular mattress respectively. The MSL was compacted in equal lifts of three, each of thickness 300 mm and above that a concrete layer of 0.2 m thickness was provided. The water table was located at 0.2 m below the ground level. The geometry of original soil stratum and reinforced soil stratum models are shown in Fig. 2 and Fig. 3 respectively.

The FEA mesh is shown for original soil stratum and Reinforced soil stratum in Fig. 4 and Fig. 5 respectively. The medium mesh factor was selected with a mesh factor of 1.0. In both cases the symmetry of the problem was used to model one quarter of the loaded area and geometry with two of the vertical mesh boundaries forming planes of symmetry along the centerlines of the loaded areas. The loading was applied to the rectangular area of 2.75 m × 6.75 m which is quarter of the overall area. The fixed base of the mesh was placed at 10.7 m below ground level coincide with the bedrock at the proposed location of the hard stand area. Clayey soil (coloured red) shown in Fig.5b was adopted to 4 m depth overlying clayey silt (coloured yellow) to 8.5 m depth overlying dense sandy soil (coloured brown) to 10.7 m depth where hard stratum was encountered. To get reinforced soil stratum, the natural ground was assumed to be excavated to 1.65 m and replaced with geo cellular mattress and MSL respectively. The Layout of reinforced soil stratum of thickness 1.65 m includes MSL, geogrid and cellular mattress adopted as shown in Fig.5a. The reinforced soil stratum namely a 1.0 m thick MSL (coloured different shades of blue in

Fig.3) and three layers of Triaxial geogrid overlying 0.65 m thick stratum (coloured purple). Both the MSL and mattress were assumed to be composed of the granular fill material. The top layer was composed of reinforced cement concrete of thickness 0.2 m respectively.

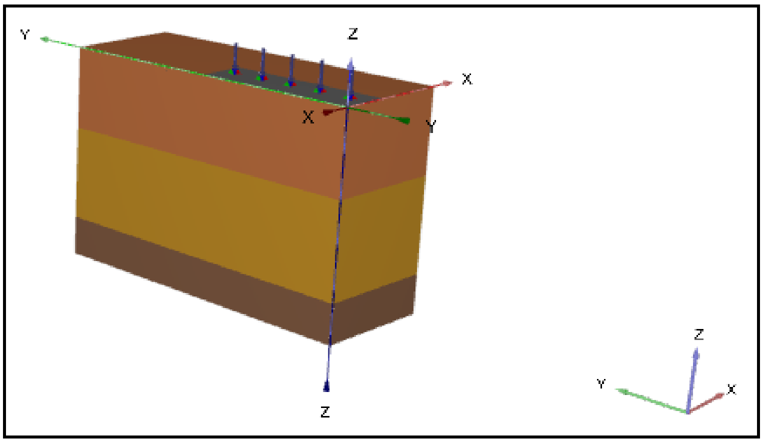

Fig. 2. Geometry Model of soil stratum

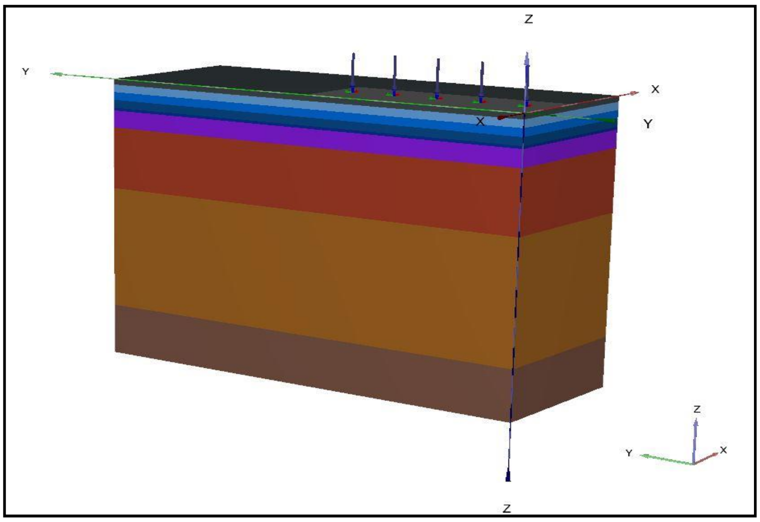

Fig. 3. Geometry Model of Reinforced soil stratum

The in-situ layers were modeled using linear elastic perfectly plastic Mohr-Coulomb model with the input parameters of soil stratum shown in Table 2. The reinforced concrete pavement surface was modelled as a linear elastic material and Table 3 shows the assumed properties of MSL, cellular mattress and reinforced cement concrete respectively. The required safe bearing pressure of area was assumed as 220 kN/m^2.

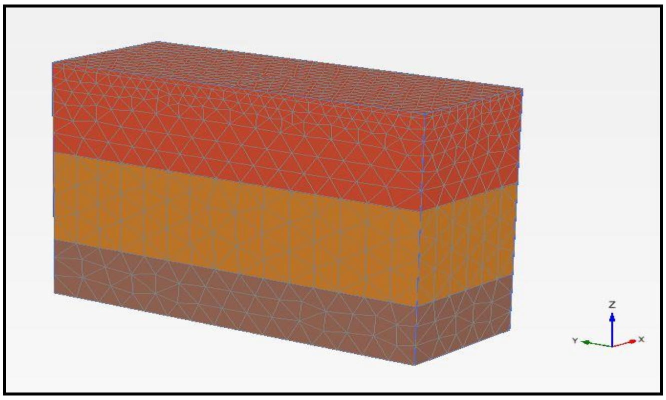

Fig. 4. FEA mesh of original soil stratum

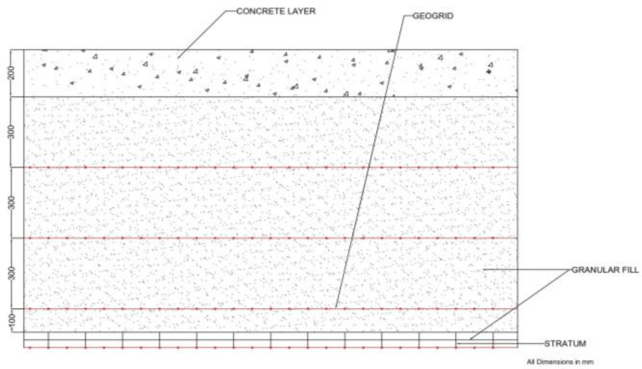

Fig. 5a. Layout of Reinforced soil stratum of thickness 1.65 m includes MSL, geogrid and cellular mattress.

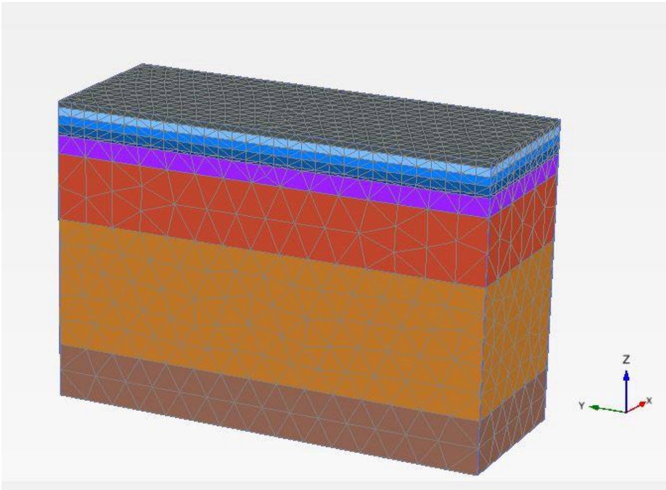

Fig. 5b. FEA mesh of Reinforced soil stratum

Table 2. Input Properties of soil used in the analysis

Property	Soft silt	Stiff silt	Dense sand
Drainage	Undrained	Undrained	Drained
Elasticity (MPa)	6	19	35
Poisson's Ratio	0.2	0.2	0.2
Angle of internal friction	0	0	34
Bulk unit weight (kN/m3)	17	17	19
Cohesion (kPa)	16	48	0.1

Table 3. Assumed Physical and Mechanical properties of MSL and cellular mattress

	MSL	Cellular mattress	Reinforced Cement Concrete
Elasticity (kN/m2)	50,000	80,000	3×107
Poisson's Ratio	0.2	0.2	0.15
Angle of internal friction	0	0	-
Unit weight (kN/m3)	17	17	24

Fig. 6 shows the total displacement of the modeled original soil stratum. The total displacement of soil stratum from Figure 6 is 3.46 m. Fig.7 shows the predicted displacements of reinforced soil stratum. The predicted total displacement of improved ground is observed to be 58.56 mm.

Fig. 8 shows the deformed mesh of the original soil stratum showing clearly the failure pattern of the ground. Fig. 9 shows the deformed mesh of the improved ground after subjecting to the surface load.

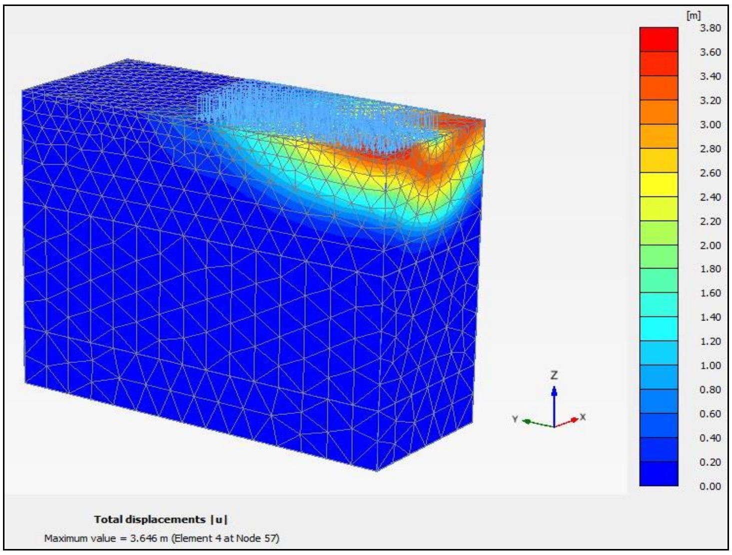

Fig. 6. Total displacements of original soil stratum.

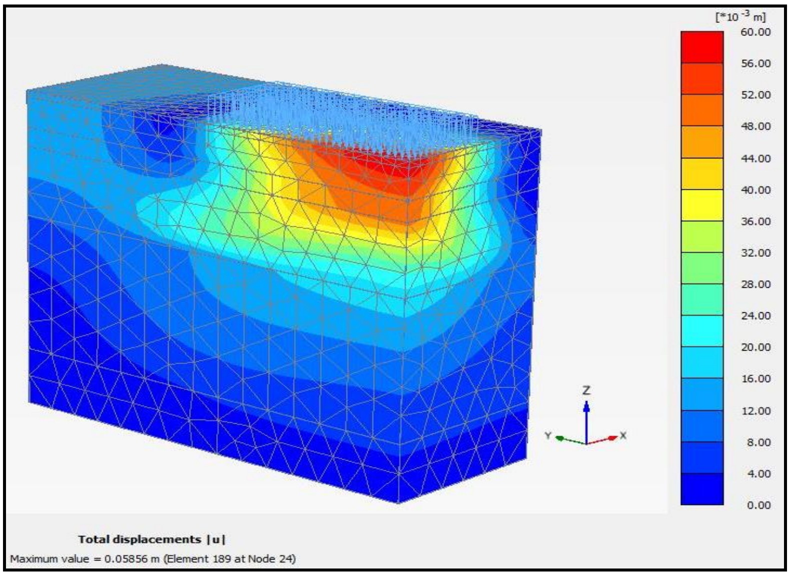

Fig. 7. Total predicted displacements of reinforced soil stratum.

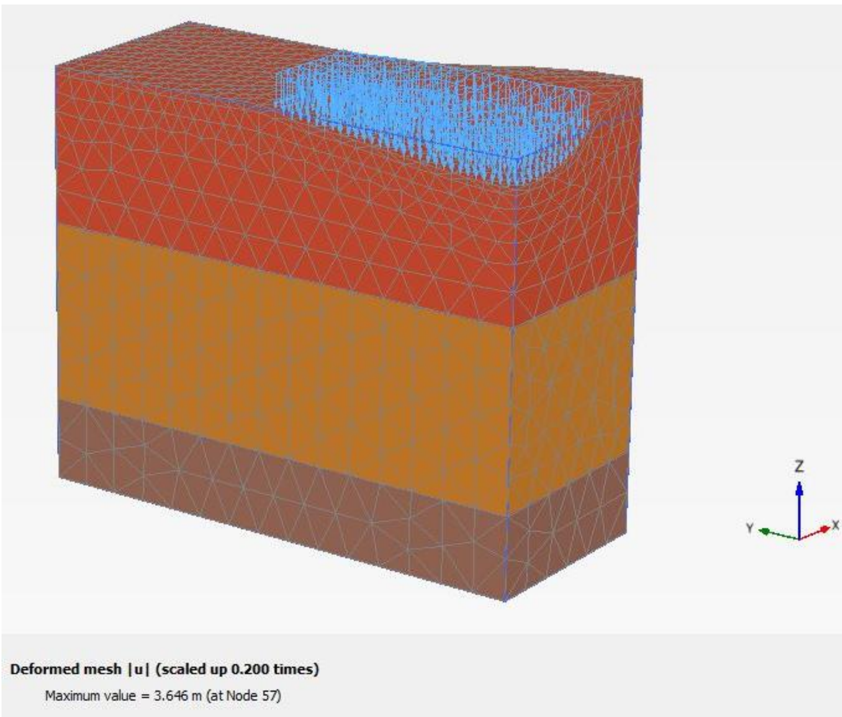

Fig. 8. Deformed mesh of Original soil stratum

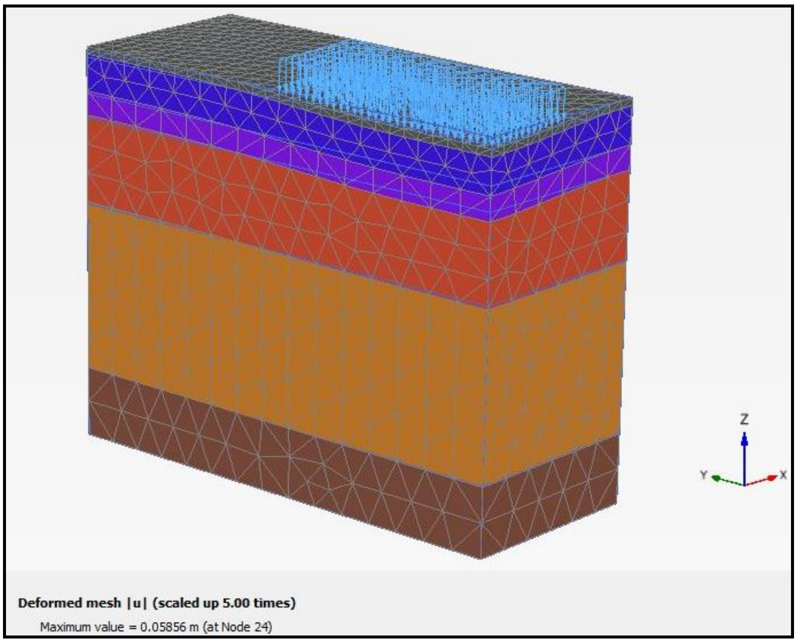

Fig. 9. Deformed mesh of reinforced soil stratum

4 Conclusions

The present study presented the numerical results of load tests on rectangular footing supported on geogrid mechanical stabilized layer overlying geo cellular mattress. Bearing capacity of natural soil stratum was calculated using conventional methods. Based on the findings from the present investigation, following conclusions are drawn

1. Provision of cellular mattress in the overlying granular fill improves the load carrying capacity and settlements are observed to be reduced substantially.
2. A maximum settlement of 58.56 mm was predicted in the area which is less than allowable settlement of 75 mm.
3. Therefore, the predicted settlement satisfies the specified settlement required in the present case.

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