ISSN: 2248-9622, Vol. 5, Issue 8, (Part - 4) August 2015, pp.10-16

RESEARCH ARTICLE OPEN ACCESS

Effect of Bearing Capacity of Strip Footing on Reinforced Double Layer Soil System with Fly ash Stabilized Clayey Soil

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ABSTRACT
This research was performed to investigate the effect of bearing capacity of strip footing on geogrid reinforced sand overlay on stabilized expansive soil (i.e. double layer soil system) and check the different parameters contributing to their performance using laboratory model tank tests. The parameters investigated in this study include H/B (thickness of top sandy layer to width of footing) u/B (location of the 1st layer of reinforcement to width of footing), h/B (vertical spacing between consecutive geogrid layers to width of footing), b/B (length of the geogrid layer to width of footing). The effect of different H/B ratios and geogrid reinforcement N values on the bearing capacity ration (BCR) and settlement reduction ratio (SRR) were also investigated. The results show that bearing capacity increases significantly with increasing the H/B ratio as well as number of geogrid layers. The bearing capacity for the soil increases with an average of 12.35% using H/B equal to0.5 and the bearing capacity increases with an average of 35.76%, 75.56% & 230.83% while using H/B equal to 1.0, 1.5 & 2.0. It also found that the use of sandy layers over flyash mixed clayey soil has a considerable effect on the bearing capacity characteristics and the use of geogrid layers in the granular overlay has remarkable effect on Bearing capacity ratio (BCR) & Settlement reduction ratio (SRR).
Keywords-Fly Ash, Geogrid, Model Tank, Bearing Capacity Ratio & Settlement Reduction Ratio.

I. INTRODUCTION

Design of foundation governs the two different requirements: one is the ultimate bearing capacity of soil below foundation and second is the acceptable settlement that a footing can undergo without any adverse effect on superstructure. In geotechnical engineering, bearing capacity is the power of the foundation soil to hold the forces from the superstructure without undergoing shear failure or excessive settlement (foundation soil is that portion of ground which is subjected to additional stresses when foundation and superstructure are constructed on the ground). Low bearing capacity and high settlement behaviour of expansive soils is the challenge for the engineers to work on it. But today, there are number of techniques are available to control/improve the improper properties of soil (like low bearing capacity, high compressibility, settlement, etc.). Soil Stabilization & Soil Reinforcement are the two different techniques which helps us to improve the engineering properties of the soil. Soil Stabilization means the improvement of stability or bearing power of the soil by the use of controlled compaction, proportioning and/or the addition of suitable admixture or stabilizers. Soil Reinforced soil is the technique where tensile elements are placed in the soil to improve stability and control deformation. The soil reinforced material includes Metal Strips and Metal Bars, Rope Fibers and Geotextiles/Geogrid/Geocells.

For the last few decades, several studies have been conducted based on the laboratory model and field tests, related to the beneficial effects of the reinforced materials, on the load bearing capacity of soils in the strip foundations, road pavements and slope stabilizations. From the finding of numerous researcher, it can be concluded that the bearing capacity of soil also changed with various factors like type of reinforcing materials, number of reinforcement layers, ratios of different parameters of reinforcing materials, and foundations such as B (width of footing), u/B (location of the first layer of geogrid to width of footing), h/B (vertical spacing between consecutive geogrid layer to width of footing), b/B (length of the geogrid layer to width of footing), H (thickness of sandy layer) & N (number of geogrid layers).

Dr. R K Tripathi & Laxmikant Yadu (2014): In their study they investigate the effect on bearing capacity ratios of strip footing for various granular fill thickness and number of geogrid layers in granular fill overlay on soft soil. They use Granulated Blast furnace Slag (GBS) as a granular fill. The effect on bearing capacity ratios of strip footing for various unreinforced GBS fill thickness have been observed and optimum thickness of the GBS fill obtained. The test results indicate substantial improvement in terms of increase in bearing capacity ratio and reduction in the footing settlement due to provision of GBS fill overlay on soft soil. Application of geogrid reinforcement further enhances the bearing capacity ratio and stiffness of the overlying GBS fill. Optimum thickness of GBS fill increases the bearing capacity ratio of soft soil by 85%. Further, reinforcement of optimum GBS fill thickness by optimum number of layers increases the bearing capacity ratio by 419%. They also conclude the presence of GBS fill overlay on soft soil bed improves the load bearing capacity and decreases the settlement of the soft soil bed. The placement of geogrid reinforcement in GBS fill further increases the load bearing capacity and decreases the settlement of the GBS-soft soil bed system.

H. A. Alawaji (2001): This paper investigates the potential benefits of geogrid-reinforced sand over collapsible soil to control wetting induced collapse settlement. The width and depth of the geogrid were varied to determine their effects on the collapse settlement, deformation modulus and bearing capacity ratios. The results showed that there is significant difference in the structural contribution of the tested geogrid which range from 95% reduction in settlement, to 2000% increase in elastic modulus and 320% increase in bearing capacity. It was found that the efficiency of the sand-geogrid system increased with increasing geogrid width and decreasing geogrid depth.

II. MATERIALUSED

Twotypes of soils are used to conduct the experimental study, i.e. clayey soil and sandy soil.

2.1 Clayey Soil:

The soft soil is collected from Kapurthala, Punjab, India. The clayey soil used in this study is classified as highly compressible (CH) clay according to the unified soil classification system (USCS). Engineering properties of the soil used are presented in Table 1.

Table 1: Properties of Clayey Soil

Properties	Values
Specific Gravity	2.74
Liquid Limit (%)	50.4
Plastic Limit (%)	26.6
Plasticity Index	23.7
Optimum Moisture Content (OMC) %	10.4
Maximum Dry Density (MDD) (g/cc)	2.03
Classificationas per (USCS)	CH*

*CH = Clay of high compressibility

2.2 Sandy Soil:

Sand is a naturally occurring granular material composed of finely divided rock and mineral particles. It is defined by size, being finer than gravel and coarser than silt. River sand is used in the study. The sand is classified as poorly graded sand (SP) by Unified Soil Classification System (USCS). (Shown in fig. 1) Table 2 shows the engineering properties of this material.

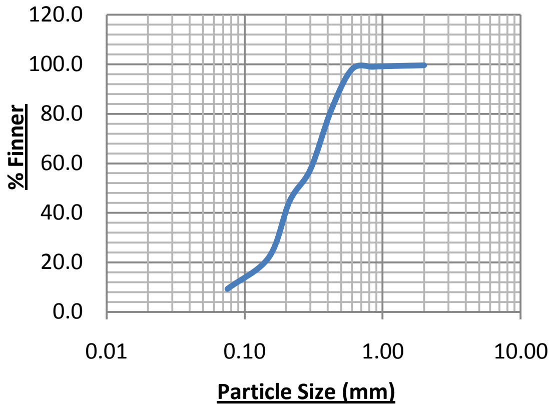

Fig.1: Particle Size distribution curve for the sandy soil used in the study

Table 2: Properties of Sandy Soil

Properties	Values
Specific Gravity	2.66
Coefficient of uniformity (Cu)	4.20
Coefficient of curvature (Cc)	1.29
Maximum unit weight (kN/m^3)	18.0
Minimum unit weight (kN/m^3)	13.0
Angle of internal friction	38^0
Classification as per USCS	SP*

*SP = Poorly graded sand

2.3 Fly ash:

The fly ash has been collected from Guru Gobind Singh Super Thermal Plant at Ropar, Punjab, India. Fly ash is one of the residues created during the combustion of coal in coal-fired power plants. Fly ash by itself has little cementatious value but in the presence of moisture it reacts chemically and forms cementatious compounds and attributes to the improvement of strength & compressibility characteristics of soils. Fly ash is a fine, glass powder recovered from the gases of burning coal during the production of electricity. These micron-sized earth elements consist primarily of silica, alumina and iron.

2.4 Geogrid:

A geogrid is geosynthetic material used to reinforce soils and similar materials. Geogrids are commonly made of polymer materials, such as polyester or polypropylene. Compared to soil, geogrids are strong in tension. Commercially available geogrid (SGi-040) is used as reinforcing elements. Table 3 shows the properties of geogrid SGi-040.

Table 3: Properties of geogrid-SGi-040: courtesy M/S Strata Geosystems (India) Pvt. Ltd, Mumbai, India

Properties	Values
Thickness	0.27 mm
Aperture size (rectangular opening)	60 x 23 mm
Cross machine direction	
Single rib tensile strength	33.9 kN m^{-1}
Single rib elongation at 30 kN m^{-1}	10.3%
Number of ribs per meter	38
Machine direction	
Single rib tensile strength	43.4 kN m^{-1}
Single rib elongation at 40 kN m^{-1}	11%
Number of ribs per meter	37

III. METHODOLOGY

Clay soil sample mixed with fly ash at optimum proportion (i.e. 10% fly ash) then place it into the model tank (with the dimensions having length (Lt) 830 mm, width (Bt) 680mm, and depth (Dt) 630mm) and compact it thoroughly. Before running the test in the model tank, check the moisture content for soil-water mixture. After compaction of the stabilized expansive clay in the model tank up to desired depth, thin sand layer will place above the compacted stabilized soil. At the interface level of two soils will place a layer of geogrid. And then place the second and third layer of geogrid in between the sandy soil layer (as shown in Fig.3) Then load will apply to the model footing (with the dimensions of length (L) 600mm, width (B) 100mm, and thickness (D) 100mm) by using a manual hydraulic jack system. The loading rate was kept constant in every test. The load and corresponding foundation settlement will measure by using a load cell and a dial gauge, respectively.

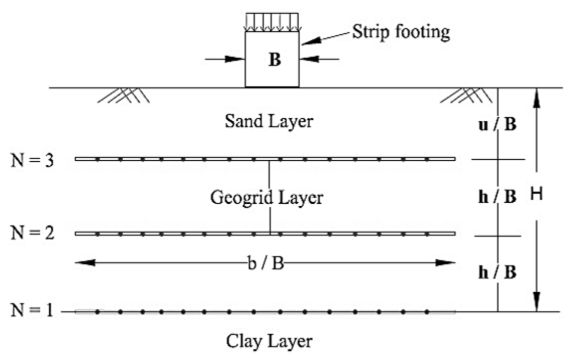

Fig. 2: Geometric parameters for a footing on sandy layer overlay on clayey soil

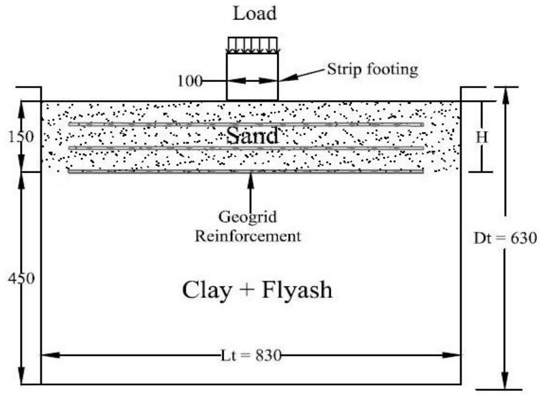

Fig.3: Cross section of model tank and with no. of geogrid layers

IV. TEST SERIES

The total no. of eight model tank tests were conduct on clayey soil and unreinforced/reinforced sandy soil overlay on stabilized clayey soil with optimum percentage of fly ash (i.e. 10%).

Table 4: Summary of test series

Test Series	Descriptions (Cases)	Variable Parameters	Constant Parameters
A	Unreinforced fly ash mixed clayey soil	--	Fly ash 10%, MDD & OMC
B	Unreinforced Sand fill overlay on soft soil bed	H/B = 0.5, 1.0, 1.5, 2.0.	R_D = 60%
C	Reinforced Sand fill overlay on soft soil bed	N = 1, 2, 3.	H/B = 1.5, R_D = 60%, u/B = h/B = 0.50, b/B = 8

V. RESULTS AND DISCUSSIONS

Different laboratory tests have been carried out as per IS: 2720. The tests were carried out both on natural soil and stabilized soil with fly ash collected from Guru Gobind Singh Super Thermal Plant.

5.1Atterberg Limits:

Atterberg limits where tested with various fly ash contents, and the results are shown in table 5 and fig. 4. Result shows that Liquid limit (LL) and the plastic limit (PL) of clayey soil decrease with the addition of 10% fly ash and thereafter both liquid limit and plastic limit gradually increased. The addition of fly ash results in the decrease of liquid limit due to the dilution of clay content of the mix. The increase in trend of Atterberg's limit is due to increase in specific surfaces and activity of the material. A possible explanation of the above results may be related to the addition of fly ash, which aids flocculation, and aggregation of the clay particles. The effect of flocculation increases the water holding capacity of soil.

Table 5: Atterberg Limits of Soil-Fly ash

Soil Type	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index
Clay	50.4	26.7	23.7
90% Clay + 10% FA	42.5	18.7	23.8
80% Clay + 20% FA	48.0	20.0	28.0
70% Clay + 30% FA	49.0	26.7	22.3

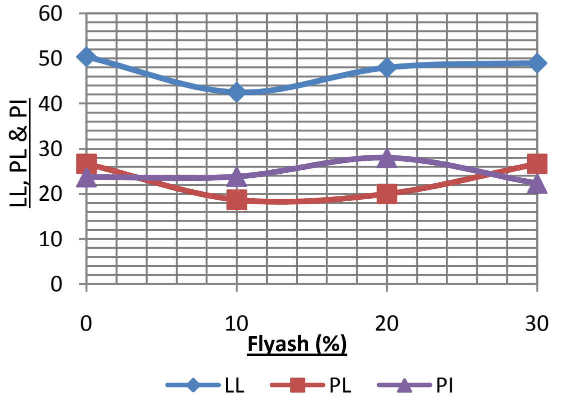

Fig. 4:Variation of LL, PL & PI with Fly ash

5.2 Compaction Test:

Fig. 5 shows the variations of the maximum dry unit weight (MDD) and fig. 6 shows the variations of optimum moisture content (OMC) with varying fly ash content (i.e. 10%, 20%, 30%). The MDD of clayey soil was 2.03 g/cc and the MDD for a stabilized clayey soil with 10%, 20% & 30% fly ash content were 1.91, 1.84 & 1.78 g/cc, this means MDD decreased with increasing fly ash content, and OMC slightly increased with addition of fly ash content. The MDD decreased because of decrease in specific gravity of the reconstituted due to increase in fly ash content. The decrease in density may be related to the flocculated and agglomerated, clay particles occupying larger spaces leading to a corresponding decrease in dry density. The increment of OMC was probably produced by the coarse grain size of fly ash compared to that of natural soil, which caused an enlarged void ratio in soil mixtures (or) the OMC of soil increases with increase fly ash content, because fly ash is finer than the soil. The more fines the more surface area, so more water is required to provide well lubrication.

Table 6: Properties of soil-fly ash Compaction test

Soil Type	OMC (%)	MDD (g/cc)
Clay	10.4	2.03
90% Clay + 10% FA	10.5	1.92
80% Clay + 20% FA	14.5	1.84
70% Clay + 30% FA	15.4	1.79

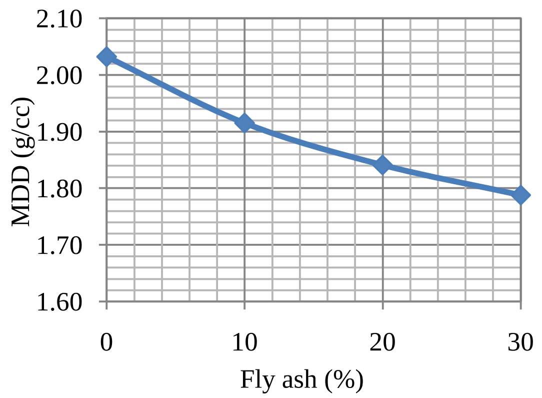

Fig. 5: Variation of MDD with Fly ash

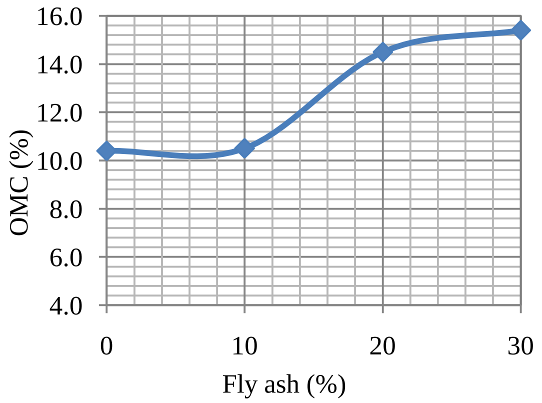

Fig. 6: Variation of OMC with Fly ash

5.3 Load- Settlement Characteristics:

The results of test series are presented in terms of Pressure V/S Settlement, Bearing Capacity Ratio (BCR) and Settlement Reduction Ratio (SRR). The following well established equation (Binquet and Lee 1975) is used for evaluation of BCR:

$$BCR = \frac{qR}{qo}$$

Where:-

q_R = Ultimate bearing capacity of unreinforced /reinforced soil.

q_o = ultimate bearing capacity of clayey soil (i.e. flyash mixed clayey soil)

Settlement Reduction Ratio (SRR) defined as percentage reduction in settlement due to unreinforced / reinforced sandy soil overlay on clayey soil relative to the without overlay of sandy soil on clayey soil bed at a constant load was used to compare the results.

$$SRR = \frac{(S_o - S_R)}{S_o} \times 100$$

Where:-
S_R = Settlement of unreinforced/reinforced soil
S_o = Settlement of clayey soil (i.e. flyash mixed clayey soil)

The bearing pressure versus settlement curves for test series A, B & C are shown in fig. 9&10. It shows that when a small thickness of sand layer is placed on the top of flyash mixed clayey soil layer, the bearing capacity increases.

5.4 Variation of Bearing Capacity Ratios (BCR):

Bearing Capacity Ratio (BCR) and Settlement Reduction Ratio (SRR) were found using above equations respectively. Fig. 7 shows the variation of bearing capacity ratio (BCR) with *H/B* ratio and number of geogrid layers (N). The value of BCR increases from 1.0 to 3.3 with the increase of *H/B* ratio from 0 to 2. Further increase of *H/B* does not show significant increase and becomes nearly constant. Therefore, it can be concluded that *H/B* = 2 gives maximum BCR (*i.e.* 3.3). Reinforcement of sand fill further increases the BCR from 1.75 (*N* = 0; *H/B* = 1.5) to 5.96 at *N* = 3. Further increase in number of geogrid layers do not help to increase the BCR and it becomes constant. Hence, it can be concluded that the maximum value of BCR obtained as 5.96 at N = 3.

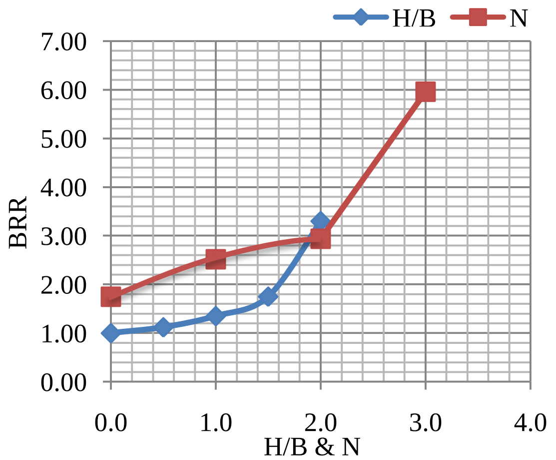

Fig. 7: Variation of BCR with N & H/B ratio

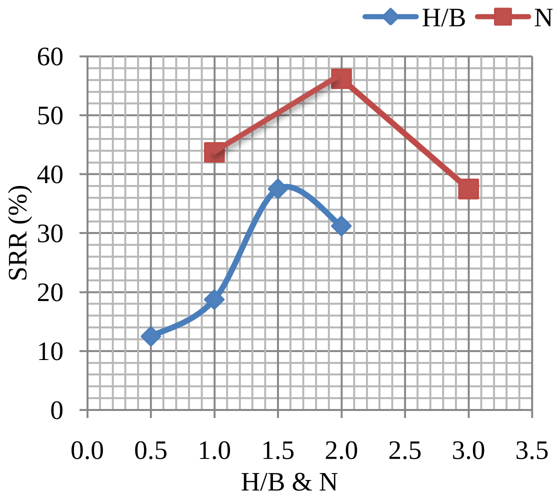

Fig. 8: Variation of SRR with N and H/B ratio

5.5 Variation of Settlement Reduction Ratios (SRR):

The variation of SRR with H/B ratio and (N) number of geogrid layers is shown in Fig. 8. The SRR increases from 12.5 to 37.5 with the increase of H/B ratio from 0.5 to 1.5 but after the increment of H/B ratio from 1.5 to 2.0, the SRR value decreases from 37.5 to 31.2. Therefore it can be concluded that H/B ratio = 1.5 gives the maximum SRR value. Geogrid reinforcement of sand layer further enhances the SRR from 43.7 to 56.2 with the increase of N value from 1 to 2. But after the increment of N value from 2.0 to 3.0 the SRR value decreases from 56.2 to 37.5. Because of reinforcement action of geogrid SRR value has been observed higher for all the cases of reinforced sandy layer as compared to unreinforced sandy layer. The sandy layer has low tensile resistance and its tensile resistance improves with the effective bond due to interlocking at the soil-reinforcement interface (Mandal and Sah 1992).

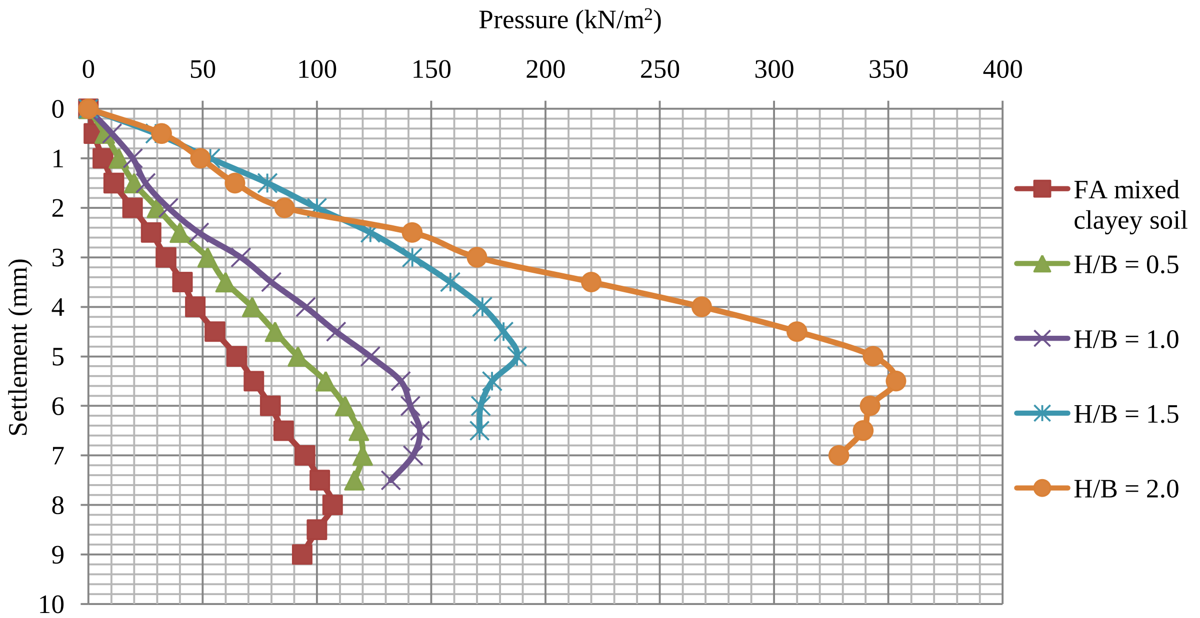

Fig. 9: Pressure versus settlement curves of fly ash mixed clayey soil & H/B ratios

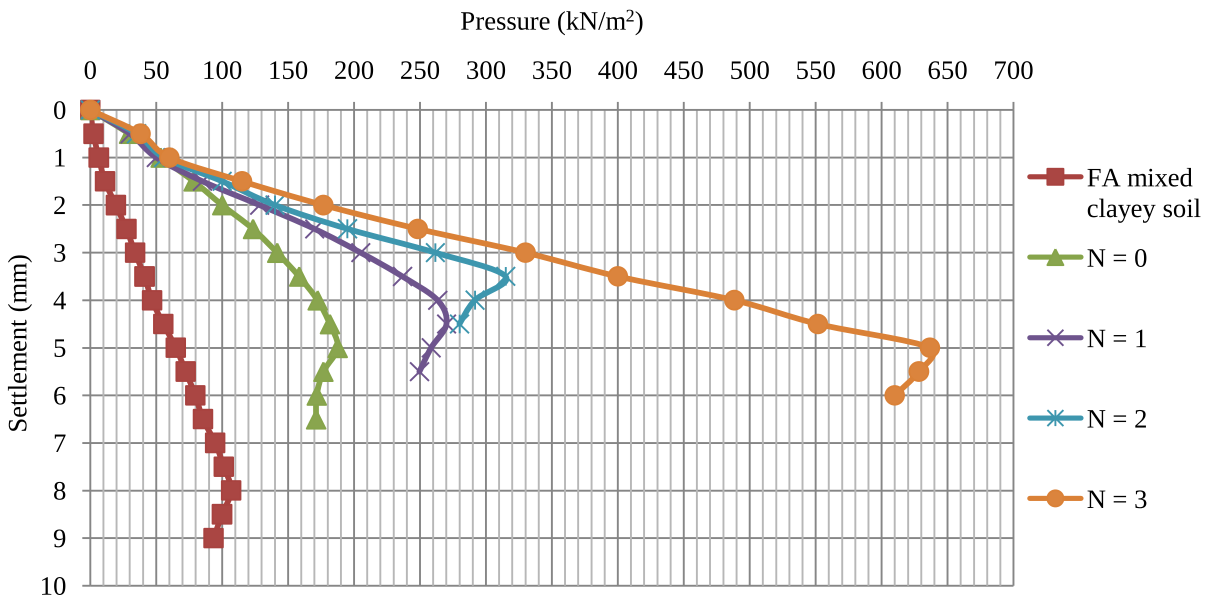

Fig. 10: Pressure versus settlement curves of fly ash mixed clayey soil & N Values

VI. CONCLUSIONS

The present study investigates the effect of geogrids on sand layer underlain by stabilized clayey soil towards the improvement of bearing capacity of strip footing. Based on the model tests, the following conclusions are drawn.

a) The mixture of 90% clay + 10% Fly ash has been observed the optimum mix, beyond which the physical properties of clayey soil does not gives the satisfactory results.
b) It is observed that replacement of thick sandy layer with stabilized clayey soil (i.e. double layer soil system) gives the better bearing capacity result as compare to pure clayey soil system.
c) The placement of geogrid reinforcement in sandy layer increases the bearing capacity and decreases the settlement of the sandy layer overlay on flyash mixed clayey soil, upto the certain limit.
d) With the increment of no. of geogrid reinforcement layers there is an increase in the settlement reduction ratio up to the N=2 thereafter it is not significantly increase the settlement reduction ratio. Same in the case of H/B ratio, settlement reduction ratio is also increased upto the H/B=1.5 but after that it is slightly decreases.

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