Civil and Environmental Research www.iiste.org
ISSN 2224-5790 (Paper) ISSN 2225-0514 (Online)
Vol.3, No.6, 2013 - Selected from International Conference on Recent Trends in Applied Sciences with Engineering Applications

Model Studies on Footing Beam Resting on Geogrid Reinforced Soil Bed

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Abstract
Geogrid reinforcement below foundation (resting on layered soil conditions having less bearing capacity) to support footing has considerable effect on shear, settlement and cost reducing alternative to conventional method of support. Therefore, in the present paper, a 2D finite element soil- foundation interaction modeling of a square footing has been carried out to investigate the effect of types of geogrid on sttlement, contact presseure and elastic strain. Performance level of geogrids made from three different types of polymer polypropylene, polyester and non-polymer (PP, PET and NP) have been analysed. Foundation system consists of a square footing beam resting on layered soil conditions (upper compacted and lower loose). Geogrid reinforcement is provided between upper dense soil and lower loose soil and has been assumed to have finite bending stress and, therefore, idealized as a beam. Both soil layers are also assumed to have finite bending stresses. Analysis is carried out by using a computer software program ANSYS with a two dimensional linear 8-noded isoparametric element. The result of analysis is compared with both the systems (foundation system with geogrid reinforcement & without geogrid reinforcement) and optimum thickness and optimum depth of placement of geogrid reinforcement have been found. It is found that use of geogrid and the types of geogrid affect the behavior of the foundation system significantly.
Keywords: Footing beam; Geogrids; Settlement; Contact Pressure.

1. Introduction

Geogrid reinforcement is most widely used to minimize settlement, contact pressure etc. and to stabilize soil. This technique increases bearing capacity of soils and reduces settlement, contact pressure and surface heave. It also reduces the cost of stabilization. In the reinforcement of soft soil using geogrids, the elastic modulus (E) plays an important role in settlement reduction.

Many experimental and analytical researches has been conducted to study performance of reinforced earth beds beneath the footing and to study their response to external loads. Few of these are Dash, Rajagopal and Krishnaswamy (2007) , Dash, Saride and Thallak (2007), Samtani and Sonpal (1989), Dash, Krishnaswamy and Rajagopal (2001) , Yetimoglu Jonathan and Saglamer (1994), Adams and Collins (1997), Kurian Beena and Krishna (1997). In all these researches, analysis is idealized for homogeneous soil whether it is experimental or analytical. Dash, Sireesh and Sitharam (2003)' proposed mathematical model for non-homogeneous soil in the form of two-layered soil system (upper dense sand and lower loose sand).

Maheshwari and Viladkar (2009) also conducted experimental study for non-homogeneous soil. Many of the researches were for circular footing whereas rectangular and square footings are used in actual practice. Therefore, in this paper, an effort has been made to add some additional features in the performance of geogrid reinforcement and to study the cases that are most common in actual practice.

2. Statement of the problem

Square footing beam subjected to strip loading of intensity, q N/mm per unit length over entire length and resting on geosynthetic reinforced earth bed (Fig.1), has been idealized by linear elastic beam (E, μ) of length (or width) b and thickness h.The earth bed has been reinforced with geogrids made from non-polymer (PP, PET and NP), which has some finite bending stiffness. This reinforcement layer has elastic modulus and three different types of polymer polypropylene, polyester and poisons ratio (E, μ) and is of length (or width) b' and thickness h'. The reinforcing layer has been assumed to have smooth surface characteristics [1]. The soil layer above the lower geogrid beam is assumed to be compacted sand (E, μ) and the soil below the lower beam is assumed to be loose sand (E, μ). Properties of all materials considered in the analysis are listed in Table No.2.

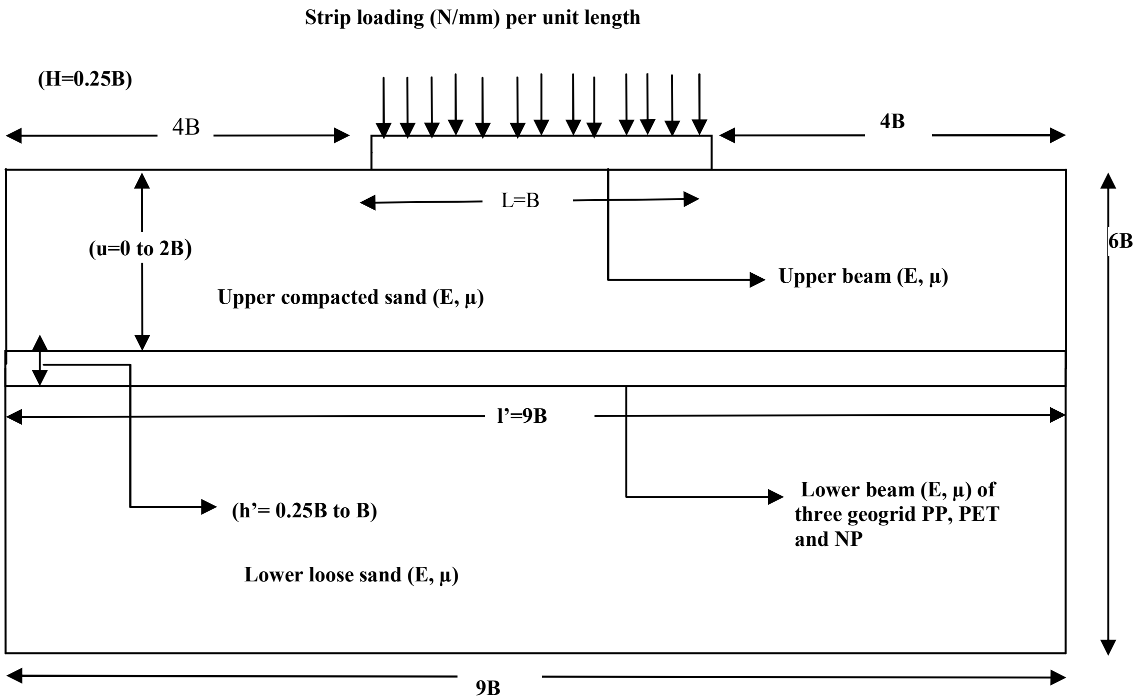

Fig 1.0 Definition sketch of the problem

3. Test Series

Different test series considered in the analysis are tabulated in following table **(Table-1).**

Test Series	Analysis Type	Constant Parameter	Variable Parameter
A	Analysis for optimum depth of placement of geogrid beam.	E = 70000 MPa, q=1600 (N/mm) per unit length and h'=100 mm	u=0, 25mm, 50mm,75mm, 100mm, 125mm, 150mm, 175mm and 200mm
B	Analysis for optimum thickness of geogrid beam.	E = 70000 MPa, q=1600 (N/mm) per unit length and u=0	h'=25 mm, 50 mm, 75 mm and 100 mm
C	Comparison of three different geogrids polypropylene (PP), non-polypropylene (NP) and polyester (PET) with respect to settlement, contact pressure and elastic strain	q=1600 (N/mm) per unit length, h'=100 mm, and u=0	(PP) E=76000 MPa (PET) E=70000 MPa (NP) E=40000 MPa

E= elastic modulus, q= load intensity, u= depth of placement of geogrid beam, h'= thickness of geogrid beam, PP= polypropylene geogrid, PET= polyester geogrid and NP= non-polymer geogrid.

4. Assumptions

The following assumptions are made in the analysis:

1. The soil and geogrid both are considered as linearly elastic isotropic materials.
2. Foundation system is two-layered soil system: (upper compacted and lower loose).
3. Non-homogeneity of the soil is considered in terms of variable Young's Modulus.
4. Geogrid beam and foundation system both are finite and plane strain condition exists in the system.
5. Elastic modulus of geogrid reinforcement is considered as elastic modulus of geogrid beam

5. Finite Element Modeling

First step is to get data regarding geometrical dimensions, element used, properties of material used, boundary conditions and loading conditions etc.So first collect data of the foundation system.

5.1 Dimensions of the Foundation System

In this paper square footing (100mm X 100mm X 25mm) has been discussed. In the analysis concrete footing was considered as a beam (Upper beam) of the same footing area. Compacted soil below the footing is reinforced with geogrid considered as finite geogrid beam (Lower beam) of length equals to its width (900 mm). Thickness of lower beam considered is 25 mm, 50 mm, 75mm and 100 mm. Soil below the lower beam is considered as loose sand having lower value of elastic modulus and poisson's ratio as compared to upper compacted sand. Size of the foundation system considered is 900mm X 900mm X 600 mm. A 2-D model of the foundation system was built using ANSYS.

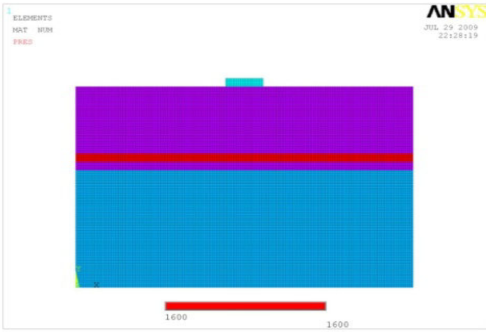

Fig.2 Meshing model on ANSYS

5.2 Material Used

Materials used in the analysis are reinforced cement concrete, geogrid and soil. Concrete beam, geogrid beam, compacted sand layer and loose sand layer all materials used for the system are considered as linear, elastic, isotropic material. Table No. 2 provides the properties of the materials.

Table 2. Material Properties

Material Used	Modulus of Elasticity (E) (MPa,)	Poisson's Ratio (μ)
Upper Beam (RCC)	20000	0.30
Upper Sand Layer (Compacted)	35 to 60	0.25
Lower Beam (Geogrid)	(PP)= 76000, (PET)= 70000 (NP)= 40000	0.30
Lower Sand Layer (Loose)	35	0.20

5.3 Geogrid and Soil

The geogrids adopted in this study are the common geogrids available in India. The geogrids are made from polypropylene polymer (PP), polyester (PET) and non polymer (NP).Soil considered in the analysis is soft soil. Basically soft soils containing clay, silt or silty clay (with high moisture content and low permeability) are normally categorized as poor to very poor subgrade material in construction of foundation. Foundation system is consists of two-layered soil system: A dense soil layer overlying the reinforcing layer and a loose soil layer lying below the geogrid reinforcement. Compacted dense soil has higher elastic modulus and poisson's ratio than those of loose sand.

5.4 Boundary Conditions

Various boundary conditions taken in the analysis are;

1. Static conditions with the loading.
2. Axis-symmetric conditions with the soil and geogrid reinforcement
3. Fix boundary conditions at the outer node of the foundation system.
4. Plain Strain condition exists within the foundation system.

5.5 Loading Conditions

Upper beam is subjected to Strip loading through entire length or width. Vertical loads were applied sequentially in equal increments of 200 N/mm per unit length to achieve better computational accuracy. Maximum load intensity applied was 1600 N/mm per unit length.

5.6 Obtain the Solution

Applying all the boundary conditions, obtained the solutions using ANSYS for the foundation system.

6. Results and Discussion

In this paper parametric study has been undertaken to understand the influence of various parameters on the flexural response of the geogrid as a reinforcement sandwitched between two layered non-homogeneous soil. These parameters include: depth of geogrid reinforcement, depth of placement of geogrid reinforcement and types of geogrid used in the analysis. These parameters were presented in detail in Table 1. For better understanding of working of proposed analytical model and results obtained, typical graphs have been drawn.

6.1 Settlement Variation of Upper (footing) beam for optimum depth of placement (u)

Fig.3 shows the settlement of upper beam with respect to depth of placement of geogrid reinforcement. Here pattern is parabolic, indicating maximum settlement value at the centre of the footing and appreciably low in the region beyond the loaded area. Similar pattern of settlement variation is found for (u/B) ratio equals to 0.75, 1.00, 1.25, 1.50, 1.75 and 2.0. It should be mentioned here that parabolic pattern of settlement indicates overall settlement of the footing in unreinforced case. However, in case of geogrid reinforcement settlement value at center reduces by 9.26%. As the depth of placement of lower beam (u) reduces by 83.33% (from 1.50 to 0.25), the settlement of the upper beam at its centre has been found to reduce by 13.12%. This reveals the fact that when the lower beam is placed at a greater depth from the ground surface, it offers less resistance to the upper foundation beam to settle downwards and so higher deflections have been observed. The maximum reduction in settlement has been found by 96.25% at (u/B) ratio equals to 0, which indicates that the reinforced material is better utilized when placed just below the footing.

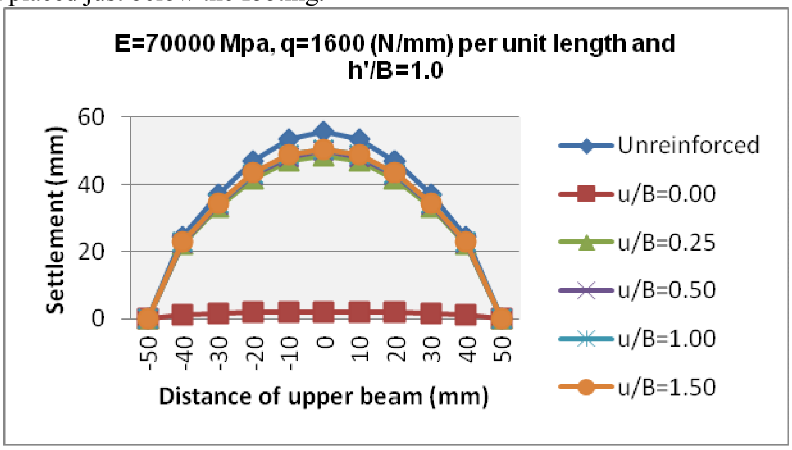

Fig.3 Settlement of upper (footing) beam along length (or width) for different (u/B) ratio (Test Series-A).

6.2 Settlement Variation of Upper (footing) beam for optimum thickness (h')

Fig.4 shows settlement of upper beam with respect to thickness of the lower beam. Settlement variation is also parabolic, It can be said that parabolic pattern indicates overall settlement of the footing in unreinforced case. Effect of thickness (h'/B) of geogrid reinforcement on settlement reduction is significant. Percentage reduction in settlement is found by 87.66%, 94.30%, 95.74% and 96.25% for different (h'/B) ratio equals to 0.25, 0.50, 0.75 and 1.00 respectively, which indicates thickness of geogrid reinforcement (h') affects performance of system significantly. It should be mentioned that increase in thickness beyond (h'/B) ratio equals to 0.5, reduction in settlement is marginal.

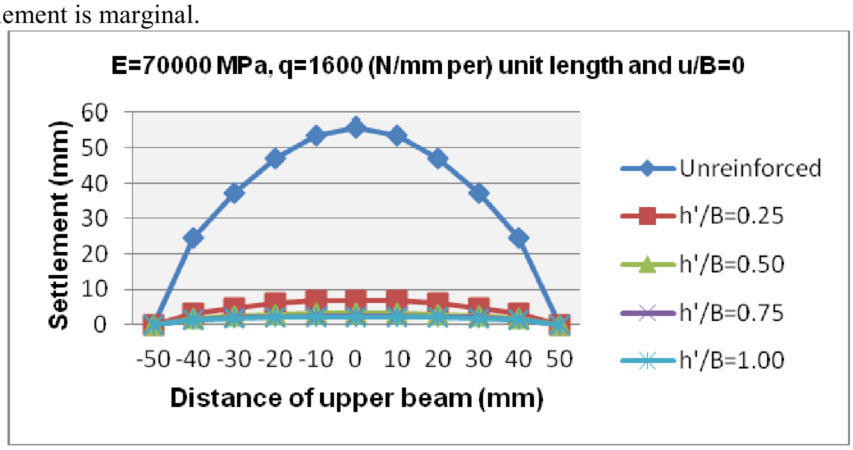

Fig.4 Settlement of upper beam along length (or width) for different (h'/B) ratio (Test Series-B).

6.3 Effect of types of Geogrid

The influence of the type of geogrid on the footing performance was studied in the test series C and the results are presented in fig.5, 6and 7. Fig. shows typical variation of settlement, contact pressure and elastic strain respectively for three types geogrid made from (PP), (PET) and (NP).

It is observed that percentage reduction in settlement, contact pressure and elastic strain for polypropylene (PP) is more as compared to other two types (PET and NP) of geogrid. It was found that, settlement in case of geogrid made of PP, PET and NP are found to reduce by 93.08%, 92.50% and 87.52% respectively for equivalent depth (h'), depth of placement (u), loading and boundary condition. However, contact pressure in case of geogrid made of PP, PET and NP are found to reduce by 89.84%, 89.03% and 81.77% respectively and elastic strain in case of geogrid made of PP, PET and NP are found to reduce by 89.37%, 88.56% and 81.02% respectively. Both the geogrid made of PP and PET have shown almost same improvement upto a distance of 50 mm from center of lower beam.

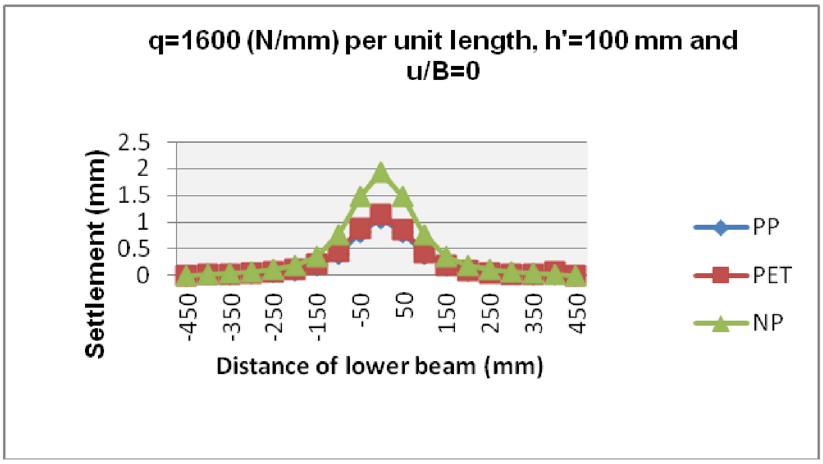

Fig.5 Settlement of lower beam along length for different types of geogrid PP, NP and PET (Test Series-C).

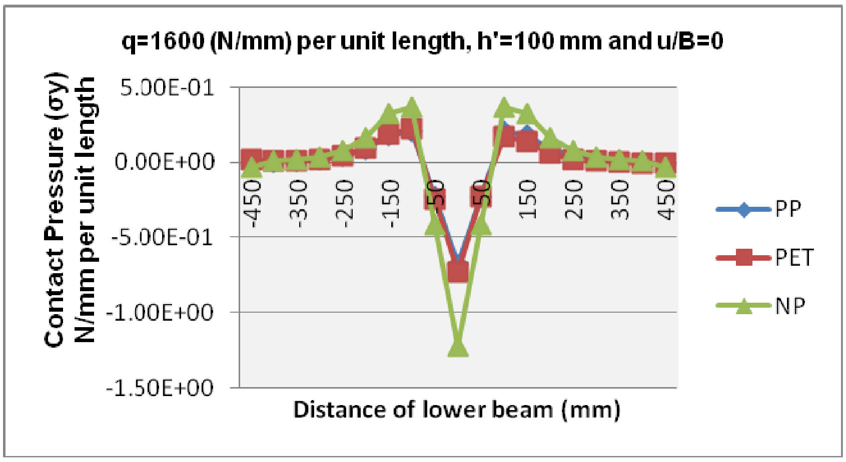

Fig.6 Contact pressure at the base of lower beam types of geogrid PP, NP and PET (Test Series-C).

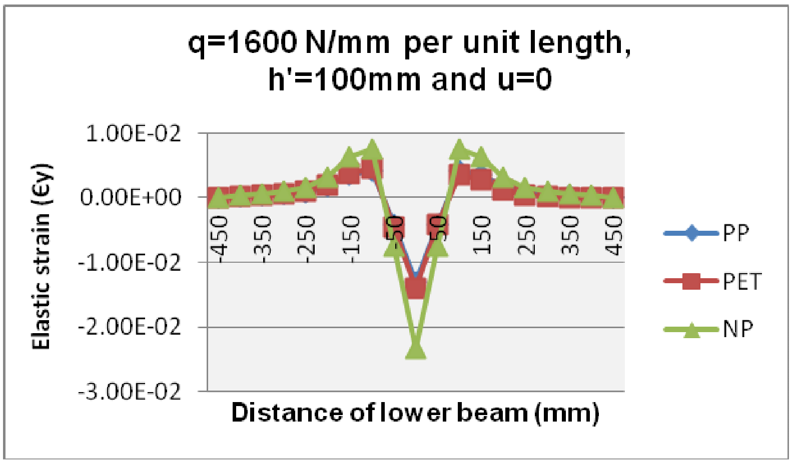

Fig.7 Elastic strain at the base of lower beam along length (or width) for different types of geogrid PP, NP and PET (Test Series-C).

7. Conclusions

In this paper an analytical model has been proposed to evaluate the performance of square footing on two layered non-homogeneous soil reinforced with polymeric and non-polymeric geogrids. Based on results obtained from the present investigation, the following conclusions can be made on the behavior of square footing resting on geogrid reinforced sand bed and the type of geogrid used in the analysis:

- The results obtained from analysis indicate that at ratio t (u/B=2) contact pressure and elastic strain values become insignificant for two-layered reinforced soil conditions.
- Geogrid efficiency increases with the increased thickness of the geogrid reinforcement upto a certain limit. Increase in thickness beyond ratio (h'/B=1), reduction in settlement is marginal.
- Using the geogrid made from polypropylene (PP), reduction in settlement value, contact pressure value as well as elastic strain value was found to be consistently higher as compare to other two cases (PET and NP).
- The performance of geogrids made from polypropylene (PP) and the polyester (PET) was found to be very similar, and both can be used with the same efficiency. However, the PP is more attractive for stiffer applications because of its performance.

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