A Project Report

On

LOAD-SETTLEMENT RESPONSE OF SQUARE FOOTING

BY

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Certificate

This is to certify that the project report entitled "**LOAD-SETTLEMENT RESPONSE OF SQUARE FOOTING**" submitted by Mr. BANDARU BALAJI SAI KUMAR (ID No. 15XJ1A0108) in partial fulfillment of the requirements of the course SE421/SE422, Project Course, embodies the work done by him/her under my supervision and guidance.

(Dr. HARI PRASAD & Signature)

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I am deeply obliged to Dr. Hari Prasad for having given me the opportunity to undertake my final year project. It has been an excellent learning experience for me as I could get to know the pertinent issues related to Geotechnology. The exposure gained using PLAXIS 2D for analysis of the soil is immense.

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ABSTRACT

Using reinforcement to increase the strength of the soil is a common practice, and understanding its behaviour is crucial. It's applications are enormous, are widely used in small to large scale construction project. Using finite element software PLAXIS 2D, load-settlement response for the square footing resting on reinforced and unreinforced sand. The elastic modulus value of the soil has been varied and the load-settlement response has been observed. The friction angle (ϕ), Diletancy angle (ψ), Unsaturated unit wt.(γ), and also the placement of the geogrid has been varied and the response is observed. The parameters considered in this study are thickness of the sand layer, depth of geogrid, width of geogrid, and relative density of the soil. The PLAXIS 2D model consists of 1000mm X 800mm dimensions. The Mohr Coulomb and hardening soil model is considered to understand the load-settlement behaviour. Load application on the soil was displacement controlled. It is understood that higher γ will have have higher bearing capacity. Optimum depth of the geogrid placement is discussed in this thesis. This study has already been done experimentally and this is to validate his paper using Finite element software.

Keywords: Square footing, Load settlement, Geogrid, Sand bed

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1. Introduction

Obtaining a soil suitable for the project is considered difficult. Different practices are followed to improve certain properties of the soil thereby reducing the cost of the project. Various techniques are followed to improve the existing soil, and one way is by reinforcing which is a common practice in ground improvement techniques. reinforcement can be in the form of geogrid, geocell, geotextile, geomembrane, etc. For strengthening the soil, geogrids are used. Geogrid can be synthetic or stainless steel. Understanding the behaviour of the soil under load in both cases is crucial and the kind of soil is suitable for which project is determined. To achieve the maximum benefit from the grogrid is by understanding its placement. This is an extension to Durga Prasad et al 2016. on "Load-Settlement Response of Square Footing on Geogrid Reinforced Layered Granular Beds" using finite element software, PLAXIS 2D.

By varying the depth of the geogrid in PLAXIS 2D, the bearing capacity of the soil is increased, but after optimum depth of the soil, the bearing capacity has no drastic change.This can be explained by pressure bulb concept discussed in the later part of the thesis. The load settlement response for dense and loose sand shows, that the capacity of the soil is increased. This depends on the compaction effort, which effects the relative density of the soil. Higher the e(void ratio), lower will be the bearing capacity as lower will be the relative density of the soil. This has been shown in the successive section in the form of load settlement response of the soil. Higher the R_d, higher will be γ and higher will be $\sigma_{bearing}$

2. Theory

The theory behind all the analysis and the load-settlement response by changing the properties of the soil is given this chapter.

Elasticity analysis

By changing the Elasticity of the soil, the settlement in the soil is reduced which is evident by the graph in the subsequent chapters. The below given formula in Advanced soil mechanics shows the dependency of E on the settlement.

$$S = \int \epsilon_z dz = \frac{\int(\delta p_z - \mu_s \delta p_y - \mu_s \delta p_x)dz}{E_s} \tag{1}$$

S= settlement; E_s= elastic modulus of the soil; μ_s=poissons ratio.
The above equation shows that with increase in value of E, settlement in the soil decreases.

Friction angle (ϕ) analysis

The bearing capacity of the soil has an indirect influence on friction angle (ϕ). Below equation shows the dependency on the bearing capacity of the soil.

$$\sigma_{bearing} = 1.4cN_c + qN_q + 0.4\gamma BN_\gamma; \tag{2}$$

where

$$N_q = \frac{e^{(0.75\pi - \phi/2)tan(\phi)}}{cos^2(45 + \phi/2)}; \tag{3}$$

$$N_c = (N_q - 1)cot(\phi); \tag{4}$$

$$N_\gamma = \frac{tan\phi}{2(K_p/cos^2(\phi) - 1)} \tag{5}$$

Hence, higher the ϕ, higher will be $\sigma_{bearing}$.

Relative density analysis

Below equations show the effect of compaction, which results in reduction in air voids, thereby reducing the void ratio (e), increasing relative density of the soil. At minimum void ratio, the unit wt. of the soil is highest, hence the bearing capacity is highest for that soil.

$$R_d = \frac{e_{max} - e}{e_{max} - e_{min}} \tag{6}$$

$\sigma_{bearing}$ is the bearing capacity for square footing.

$$\sigma_{bearing} = 1.4cN_c + qN_q + 0.4\gamma BN_\gamma \tag{7}$$

Cohesion effect

The cohesion of the soil has also been varied keeping other parameters constant. Above equation shows that $\sigma_{bearing}$ increases with increase in c. The graph below shows the effect on load-settlement response for different cases. Although sand is cohesionless soil, some cohesion has been taken to account for real conditions. Settlements are higher for cohesion soil.

3. Model

PLAXIS 2D, a Finite element software is used to determine the load- settlement response. The model used is Mohr-Coulomb for different studies and the dimensions of the bore is 1000mm X 800mm. Below figure 1 shows the PLAXIS model. The grogrids in the model are activated when the results

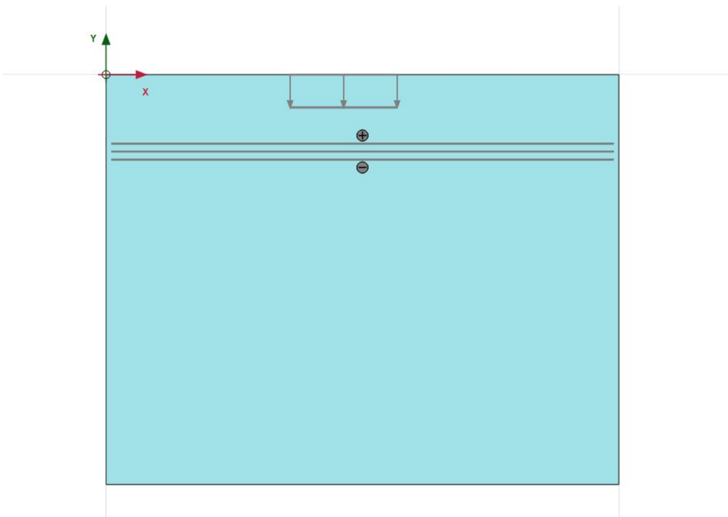

Figure 1: PLAXIS model

for the load-settlement response is to be obtained. The loading is static load and is displacement controlled.

Model to be approximated

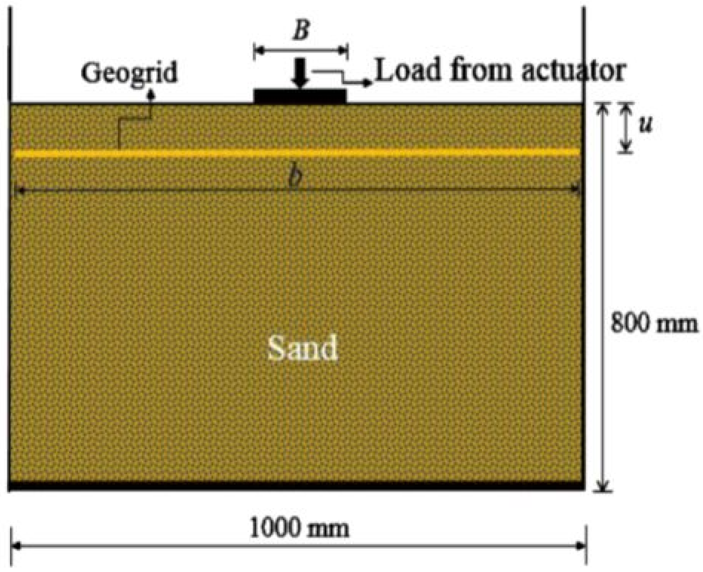

Figure 2: Soil model

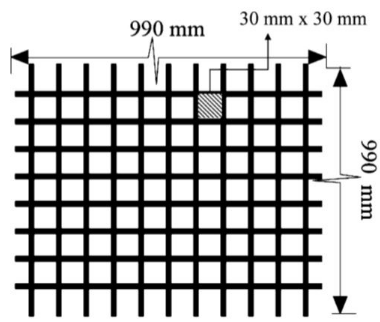

Fig. 3 Schematic diagram of geogrid reinforcement

Figure 3: Geogrid

Phases

In each phase, the displacement is changed and the elements like geogrid, plate, line displacement is activated/deactivated. The table contains all the displacement changes in each phase. The loading type was staged construction and the calculation type was Plastic. These calculations ignore the temperature effect.

Table 1: Table showing different mesh and displacement in each mesh

Phases	**Displacement(mm)**	**Phases**	**Displacement(mm)**
Initial phase	0	Phase 12	15
Phase 1	1	Phase 12	20
Phase 2	2	Phase 13	25
Phase 3	3	Phase 14	30
Phase 4	4	Phase 15	35
Phase 5	5	Phase 16	40
Phase 6	6	Phase 17	50
Phase 7	7	Phase 18	60
Phase 8	8	Phase 19	70
Phase 9	9	Phase 20	80
Phase 10	10	Phase 21	100

Mesh

The mesh used for the calculation changes accuracy of the answer. The project is started with mesh analysis. The project is said to work if the solution to different mesh is converging. Different mesh options in PLAXIS 2D are:- Very Coarse, Coarse, Medium, Fine, Very Fine. The number of nodes in each mesh changes with different meshes. Below table includes no. of nodes for each mesh.

Below figure shows the load-settlement curve for different meshes. It can be

Table 2: Mesh and no. of node and elements

Mesh	**No. of nodes**	**no. of elements**
Very Coarse	5291	587
Coarse	6877	782
Medium	9319	1083
Fine	16015	1901
Very Fine	3242	27013

observed that all the meshes are converging. Hence the model can proceed to analysis.

Structures

In the structures section of PLAXIS 2D, the elements like Line Displacement, plate, geogrid, interfaces are added and their properties are defined. Below table gives the properties of the elements. These have been acti-

Table 3: Data of the structural elements of the model

Elements	**Value**
Geogrid	EA=640
Plate	EI=80E3; EA=266
Line displacement	Y_{int}=1mm
Positive and negative interface	strength reduction

vated/deactivated during the phases to obtain the desired conditions. The next section includes the properties of the soil.

Soil

The soil properties are taken from Durga Prasad et al. 2016 on "Load-Settlement Response of Square Footing on Geogrid Reinforced Layered Granular Beds". The sand is river sand and is classified as poorly graded. The properties of the sand taken are given the table below.

Table 4: Soil properties used in PLAXIS

Property	**value**
γ_{unsat} (unsaturated unit wt.)	17.8
E (elastic modulus)	5MPa
ν(poisson ratio)	0.3
c (cohesion)	10
ϕ (friction angle)	36
ψ (diletancy angle)	11

Water table effect is not included as the water table is considered at a greater depth.

4. Results

Elasticity analysis

The elasticity of the soil is changed from 5MPa to 40MPa keeping other parameters constant and the results have been observed.
ϕ=36, c=10; γ =17.8; ν = 0.3; ψ=11;

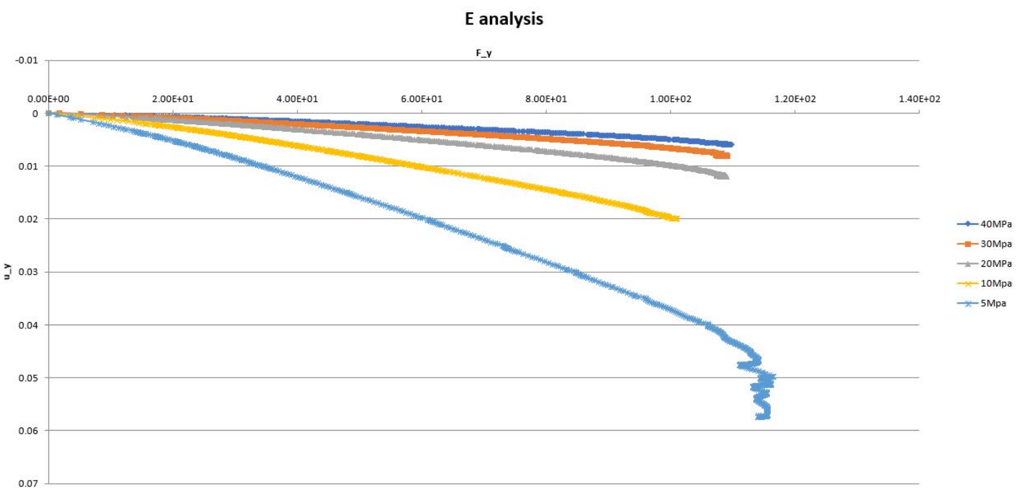

Figure 4: Load-settlement curve of sand with different E values

Friction angle (ϕ) analysis

The friction angle of the soil has been varied keeping other parameters of the soil constant. The relation between dilentancy angle of the soil and friction angle is given below

$$\psi = \phi - 30; \tag{8}$$

Below figure shows the effect of ϕ on the load-settlement curve of the soil. It can be observed that for $\phi < 28$, the failure pattern is different from ϕ >28.

For $\phi < 28$, failure pattern is local shear failure and for $\phi > 28$, the failure pattern is general shear failure. ϕ of the soil has been varied 10-40 deg.

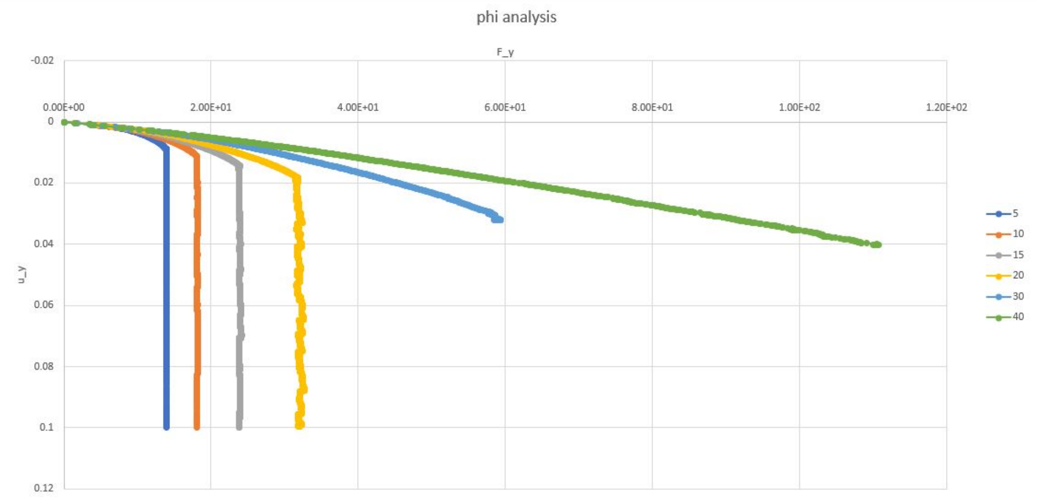

Figure 5: Load-settlement curve for soil with different friction angles

Mesh analysis

As discussed in previous chapter, different meshes give different levels of accuracy. For the project to work well, mesh analysis for different meshes are performed. If the load-settlement curves are converging, then the model is working. Below figure shows the load-settlement curve for different meshes.

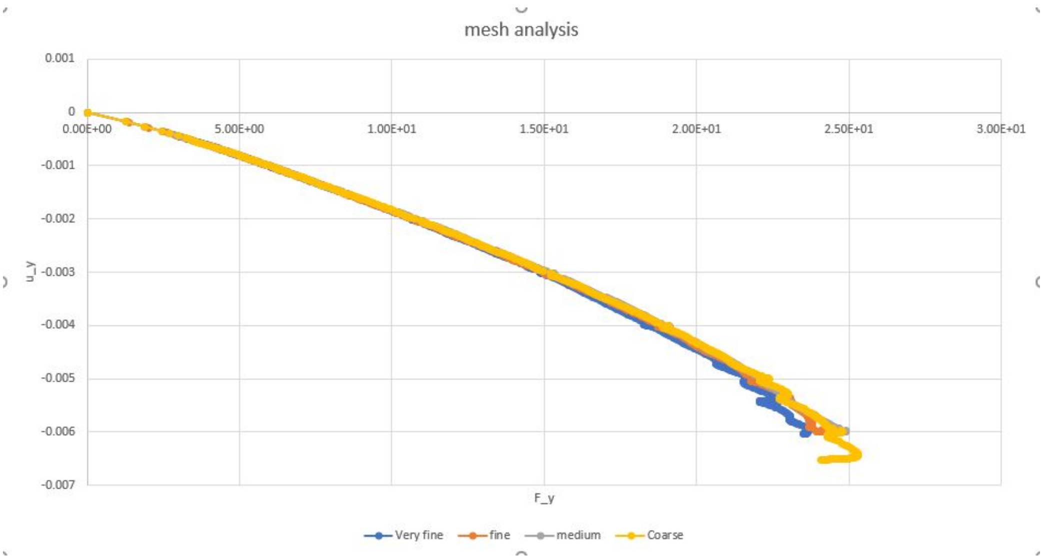

Figure 6: load-settlement for different Mesh

Relative density analysis

The relative density of the soil is changed by changing the unit wt. of soil γ and observing the load-settlement response. Below graph shows the load-settlement response on increasing/decreasing the γ

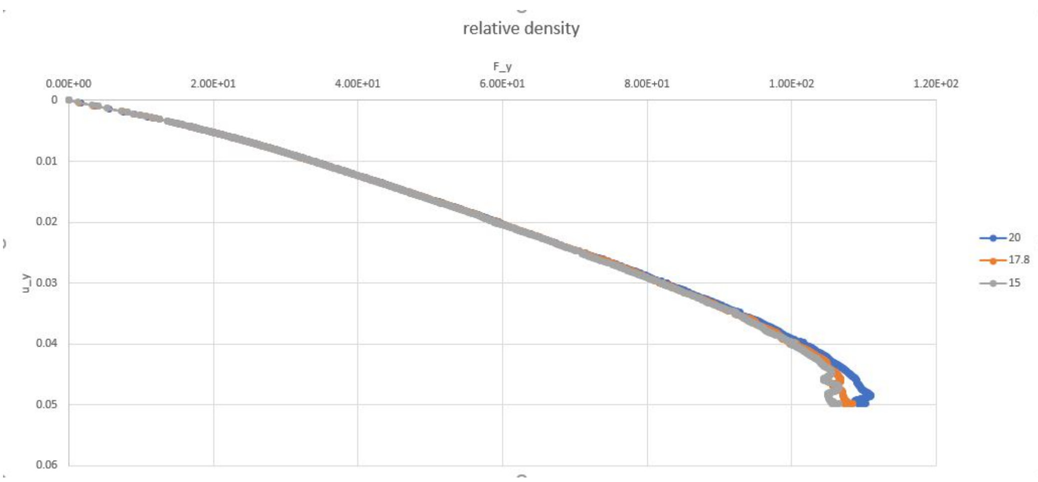

Figure 7: Load-settlement for different γ values

Geogrid analysis

Geogrid have been placed at different depths and the load-settlement curves are obtained. With increase in depth, there is increase in the bearing capacity. Increasing the depth beyond the optimum depth will not increase the bearing capacity. The figure shown below is the load-settlement curve for reinforced soil at different depths.

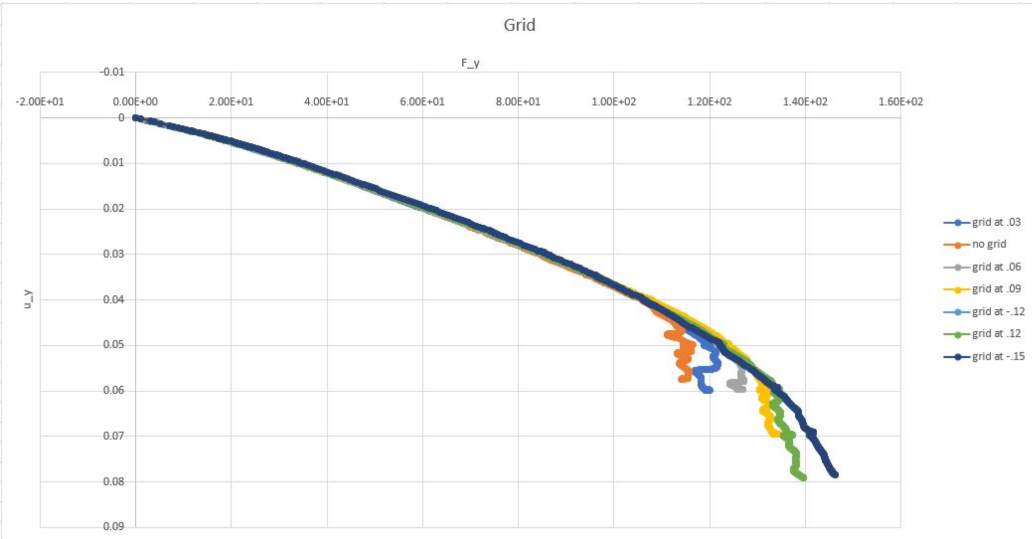

Figure 8: Load-settlement response for geogrid placed at different depths

Cohesion effect

Cohesion has been varied from 0-20, and load-settlement behaviour has been observed. It can be seen that for higher cohesion, higher is the capacity and higher is the settlement. After analysing the soil by varying different parameters, the model has been changed and the load-settlement behaviour has been observed.

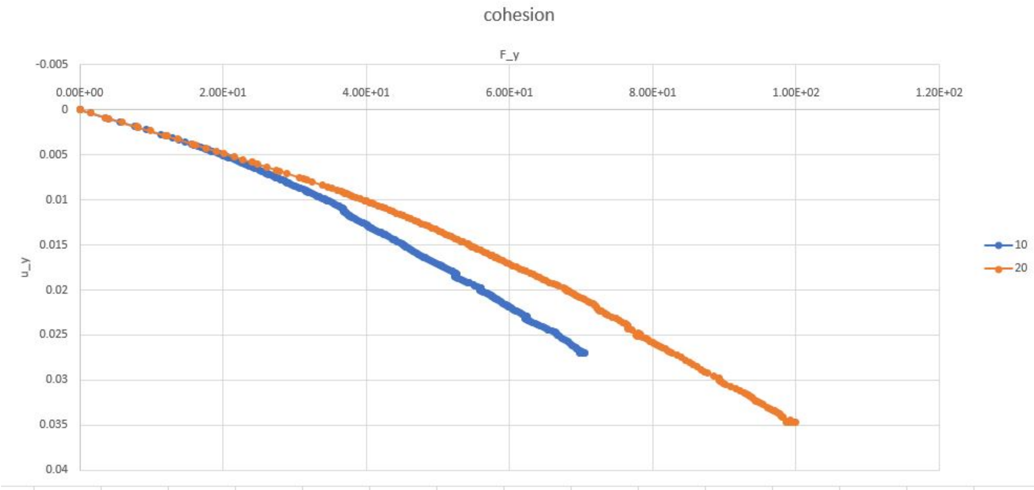

Figure 9: Cohesion effect on load-settlement response

5. Conclusion

In this report, a general review of Geogrid placement and parameters of the soil used for analysing in PLAXIS 2D have been made with special consideration. Below the some of the pointers that can be concluded from the above results.

- The optimum depth of geogrid reinforcement placed in sand alone was found to be 0.45 times the width of the footing. When the reinforcement was placed at the depth grater than optimum depth, the bearing capacity has no drastic change in it.
- With increase in Elastic modulus of the soil, the settlement is decreased and vice-versa.
- ϕ (friction angle) determines the type of failure the soil will undergo. It also determines the amount of settlement it can go till failure.
- Dense sand have higher bearing capacity over loose sands which is evident from the relative density graph.
- Hardening soil model is more accurate but due to unavailability of the data relating to that model, Mohr-Coulomb model is used.
- Mesh should converge to obtain accurate results

6. References

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