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Numerical Modelling of Soil Improvement Using Geo-fabrics

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Abstract
A series of finite element (FE) simulations are carried out to evaluate the benefits of integrating a high modulus geo-fabric as reinforcement into the soil-layers in this paper. Finite element analysis can handle complex geometry, different boundary conditions and material properties with ease. In the present study a finite element program, PLAXIS, which has proved its efficacy in geotechnical application, is used. This paper presents a two dimensional plain strain finite element model that analysis of foundation in unreinforced and geo-fabric reinforced soil subjected to distributed load condition.
Keywords- Finite Element Method, Bearing capacity, Settlement, Reinforced layer, Contour curve, Deformed Mesh

I. INTRODUCTION

As part of a program of research into the behavior of reinforced soils, attention has been given to the important practical application of geo-grid reinforcement. The objective of this paper is to improve the bearing capacity of shallow foundations by the utilization of geo-fabric by numerical simulation.The another aim of this paper is also to have a region of placing of geo-fabrics in soil to get maximum bearing capacity**.**

II. ADVANTAGE OF USING PLAXIS

¬ Plaxis is a finite element program intended for practical analysis for geotechnical applications. The soil models created in Plaxis are used to simulate the soil behavior.

¬ Plaxis also gives the option to either apply a distributed load or a point load on the foundation to initiate the process of receiving a load vs. displacement curve.

¬ The cost of constructing and monitoring full-scale reinforced foundations on embankments soil is rather high. Hence, a suitable alternative, such as a numerical simulation by means of appropriate methods, must be sought.

III. GEO-SYNTHETICS AND IT'S USE IN PLAXIS

- Recently, geo-synthetics have been used extensively as reinforcements for improving the load-settlement characteristics of soft foundation soils. Their use has been proven to cost-effectively improve the bearing capacity and settlement performance of earth structure
- Studies have shown that geo-fabric reinforced foundations can increase the ultimate bearing capacity or/and reduce the settlement of shallow footings, compared to the conventional methods.
- Geo-fabric can provide tensile reinforcement through frictional interaction with base course materials, thereby reducing the applied vertical stresses on the sub-grade.
- Finite element method will remain the most practical and cost effective approach, due to the high cost associated with constructing and monitoring geo-fabric.
- The finite element parametric analysis performed as a part of this study in order to investigate the influence of various factors on the bearing capacity and the settlement of shallow Foundation.
- Objective was achieved by conducting numerical modelling programs of clay-foundation system in which course layer was reinforced with the geo-fabric layer. Suitable material model was implemented to simulate different material in the system

IV. GEOMETRIC MODEL

A geometry model is the 2D representation of the three-dimensional problem consists of points, lines and cluster. This model includes the representative division of the subsoil into distinct soil layers, structural objects, construction stages and loading. The foundation is modelled as a multilayer structure of linear elastic material subjected to distribute loading condition. Mohr-Coulomb material model was used to simulate granular sub-layers. After the creation of the geometry model, a finite element model can automatically be generated based on the composition of the cluster and lines in the geometry model.

Load Model

Now Plaxis also has the option to either add a point load or a **distributed load**. For the purpose of this project, we are using a distributed load, because it best represents a shallow foundation. The foundation is regarded as rigid, so applying load on the footing is equal to applying uniform vertical downward displacements at the nodes immediately underneath the foundation. Horizontal displacements at the interface between the foundation and the soil were restrained to zero assuming perfect roughness of the interface and symmetry of the foundation.

Material Models

Plaxis support various models to simulate the behaviour of soil and the other continua. **Mohr-coulomb model** is used to do the first approximation of soil behaviour in general. The model involves five parameters namely, Young's modulus E, poissons' ratio v, the cohesion c, friction angle, and the dilatancy angle.

Material type

Undrained behaviour is used for a full development of excess pore pressure flow of water can sometimes be neglected due to a low permeability. All the clusters that have been specified as undrained will indeed behave undrained.

Parameter	Name	Value	Unit
Material Model	Model	Mohr-coulomb	-
Type	Type	undrained	-
Soil unit weight above the phreatic level	γ_{unsat}	137.9	Lb/in^3
Soil unit weight below the phreatic level	γ_{sat}	119.1	Lb/in^3
Permeability in horizontal direction	kx	1.0	In/day
Permeability in vertical direction	ky	1.0	In/day
Young's modulus	E		Lb/in^3
Poisson's ratio	μ	0.3	-
Cohesion	c	4.075	Lb/in^3
Friction angle		0	o
Dilatancy angle		0	o

Effect of Reinforcement Layers

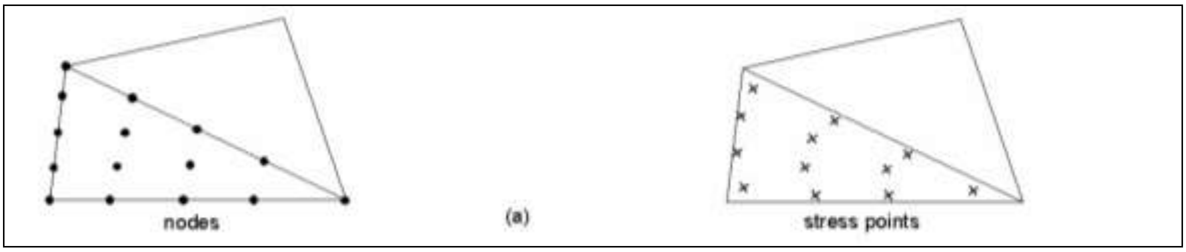
In these studies the geosynthetic reinforcement membrane is considered as an isotropic elastic material. Material models which include components of plasticity creep, and directional dependency of the high modulus geosynthetic polymeric geogrid may be more realistic, however, these models require many parameters for numerical simulation. Therefore in this study the geogrid is assumed to act as a linear isotropic elastic material. Geo-grids are the slender materials with the normal stiffness but no bending stiffness. It can only sustain tensile forces not the compression. The creation of the geo-grid in the geometry model is similar to create geo-grid lines in the soil model. Geo-grid is appeared as the yellow line. The only material property of the geo-grid is the elastic normal stiffness EA.

Table 2: Mechanical properties of geogrid reinforcement

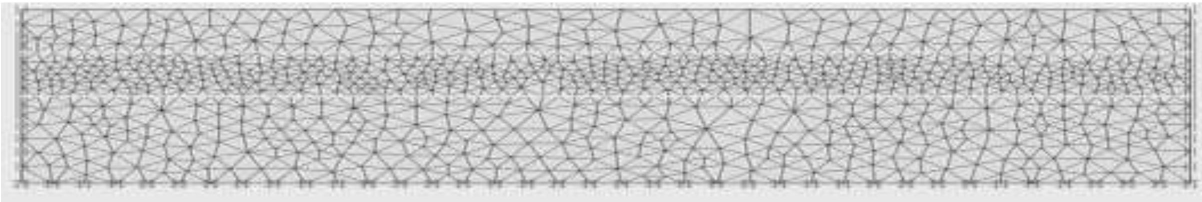
Material	Elastic axial stiffness(lb/in^3)	Passion ratio
Geo-grid	**145**	**0.3**

Mesh analysis

Plaxis **mesh generation** takes full account of the position of points and Lines in the geometry model so that exact position of layer load and Structures is accounted. During the generations of the mesh clusters are divided into triangular elements. The powerful 15 **node** element provides an accurate calculation of the stresses and the failure load. The distribution of nodes over the elements is shown in the fig 'a 'adjacent elements are connected through their common nodes. During the finite element calculations the displacements (*Ux* and *Uy*) are calculated at the nodes. The nodes may be pre-selected for the generation of the load-displacement curves. In contrast to displacements, stresses and strains are calculated at individual Gaussian integration points rather than at the nodes. A 15 node triangular element contains 12 **stress points** as indicated in the figure.



In our numerical simulation **the mesh generation** process is based on the robust triangulation principal that searches for optimized triangle, which results in unstructured mesh. The numerical performances of these meshes is however better than the structured meshes with regular array of elements. The figure of one these meshes have shown below.



(b)

Calculation process

In our calculation process we are using staged construction. In this special feature of the plaxis it is possible to change the geometry and the load configuration by activating or deactivating the load, volume cluster and the structural objects as created in the geometry input. Staged construction method enables accurate and realistic simulations of various loading, construction and the excavation process. Here we have done this analysis by the execution of the plastic calculation.

M-stage

This is the main load multiplier which is being used in our simulations. In general this load multiplier goes from zero to 1 where the staged construction process has been selected as the loading input. In some very special simulations it may be useful to perform only a part of the construction phase. If the value of this is lower than the smallest input 0.001 then the load is considered to be negligible and no calculation takes place. By entering the default value 1.0 the calculation process goes on in normal way. In general care must be taken with an ultimate level of this vale smaller than 1.0, since this results in out-of-balance force at the end of the calculation phase.

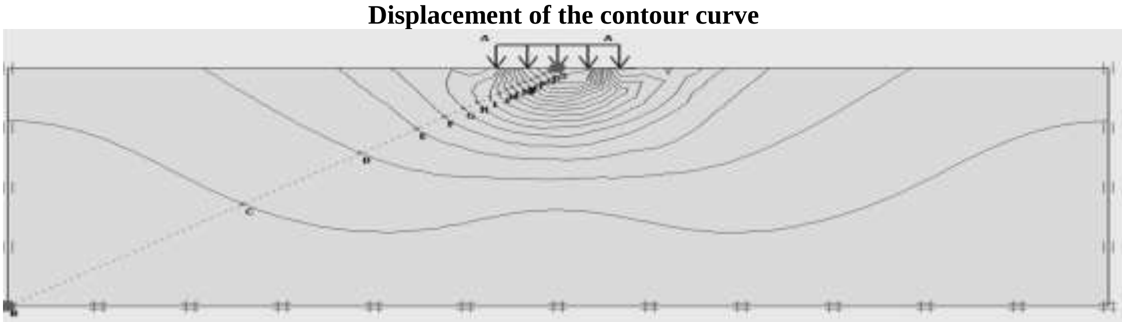
V. RESULT & CONCLUSION

A numerical simulation was performed with a soil layer of cross-section 3.5in* 12in

1. Without geo-grid:

Load (lb/in^3)	*Displacement (in)*
182.6	0.201
225.63	0.242
258.96	0.285
280.67	0.310
328.68	0.38

Displacement of the contour curve



We have calculated the bearing capacity by dividing the applied load by area of the foundation. We took the height of the foundation as 1 inch and the breadth is 1 inch by convention of the 2-D software. So in every case our

Area= (1*1) in^2.
Bearing Capacity= (Load/Area)
So the chart with the Bearing Capacity and the Displacement as follows

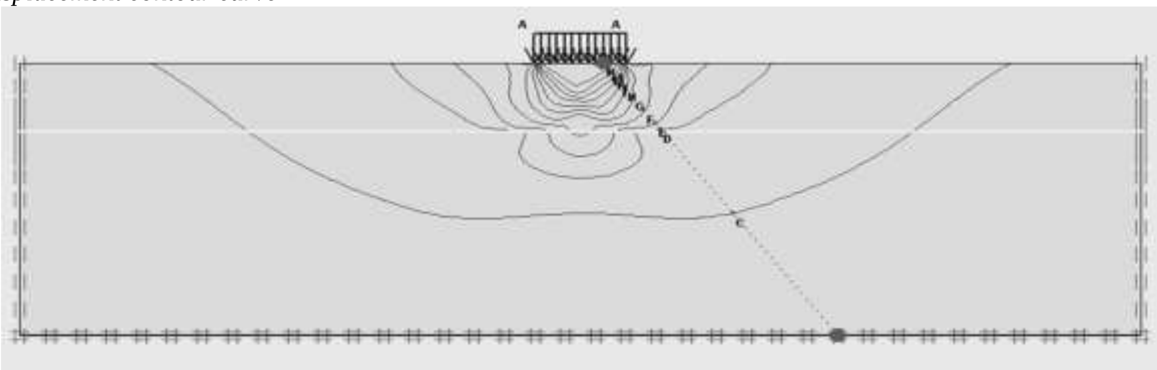
Displacement	Bearing capacity
0.201	182.6
0.278	219.12
0.380	328.68

2. The geogrid is at the 3rd layer i.e. at 0.875 inch from the top of the foundation

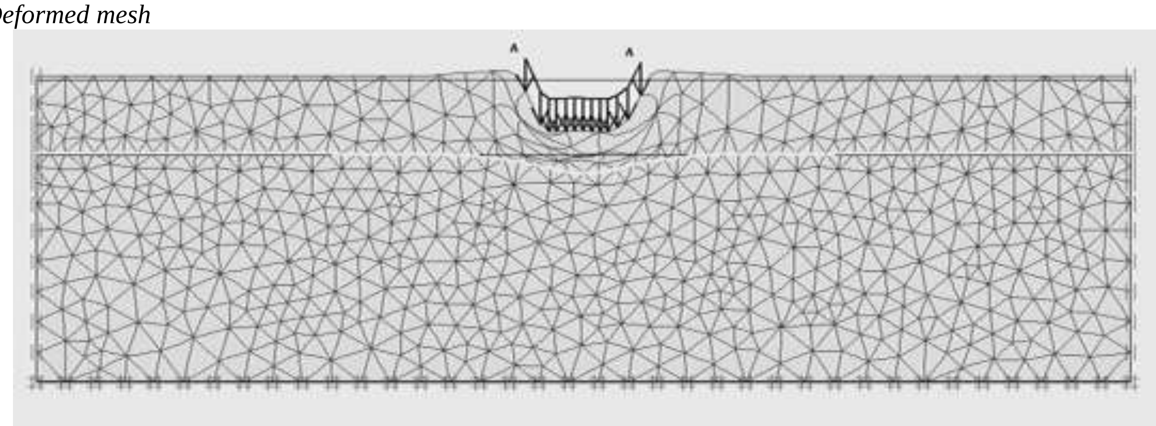
Load (lb/in^3)	*Displacement (in)*
160.5	0.11
219.08	0.148
268.25	0.182
288.52	0.198
328.68	0.238
350.20	0.259

We can find a major difference in the contour curve and the deformed mesh structure by applying two different aggregate**.**

A) Very fine aggregate is applied
Displacement contour curve

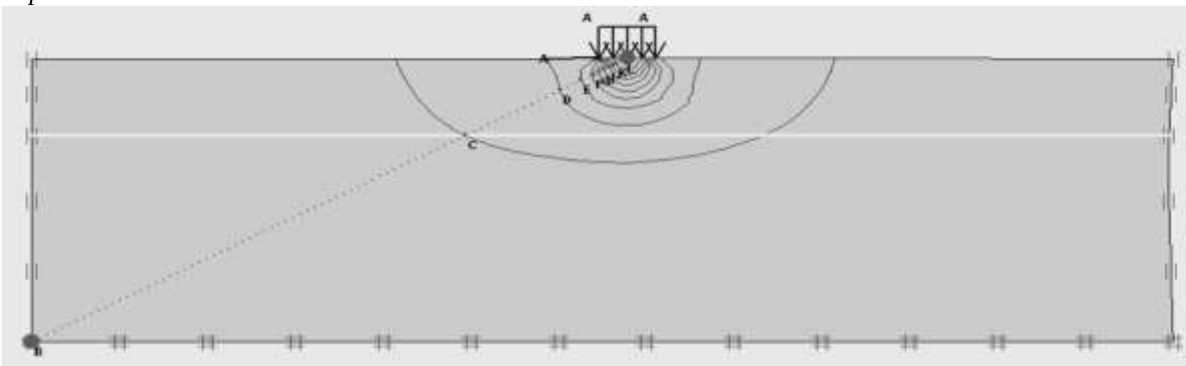


Deformed mesh

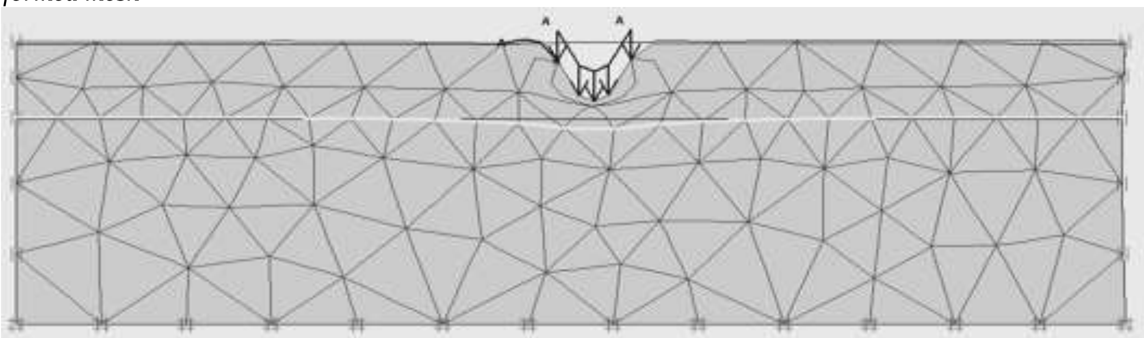


B) Coarse aggregate is applied

Displacement contour curve



Deformed mesh

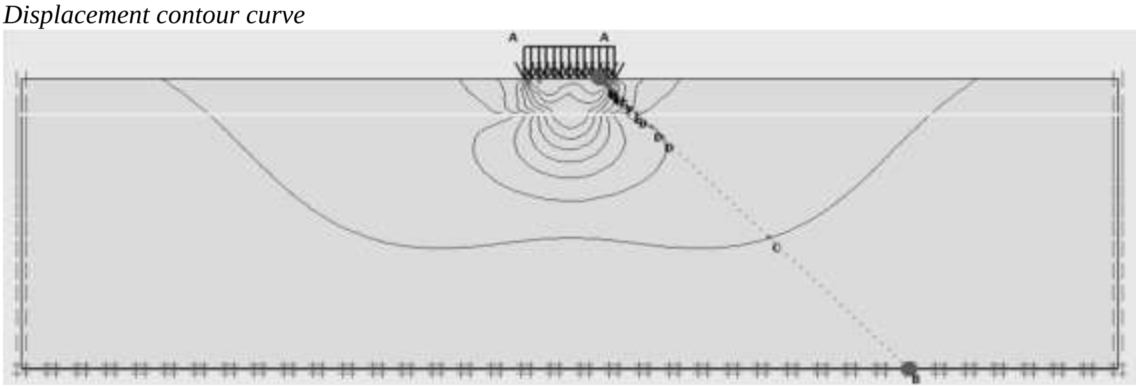


Now all the simulations have done with the very fine aggregate

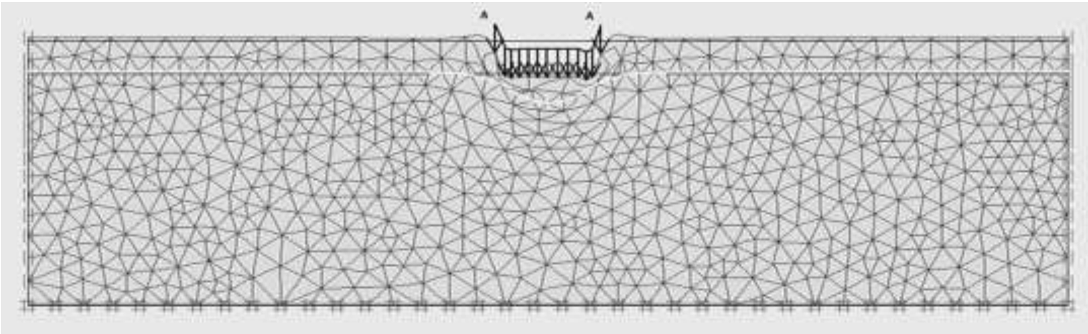
3. The geo-grid is at 3.5th layer i.e. at 0.4375 inch from the top of the foundation

Load (lb/in^3)	***Displacement (in)***
140.72	0.098
219.12	0.140
275.23	0.178
295.65	0.191
335.85	0.228
355.62	0.246
380.52	0.278

Displacement contour curve



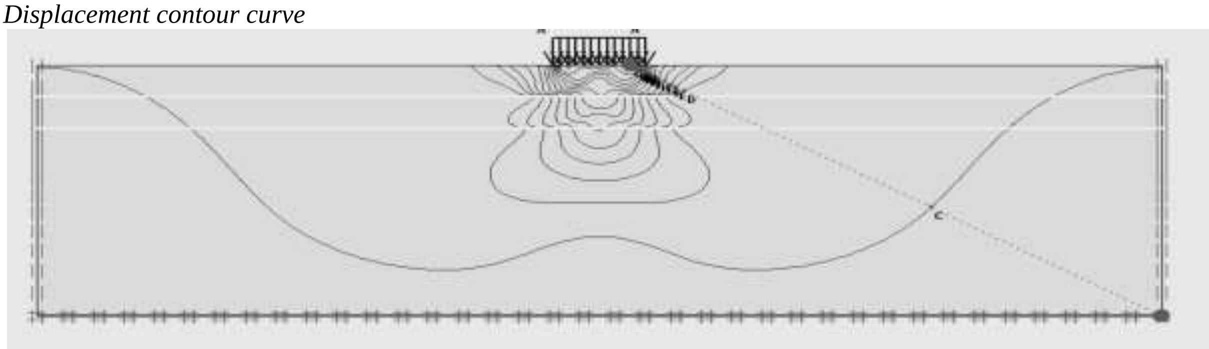
Deformed mesh



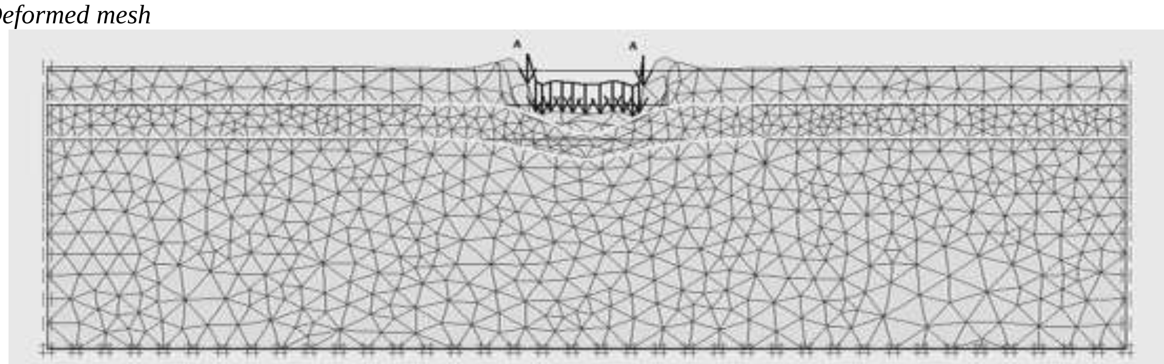
4. One geo-grid is at 0.875 inch and another one is at 0.4375 inch from the top of the foundation

Load (lb/in^3)	**Displacement (in)**
148.52	0.101
221.32	0.136
295.21	0.185
350.45	0.23
380.76	0.255
401.72	0.278

Displacement contour curve



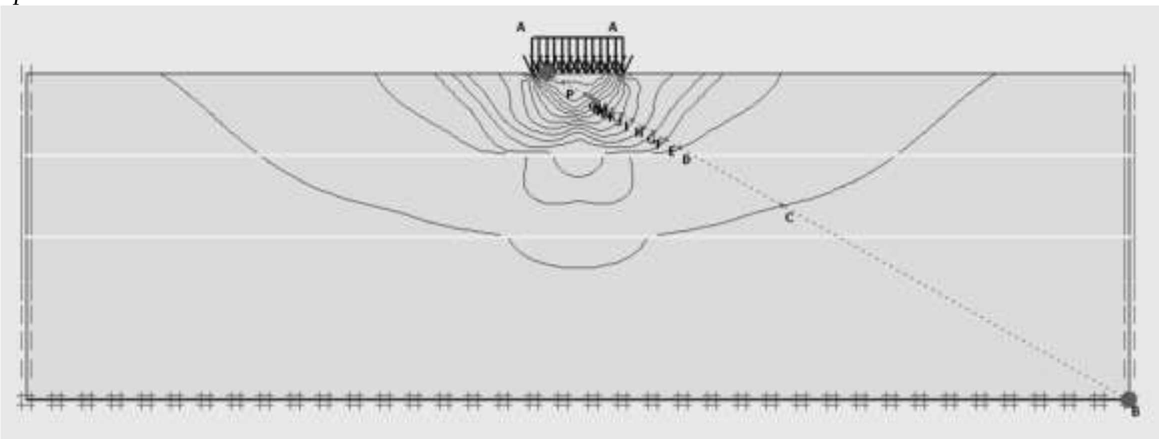
Deformed mesh



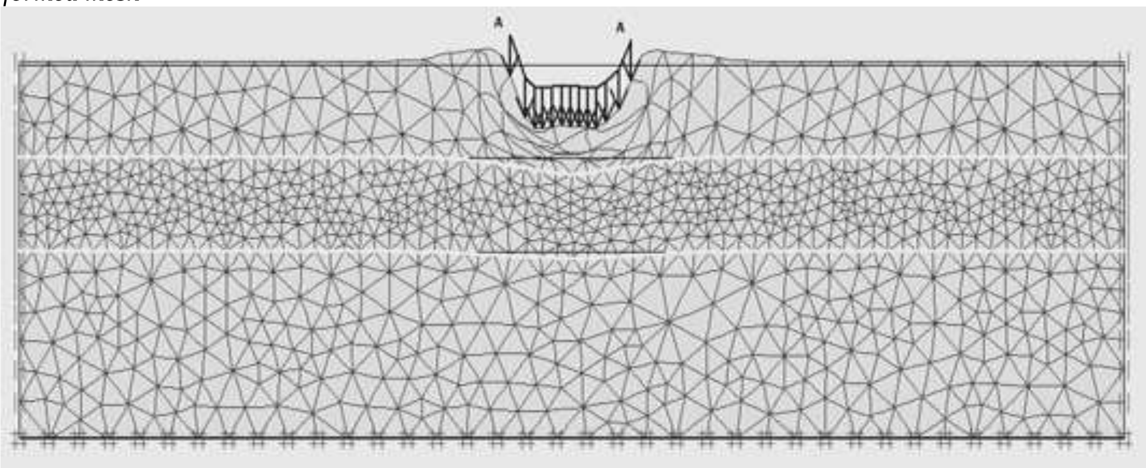
5. One geo-grid is at 2nd another one is at 3rd layer i.e. at 1.75 in and 0.875 in respectively from the top of the foundation

Load (lb/in^3)	**Displacement (in)**
130.95	0.095
219.12	0.135
268.57	0.170
289.63	0.185
339.62	0.23
365.20	0.258
390.23	0.285

Displacement contour curve



Deformed mesh

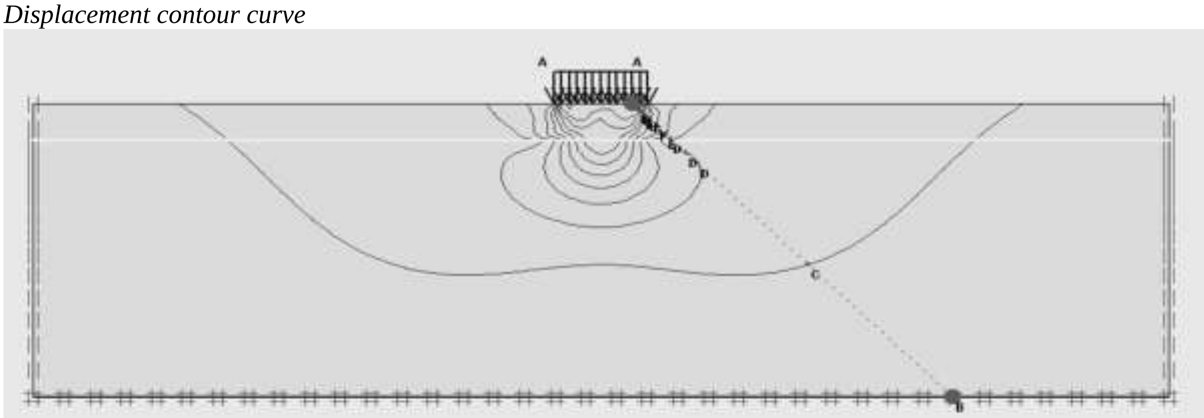


6. Two geo-grid is at 3.5th layer of soil i.e. at 0.4375 inch from the top

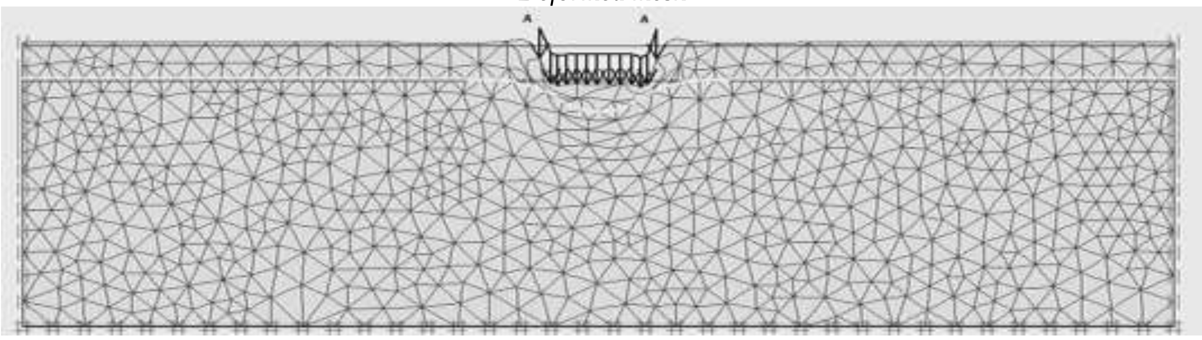
We have got the best result i.e. highest bearing capacity and the lowest displacement in this case.

Load (lb/in^3)	Displacement (in)
120.52	0.085
224.52	0.130
312.85	0.18
360.48	0.221
390.25	0.244
419.98	0.278

Displacement contour curve



Deformed mesh



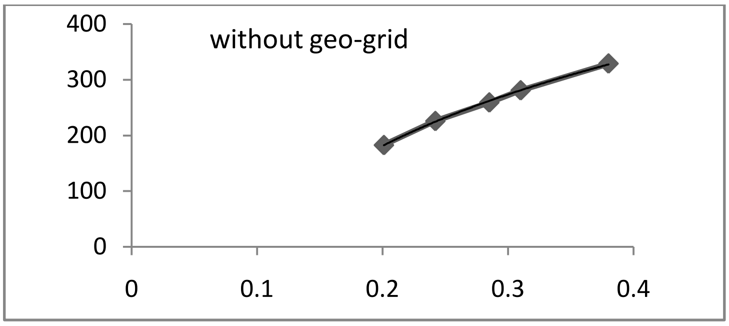
Comparing the above results we can have the highest bearing capacity in every respective case. In numerical simulation we can have a competitive study of bearing capacity with respect to the displacement in these cases.

Position of the geo-grid (inch)	**Bearing capacity (lb/in^3)**
At 0.875	364.68
At 0.4375	380.52
Two layer at 0.4375	419.98
Two layer at 0.875 and 0.4375	401.72
Two layer at 1.75 and at 0.875	380.23

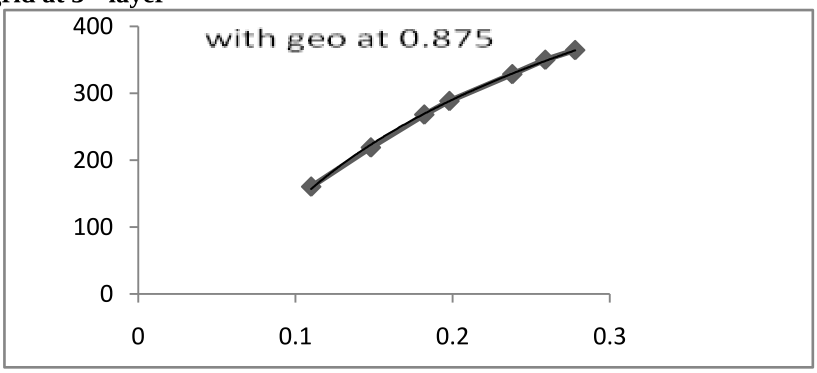
Curves

Competitive study on the various load vs. displacement curves in each and every case have shown below

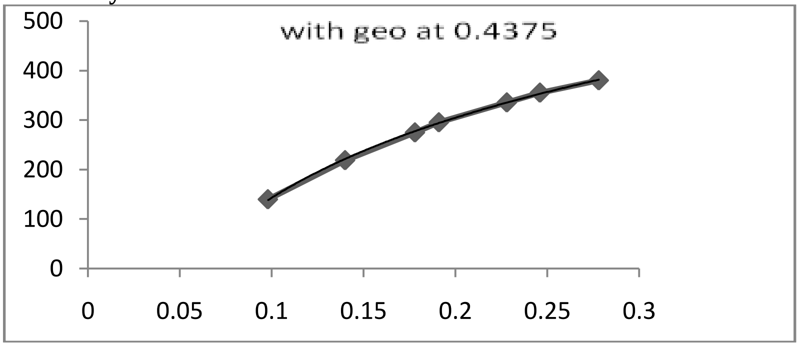
1. **Without geogrid**



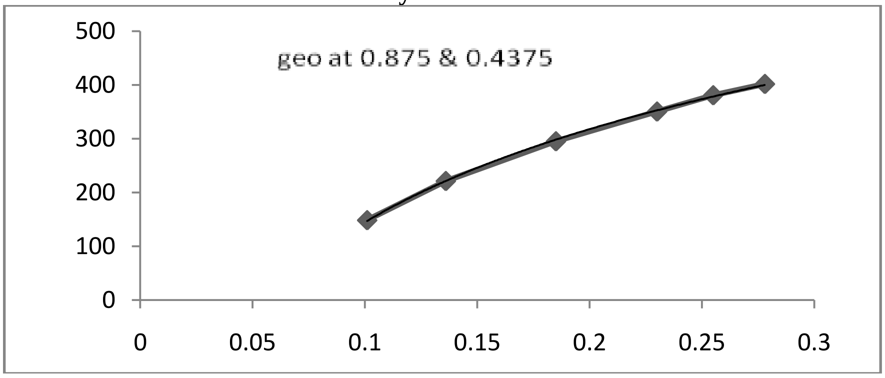
2. **With geogrid at 3rd layer**



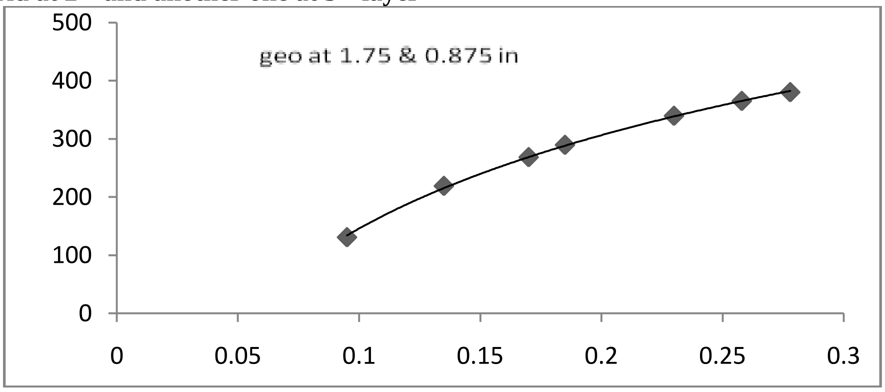
3. With geogrid at 3.5th layer



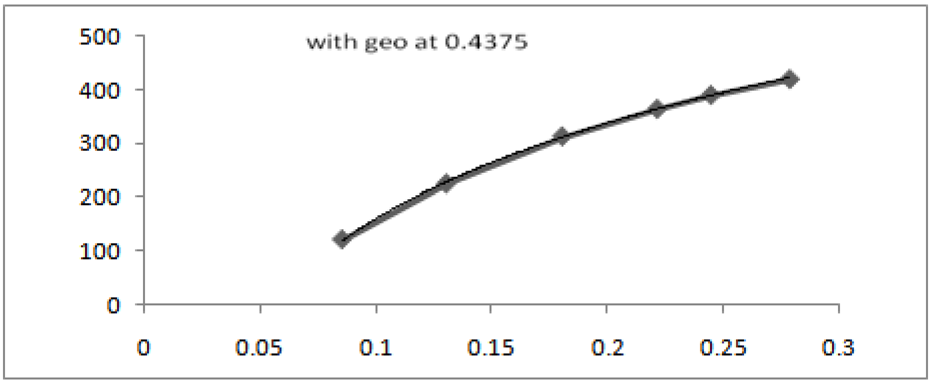
4. One geogrid at 3rd and another one at 3.5th layer



5. One geogrid at 2nd and another one at 3rd layer



6. Two layer of geogrid at 3.5th layer



VI. CONCLUSION

- Geo-fabric increased the radius of influence of the foundation so the load is distributed over a larger area into the bottom layers.
- The settlement reached around 10% of the original depth which determined the failure for the foundation
- The settlement increased exponentially with the increase of the load
- When two geo-fabrics were placed at 1.75 inches and 0.88 inches, the bearing capacity was significantly lower than in the case of placing two geo-fabrics together at 0.44 inches.
- We found the bearing capacity of the geogrid reinforced foundation had almost two times to that of the non geogrid one.
- The bearing capacity is dependent on the settlement of the foundation. The settlement depends on the water content and the unit weight of the foundation. Every foundation has different set of values for all these. We can vary these values easily in case of our numerical simulation. This is very time consuming to have a perfect measurement on any type of foundation.
- The effect of reinforcement spacing becomes less significant as the spacing is reduced to below 50% of the total depth.
- The ultimate bearing capacity of the reinforced soil increases and settlement decreases with the increase in the geogrid tensile modulus (or stiffness). However, the stiffness-related increase is more pronounced at geogrid tensile modulus in the 120-180 lb/in and gradually decreases above its upper boundary.
- The increase in footing embedment depth and footing width improves the ultimate bearing capacity of the unreinforced soil more than that of the reinforced soil.
- From the strain distributions of geogrid and the study of the effect of geogrid length, the length of the geogrid has to be at least four times of the footing width ($L=4B$) to fully mobilize the benefits.

VII. ACKNOWLEDGEMENT

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