INFLUENCE ON BEARING PRESSURE OF SHALLOW FOOTING RESTING ON GEOGRID REINFORCED DOUBLE LAYERED SOIL SYSTEM

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Abstract

Model test was conducted to investigate the effect of geogrid reinforcement on bearing pressure of strip footing resting on sand overlay on clayey soil stabilized with fly ash. Various percentages of fly ash mixed with clayey soil and found the optimum proportion. The optimum percentage of fly ash mixed with clay and then used as a second layer in the model test. Experiments were conducted on model test of strip footing, calculated the bearing pressure of double layer soil system without geogrid, with geogrid at the interface level and at designated levels within the sand layer. To check the different parameters contributing to their performance using model test of tank size is 830mm x 680mm x 630mm. The parameters investigated in this study include H/W (thickness of top sandy layer to width of footing), x/W (depth of the 1st layer of geogrid to width of footing), d/W (spacing between consecutive geogrid layers to width of footing), l/W (length of the geogrid layer to width of footing). The effect of different H/W ratios and no. of geogrid layers (n) on the bearing pressure ratio (BPR) and settlement reduction ratio (SRR) were investigated. Based on the Atterberg's limit the optimum mix obtained is 90% clay and 10% fly ash. The optimum mix was used as bottom layer in the model tank. The result indicates that bearing pressure increases with increasing the H/W ratio and n values. The bearing pressure calculated without geogrid at three different materials like clay alone, optimum mix of clay and fly ash and double layers (sand, optimum mix of clay and fly ash) are 104.1, 106.8 and 187.5 kN/m^2 respectively. Geogrid reinforcement used at the interface (n=1) and at two different levels within sand layer (n=2, 3), the corresponding bearing pressure values are 270 kN/m^2, 315 kN/m^2 and 636.7 kN/m^2 respectively. The bearing pressure for the soil increases with H/W = 0.5, 1, 1.5 and 2, the average values are 12.35%, 35.76%, 75.56% and 230.83% respectively. It was found that the use of geogrid at interface and multiple layers has a considerable effect on the bearing pressure. Use of geogrid layers in the granular overlay has significant effect on Bearing pressure ratio (BPR) & Settlement reduction ratio (SRR).

***Keywords**: Model test, optimum mix, geogrid, bearing pressure, SRR.*

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1. INTRODUCTION

The design of foundation governs the two different requirements, one is the ultimate bearing pressure of soil and other is settlement within permissible limits. Low bearing pressure and high settlement behaviour of expansive soils is the challenge for the engineers. There are number of techniques are available to control/improve the properties of soil (low bearing pressure, high compressibility, settlement, etc.). Soil Stabilization & Soil Reinforcement are the two different techniques which helps us to improve its properties.

The bearing pressure of different footings on expansive soil can be increased significantly by placing a layer of granular fill of limited thickness with geogrid reinforcement at granular fill-expansive soil interface (Krishnaswamy et al. 2000; Alawaji 2001; Das et al. 2003; Deb et al. 2011; Ornek et al. 2012; Mahallawy and Rashed 2012). The improved on bearing pressure ratios for strip footing of various granulated blast furnace slag fill thickness and number of geogrid layers in granular slag fill overlay on soft soil (Tripathi and Yadu (2014). Experimental and numerical investigations conducted on bearing pressure of circular footing on geogrid-reinforced compacted granular fill layer overlying on natural clay, the degree of improvement depends on thickness of granular fill layer, properties and configuration of geogrid layers (Demir et al. 2014). Pressure – settlement behaviour and ultimate bearing pressure of strip footing resting on top of fly ash slope can be enhanced by the presence of geogrid reinforced layer (Jha et al. 2009). The behaviour of shallow footing's on an upper layer of processed cemented soil that overlies at layer of weak bonded residual soil with a high void ratio, as H/D (thickness of cemented soil to weak soil) increases, the load–settlement response becomes stiffer and stronger (Thome et al. 2005).

2. MATERIAL AND LABORATORY MODEL TEST

The sand, clay, flyash and geogrid are the basic materials that are used in this research study. Model tank of dimensions 830mm x 680mm x 630mm is used throughout the investigation. The clayey soil (Fig. 1) used in this research is collected from Kapurthala, Punjab, India and it is classified as highly compressible clay (CH) as for the unified soil classification system (USCS). The properties of the original clay are presented in Table. 1.

Fig. 1 Clayey soil

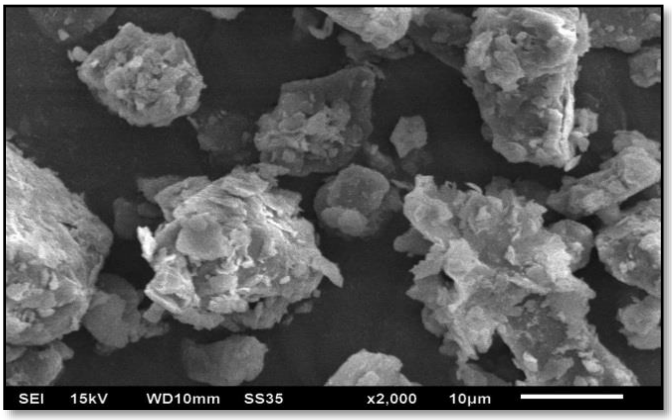


Fig. 2. SEM image of clay at 2000 magnification

Fig. 2. SEM image shows that the morphological characteristics of clayey soil, it shows the shapes of the particles are rounded and rough angular surface at lower magnification level, but higher magnification level shows flat and smooth plate like structure surface. As per EDS (Energy dispersive spectrum) investigation, chemical composition of clayey soil presented in Table 2.

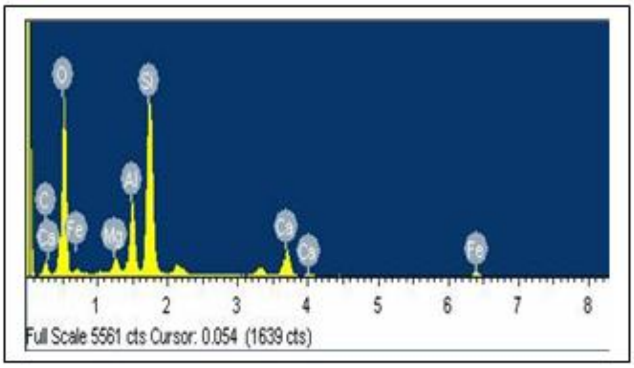
Table.1 Geotechnical properties of clay

Properties	**Value**
Specific Gravity	2.74
Liquid Limit (%)	50.4
Plastic Limit (%)	26.6
Plasticity Index	23.8
OMC, (%)	10.4
MDD, (g/cc)	2.03
Classification as per USCS	CH*
UCS (kN/m^2)	88
CBR (%)	1.3

***CH** = Clay of high compressibility

Table.2: Chemical Compound of Clayey Soil (as per EDS), EDS Image

Formula	Value (%)
Carbon dioxide, CO_2	48.94
Silica, SiO_2	31.17
Alumina, Al_2O_3	10.98
Calcium oxide, CaO	4.42
Magnesium oxide, MgO	2.45
Ferrous oxide, FeO	2.03

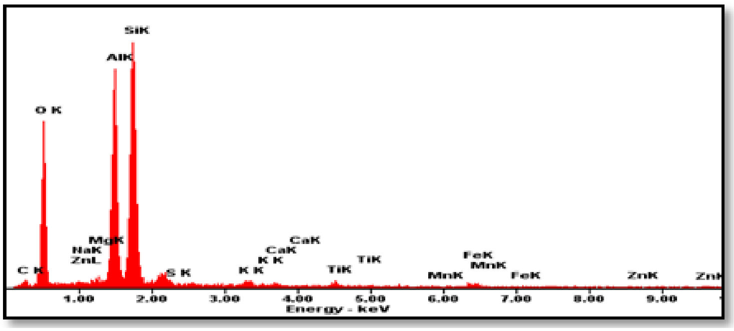


2.1 Fly Ash

The class F fly ash collected from Guru Gobind Singh Super Thermal Plant at Ropar, Punjab, India. As per EDS investigation chemical composition was observed and submitted in Table 3.

Table 3: Chemical Compound of Fly ash (as per EDS), EDS image

Formula	Value (%)
Carbon dioxide, CO_2	32.60
Alumina, Al_2O_3	28.29
Silica, SiO_2	37.72
Calcium oxide, CaO	00.18
Ferrous oxide, FeO	01.21



2.2 Sand

River sand is used in the study and it is classified as poorly graded sand (SP) by Unified Soil Classification System (USCS). Table. 4. Shows the engineering properties of sand.

Table 4: Properties of Sandy Soil

Properties	Value
Specific Gravity	2.66
Coefficient of uniformity (Cu)	4.20
Coefficient of curvature (Cc)	1.29
Maximum unit weight (kN/m³)	18.0
Minimum unit weight (kN/m³)	13.0
Angle of internal friction	38^0
Classification as per USCS	SP*
*SP = Poorly graded sand	

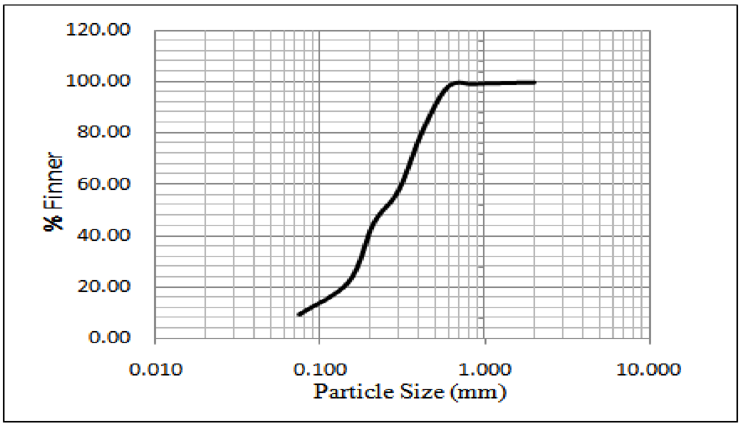


Fig. 3 Grain size analysis

2.3 Geogrid

Polypropylene geogrid bought from M/s Strata Geosystem (India) pvt. ltd, Mumbai, India. Uniaxial geogrid (SGi-040) used as reinforcing element. Table. 5 show the properties of geogrid SGi-040.

Table .5: Specification of geogrid-SGi-040: courtesy M/S Strata Geosystems (India) Pvt. Ltd, Mumbai, India

Properties		Value
Mechanical properties		
Tensile strength (ASTM D 6637)	MD	40 kN/m
	CMD	20 kN/m
Creep Reduction Factor (at 20^0C, 114 years design life)		1.47
Creep limited strength	MD	27.2 kN/m
Partial Factor Installation Damage ASTM D 5818		
In clay, silt or sand		1.07
In sandy gravel		1.07
In gravel		1.35
Grid Aperture sizes	MD	60mm
	CMD	23mm

2.4 Model Tank

The model tank as shown in fig.4a was used to determining the bearing pressure and settlement of strip footing in the laboratory. Tank is fabricated with the 12mm thick mild steel plates; the size of the tank is 830 mm (Lt) x 680mm (Bt) x 630mm (Dt). The bottom and side plates of the tank are stiffened by using steel angle sections at the top, bottom and middle of the tank to avoid any lateral yielding during soil compaction and while applying load. The inner surfaces of the tank were smooth to reduce the side friction. The load on the footing is applied by a hydraulic jack; settlement of the footing is measured by a set of dial gauges of sensitivity 0.02 mm.

Fig 4a: Model Tank **Fig 4b:** Model Footing

2.5 Model Footing

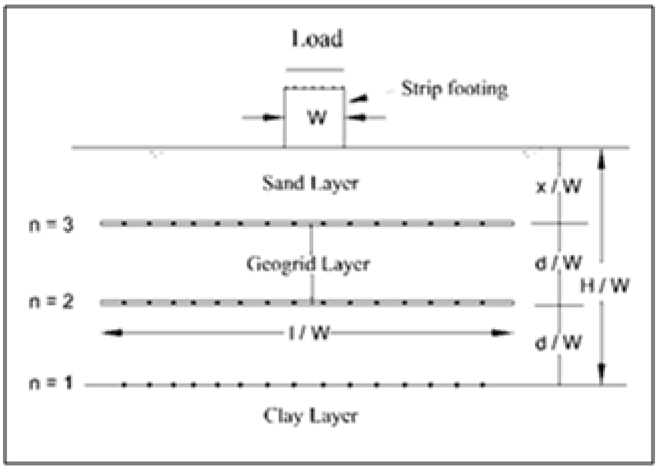
Footing dimensions are 600mm x 100mm x 100mm (length, width and depth) used in the tank. Footing sizes are selected based on the tank's dimensions. It was made in a way that its width is less than 6.5 times the depth of the tank, so that the effect of the loading should not reach to the walls of tank. Fig. 4b shows the pictorial view of model footing.

3. EXPERIMENTAL INVESTIGATION

Geotechnical experiments were conducted for finding the optimum proportion of the fly ash with clayey soil. The Fly ash mixed with clay at various percentages of 10%, 20% and 30% and then determined the Atterberg's limits, compaction characteristics and uniaxial compressive strength.

3.1 Placement of Geogrid

In case of reinforced sand bed, it is very essential to decide the magnitude of (x/W), (d/W), (H/W), (l/w) and (n) to take the maximum advantage in bearing pressure of reinforced sand. After going through several literatures, for strip footing it has been found that (x/W) between 0.5 to 1.5, (l/W) is 8, and (H/W) lies between 0.5 to 2.0. By keep the above factor in consideration, parameters are fixed as (x/W) = 0.5, (l/W) = 8.0 & (d/W) = 0.5 and (H/W) = 0.5, 1.0, 1.5, 2.0. Fig. 5 shows the arrangement of geogrid with different parameters.



W = Width of footing
H/W = Top sandy layer thickness
x/W = distance of 1st layer of reinforcement to level of footing
d/W = Spacing between consecutive geogrid layer to width of footing
l/W = Length of the geogrid layer to width of footing
n = Number of Geogrid layers
R_D = Relative density of sand

Fig. 5: Geometric parameters of a footing resting on reinforced sandy layer overlay on clay mixed with flay ash

4. TESTS SERIES

A series of tests were conducted in model tank on clayey soil alone, clay mixed with fly ash (optimum) and double layered soil at unreinforced condition. Using geogrid reinforcement three tests were performed. Table 6 shows the series of tests conducted.

Table. 6: Scheme of tests in model tank

Series	Descriptions	Variable Parameters	Constant Parameters
A	Unreinforced clayey soil	Fly ash = 0%, 10%.	MDD & OMC
B	Unreinforced sand fill overlay on fly ash mixed clayey soil	H/W = 0.5, 1.0, 1.5, 2.0.	R_D = 60%
C	Reinforced sand fill overlay on fly ash mixed clayey soil	n = 1, 2, 3.	H/W = 1.5, R_D = 60%, x/W = d/W = 0.50, l/W = 8

4.1 Test Series A

Two numbers of tests were performed, one with pure clayey soil and other clay mixed with fly ash (optimum). In series A for first test, tank is completely filled with the clayey soil, whereas in second test, tank is filled with uniform mix of clay and 10% fly ash. Both the cases soil compacted at MDD & OMC values of heavy compaction test. Nuclear density meter used to check the MDD & OMC values in the tank. Load applied through the hydraulic jack then calculated the pressure versus settlement values.

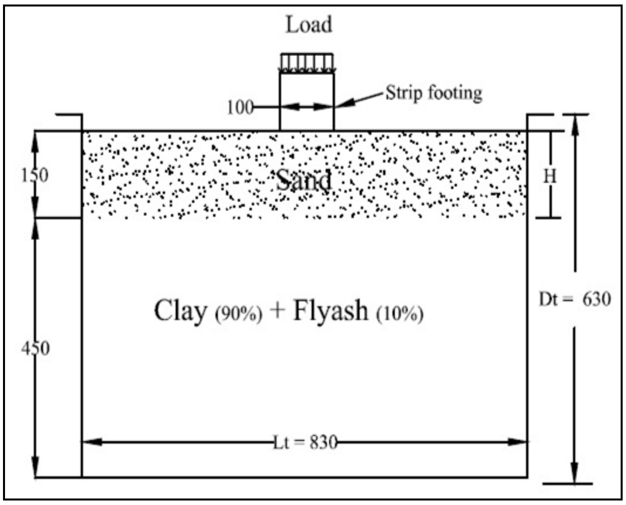
4.2 Test Series B

It is double layer system consists of sandy layer overlay the uniform mixed clay with 10% fly ash without any geogrid reinforcement. Four tests were conducted with four H/W ratios (i.e. H/W=0.5, H/W=1.0, H/W=1.5 & H/W=2.0). H/W is the top sandy layer thickness to width of footing.

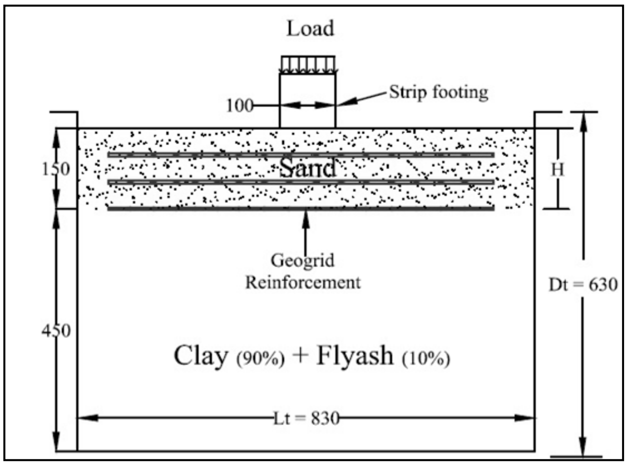
4.3 Test Series C

Sand thickness taken as 150mm (constant, H/W =1.5) as a first layer, second layer is clay mixed with 10% fly ash. Geogrid placed at interface level and x/W, d/W is equal to 0.5 (i.e. n=1, n=2 & n=3). The 60% relative density of sand used for test series B and C.

Fig. 6 shows the pattern of the tank tests without reinforcement and with reinforcement.



(a)



(b)

Fig. 6: c/s of model test (a) without reinforcement (b) with reinforcement

5. RESULTS AND DISCUSSION

Atterberg's limit test performed with clayey soil varying fly ash content 0%, 10%, 20% and 30 %, and the results are shown in table 5 and fig. 7. Liquid limit (LL) & plastic limit (PL) decreases at 10% fly ash and after that they increased with 20% & 30% fly ash. Fly ash inclusion diminished the clay size fraction of soil in view of flocculation of the clay particles by cementation. The increase in trend of Atterberg's limit is may be due to increase in more fines.

Table 5: Atterberg limits of soil–flyash mixtures

S. No.	Soil Type	Liquid Limit (LL) (%)	Plastic Limit (PL) (%)	Plasticity Index (PI)	MDD (g/cc)	OMC (%)
1.	Clay	50.4	26.7	23.7	2.03	10.4
2.	90% Clay + 10% FA	42.5	18.7	23.8	1.92	10.5
3.	80% Clay + 20% FA	48.0	20.0	28.0	1.84	14.5
4.	70% Clay + 30% FA	49.0	26.7	22.3	1.79	15.4

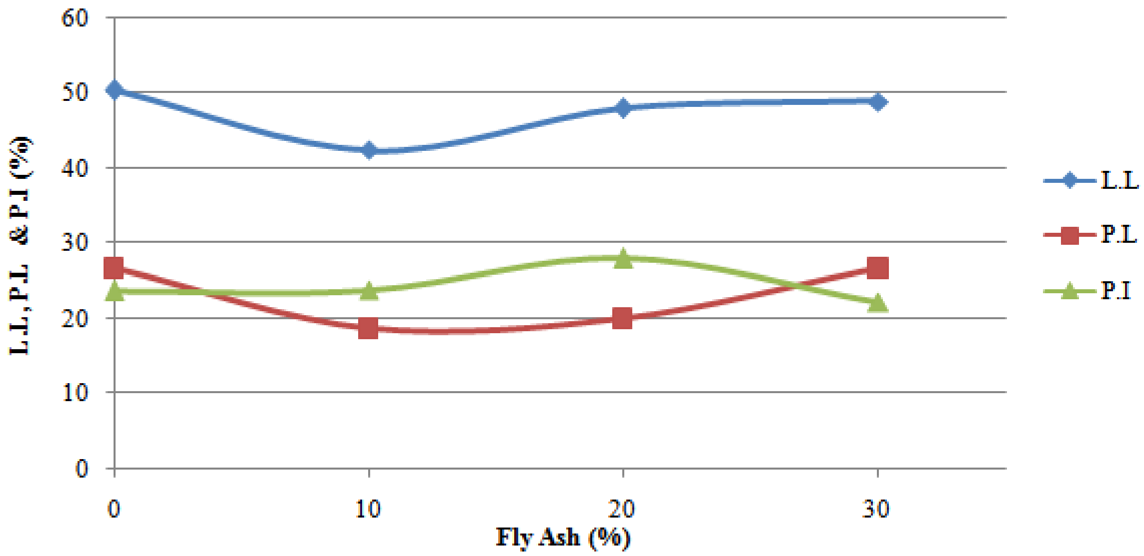


Fig. 7 Variation of Atterberg's limits with fly ash (%)

5.1 Compaction Test

The variation of the MDD (maximum dry density) and OMC (optimum moisture content) with fly ash content as shown in Fig. 8. The MDD of original clay soil is 2.03 g/cc and clay with 10%, 20% & 30% fly ash conten t were 1.92, 1.84 & 1.79 g/cc, MDD decreases with increasing content of fly ash and OMC slightly increases with addition of fly ash.

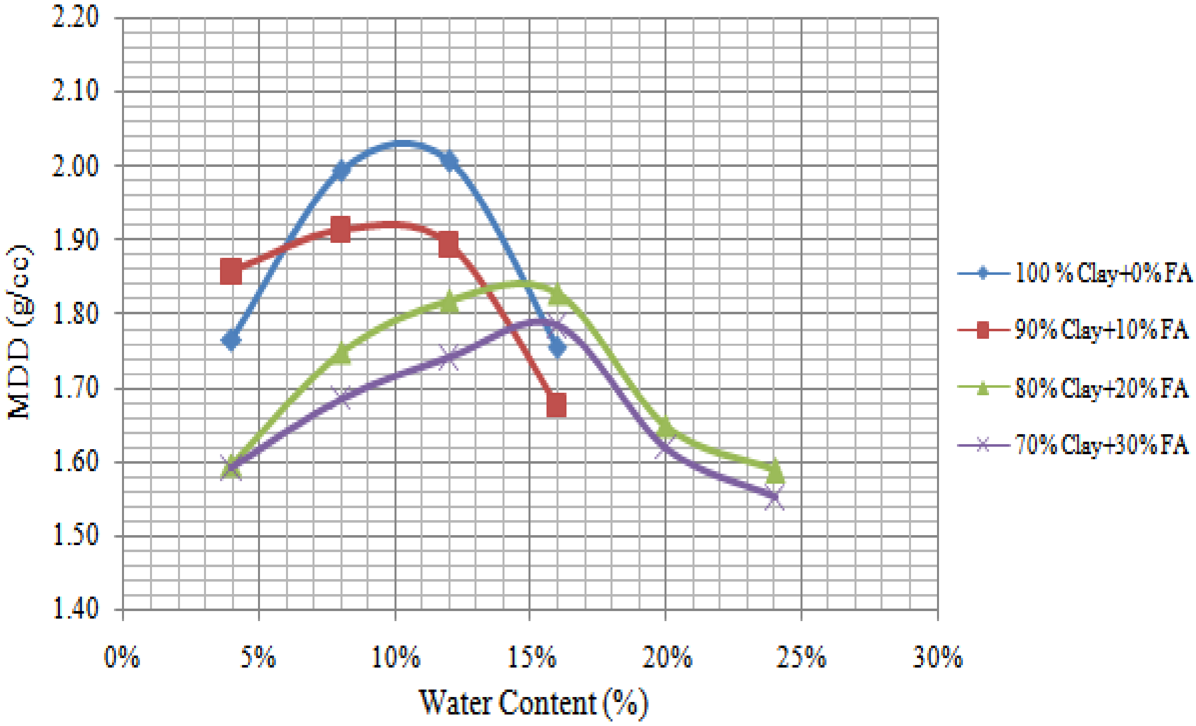


Fig. 8 MDD and OMC for clay uniform mix with fly ash

The reason of decrease in dry density may be due to flocculation and agglomeration process, it will change the texture of the mixed soil and due to which it cover large space into the soil particles and increase water holding capacity. Increment of OMC may be fineness of fly ash, which caused an enlarged void ratio in soil mixtures.

5.2 Pressure V/S Settlement

Result of model tests are plotted in the form of pressure-settlement curve, as shown in Fig.9 to Fig.11. Footing size (600mm x 100mm x 100mm) and tank dimensions (830mm x 680mm x 630mm) are kept constant in all cases, and the variables are H/W, d/W, x/W, l/W & n. The total nine numbers of model tests were conducted on test series A, B and C.

5.3 Pressure-Settlement Characteristics

The results of test series are presented in terms of pressure - settlement, bearing pressure ratio (BPR) and settlement reduction ratio (SRR). To calculate the bearing pressure ratio, the following equation was used (Binquet and Lee) (1975).

$$\text{Bearing Pressure Ratio (BPR)} = \frac{qR}{qo}$$

Where:-
q_R = Ultimate bearing pressure of unreinforced (or) reinforced soil.
q_o = Ultimate bearing pressure of clayey soil (i.e. flyash mixed clayey soil)

$$\text{Settlement Reduction Ratio (SRR)} = \frac{(So-SR)}{So} \times 100$$

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

5.4 Result of Test Series A

The pressure-settlement curves for test series A are shown in fig. 9.

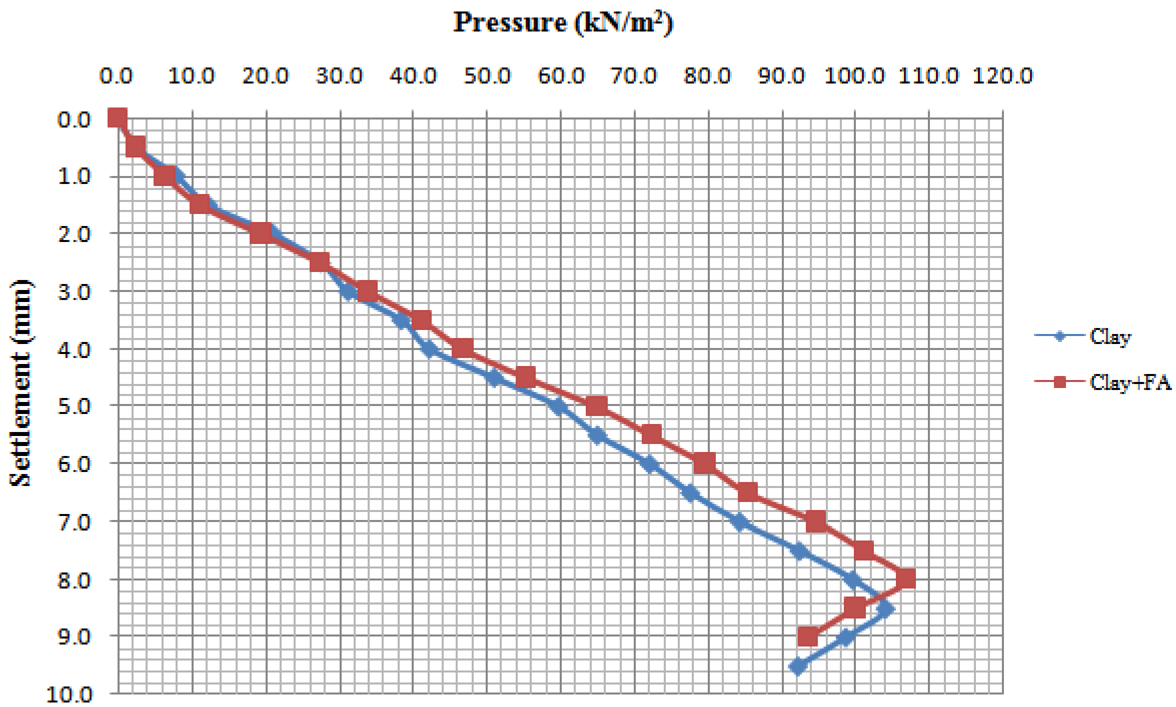


Fig. 9 Pressure-Settlement curves of unreinforced clay and clay mixed with 10% fly ash

From the graph, it can concludes that the bearing pressure of original clay is slightly less than to that of clay mixed with 10% fly ash, but settlement in original clay is more than the fly ash mixed clayey soil. The ultimate bearing pressure is 104.10 kN/m^2 for original clay and 106.80 kN/m^2 for fly ash mixed clayey soil. The bearing pressure for fly ash mixed clayey soil slightly increases with an average of 2.59%. Reason may be due to pozzolanic reaction of the fly ash.

5.5 Result of Test Series B

Test series B, the effect of double layer soil system on bearing pressure of the footing on without reinforcement case was investigated. The thickness of sandy layer was changed as H/W= 0.5, 1.0, 1.5 & 2.0. The relative density of sandy soil was 60%. The pressure –settlement curves are published in Fig.10.

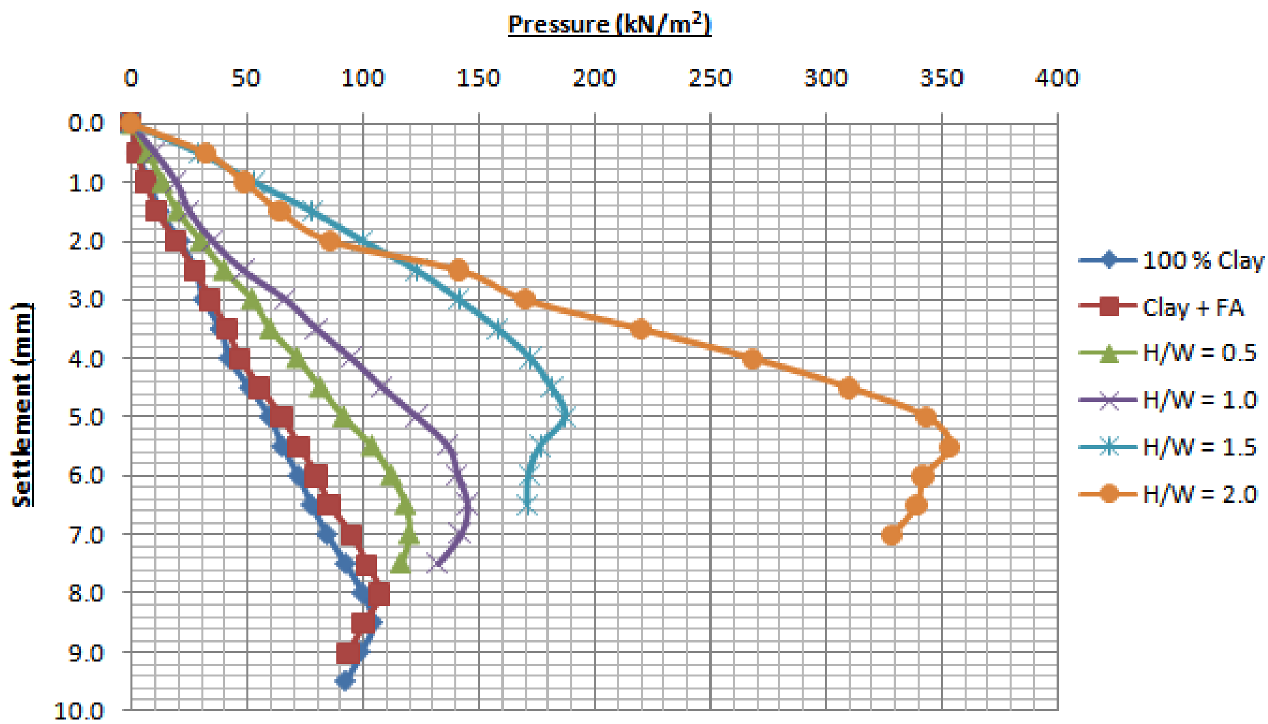


Fig. 10 Pressure - Settlement curves of H/W ratios

From Fig.10 indicates the increase in bearing pressure with double layer system i.e. sandy soil, uniform mix of clay with 10% of fly ash. The average increasing values of bearing pressure with the original clayey soil are 12. 35%, 35.76%, 75.56% and 230.83% for H/W = 0.5, 1, 1.5 & 2 respectively. This may be due to the shear parameter angle of internal friction and stiffness of sandy soil contributing to the load increment. It is shows that among the four H/W ratios, H/W=2.0 indicate the maximum improvement in bearing pressure of soil, but beyond H/W=1.5 it was observe that the settlement value doesn't decreases. Das et al. (2005) similar results published in strip footing supported by the sandy soil.

5.6 Test Series C

The effect of geogrid reinforcement in sandy layer overlay on flyash mixed clayey soil was investigated. The thickness of sandy layer is 150 mm (i.e. H/W = 1.5) and place three layers of geogrid at three different thickness. Variations of pressure – settlement curves published in Fig.11.

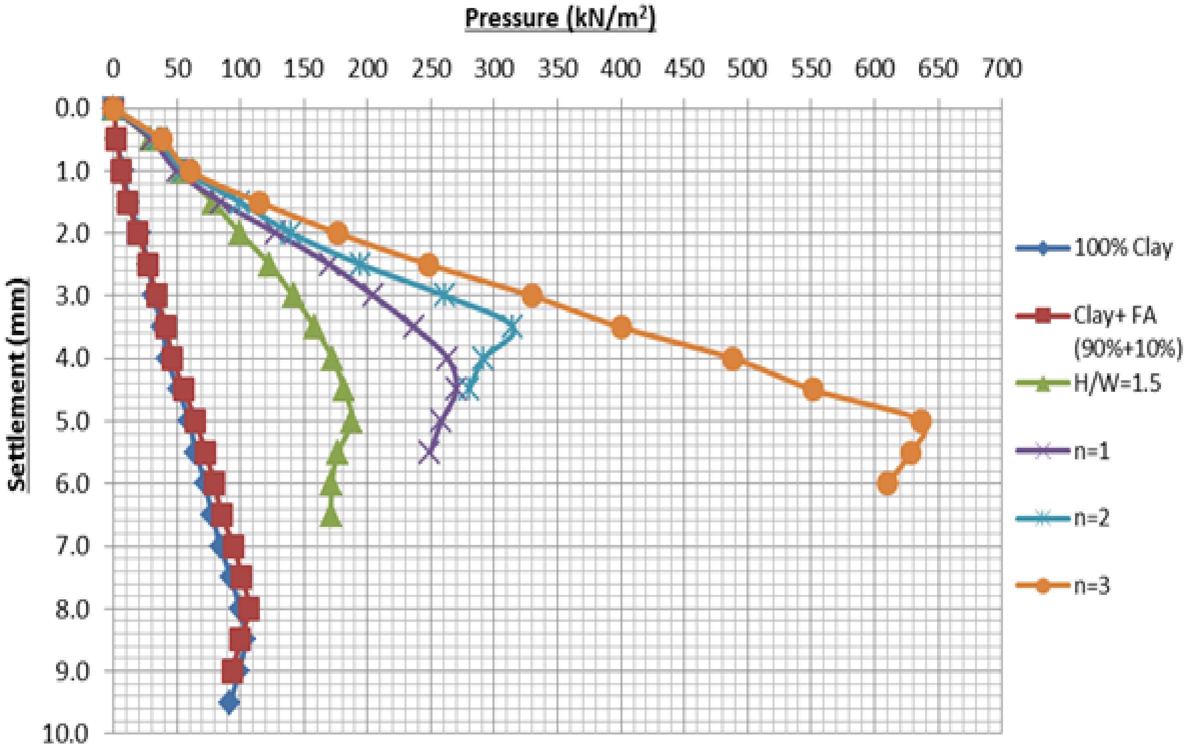


Fig.11. Pressure - settlement curves of number of geogrid layers (n)

With the provision of geogrid reinforcement at the interface and in sand layer, the load carrying capacity increased with that of unreinforced case. Fig.11 indicates the bearing pressure of the reinforced soil increases from layer n = 0 to layer n = 3. The bearing pressure value lies between 187.5 kN/m^2 to 636.7 kN/m^2 for n = 0 and n = 3 respectively. The bearing pressure increases to 80% from original clay (single) to double layer without geogrid, 239% from double layered of without geogrid to three layers of geogrid. Reason may be due to interlocking nature of geogrid, tensile strength of the geogrid and stiffness of the material. The graph indicates slight increase in the settlement value in case of number of layer of geogrid is three (n=3).

6. BEARING PRESSURE RATIO (BPR)

Fig.12 presents the variation of bearing pressure ratio (BPR) with different H/W ratios at unreinforced case. It is observed that if the thickness of sandy layer increases the BPR value was increased. The maximum value of BPR is obtained at H/W =2.0

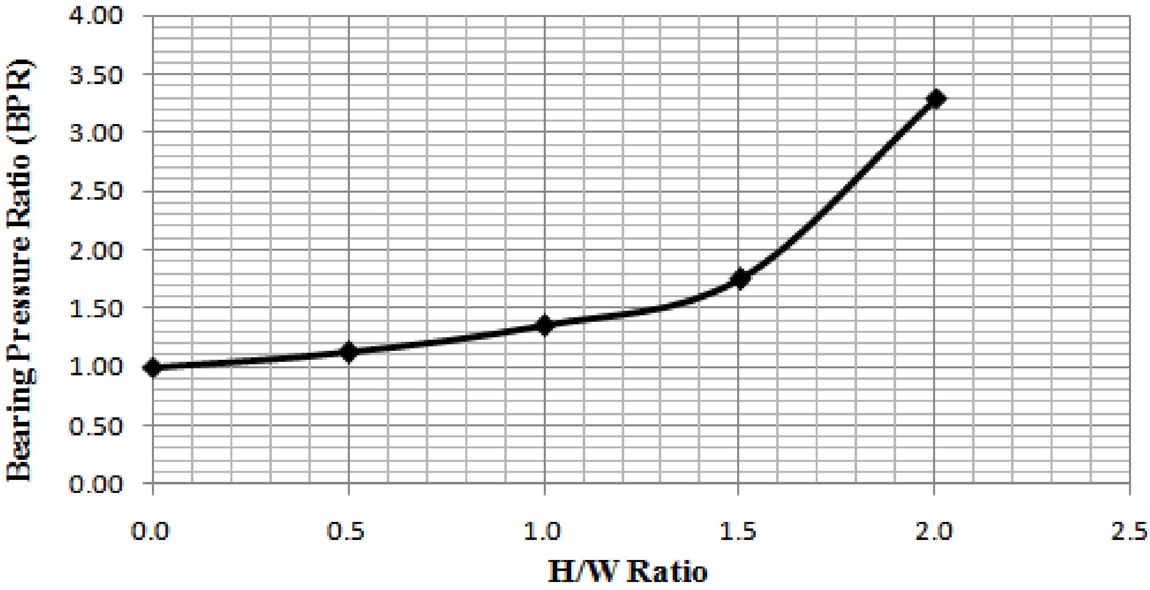


Fig. 12: Influence on bearing pressure ratio (BPR) with H/W ratio

In case of reinforcement, it has been observed that maximum BPR obtained at n=3; results presented in Fig.13. With the use of geogrid layer at the interface of double layered soil the BPR increased from 1.75 to 2.52. Geogrid placed in sand at 50 mm, 100 mm depth from the bottom of footing, the maximum value of BPR is 5.96 at n=3. It can conclude that the use of three reinforcement layers in sand, increase the BPR value up to 2.4 times from single layer of geogrid.

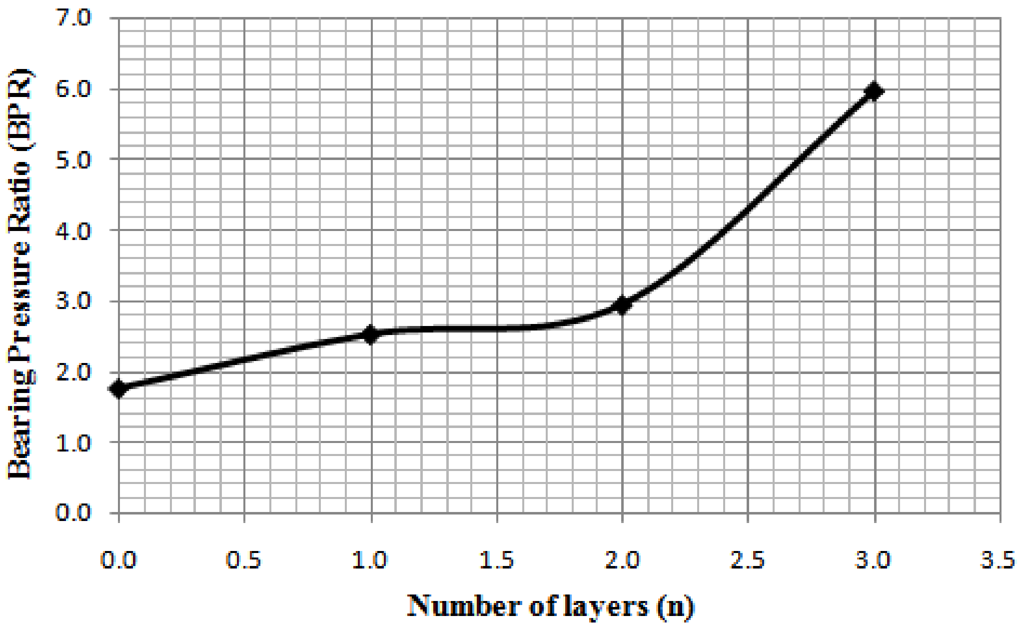


Fig. 13 Variation of bearing pressure ratio (BPR) with no. of geogrid layers (n)

7. SETTLEMENT REDUCTION RATIO (SRR)

The result drawn from the pressure settlement curve, the settlement reduction ratio (SRR) of double layer soil system increase with the increase in thickness of sandy layer (H/W) up to H/W = 1.5, in case H/W = 2, SRR slightly decreased as shown in Fig. 14.

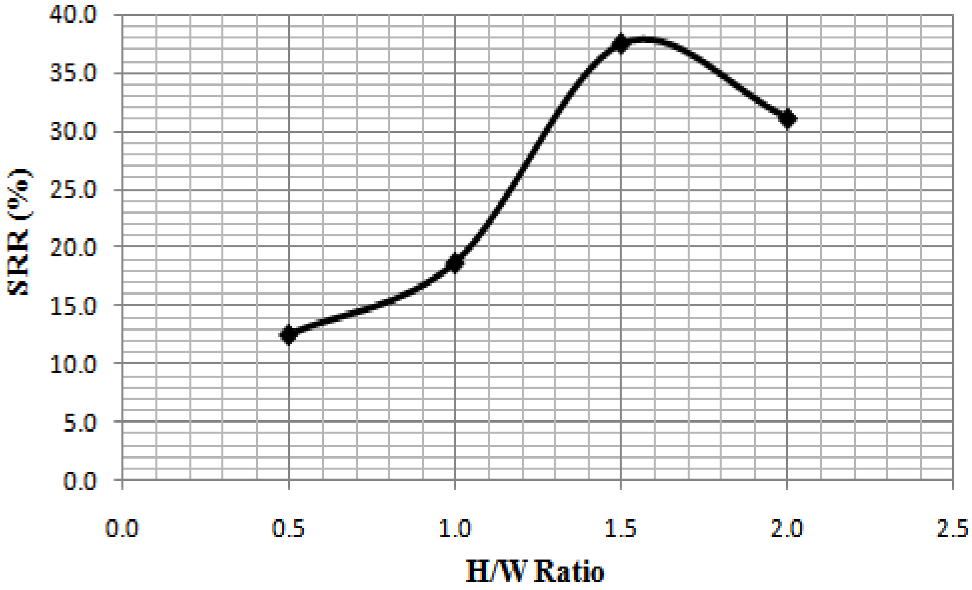


Fig. 14: Variation of SRR with H/W ratios

In case of geogrid reinforcement, SRR significantly increases compare to that of without reinforcement. Fig.15 indicates the reduction ratio of settlement increases with number of geogrid layer (n) up to two, after that author observed SRR slightly decreases with three layers of geogrid. The SRR increases about 13.5% from H/W= 1.5 of without reinforcement to geogrid at interface.

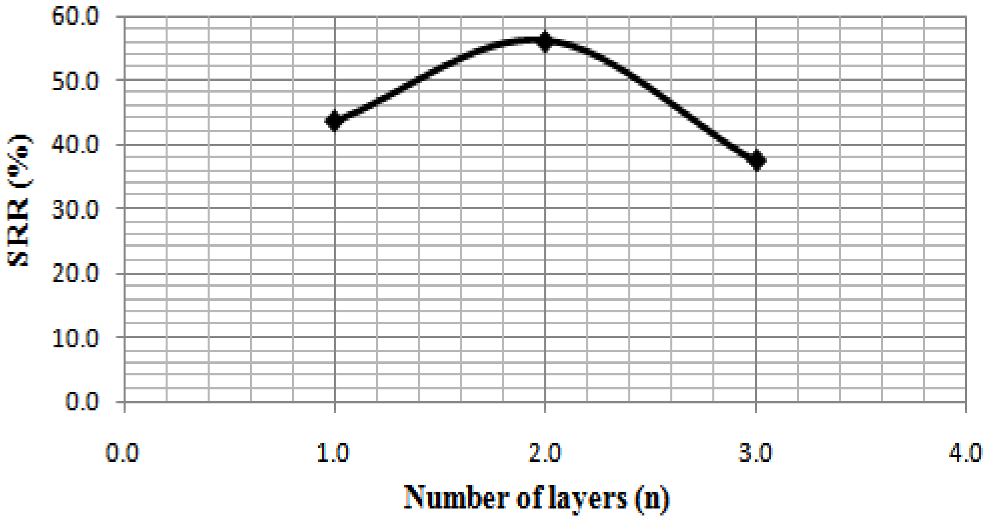


Fig. 15: Variation of SRR with number of geogrid layers (n)

8. IMPROVEMENT FACTOR (IF)

The term improvement factor is comparison of bearing pressure at different settlement values. Improvement factor (IF) is the ratio of bearing pressure at reinforced / unreinforced (P_R) to the bearing pressure on clayey soil (P_O) at different settlement values.

$$IF = P_R/P_O$$

Fig. 16 indicates the variations of IF for different H/W values at different settlement levels. IF increases with an increase in H/W ratio up to H/W=1.5 at same settlement value but after H/W is at 1.5 to 2.0 IF decreases from 8.37 to 7.69.

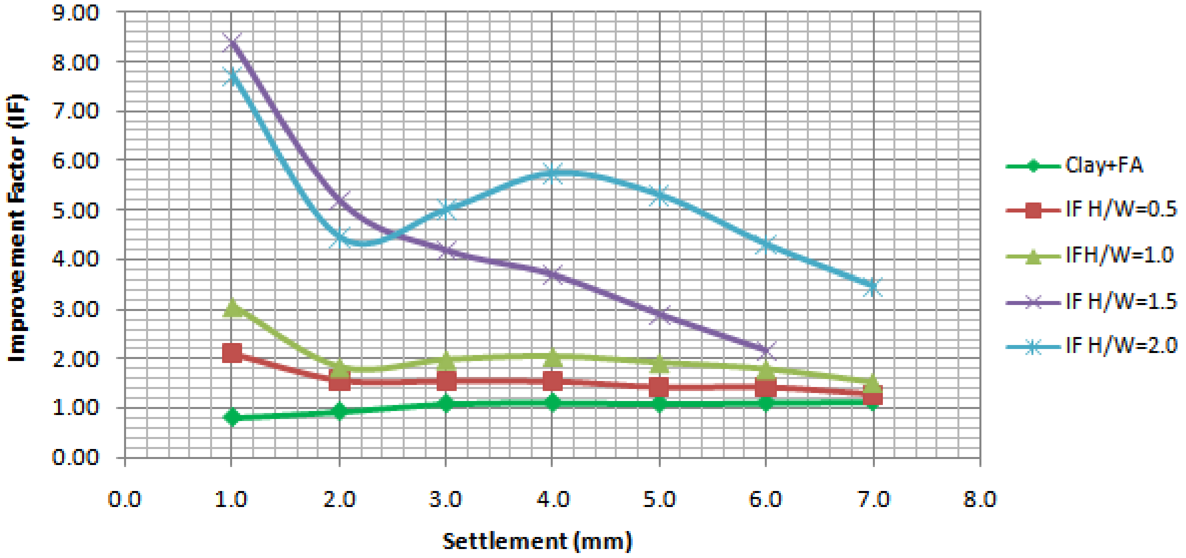


Fig. 16 Variation of improvement factor (IF) with H/W ratio

Fig.17 is the variation of Improvement factor (IF) for n values at different settlement levels. Due to the reinforcement placement the value of IF increases from 8.37 to 9.42. The IF value varies from 8.37 for n= 0 to 9.42 for n=3 at 1mm settlement and 2.16 for n=0 to 7.66 for n=3 at 6 mm settlement.

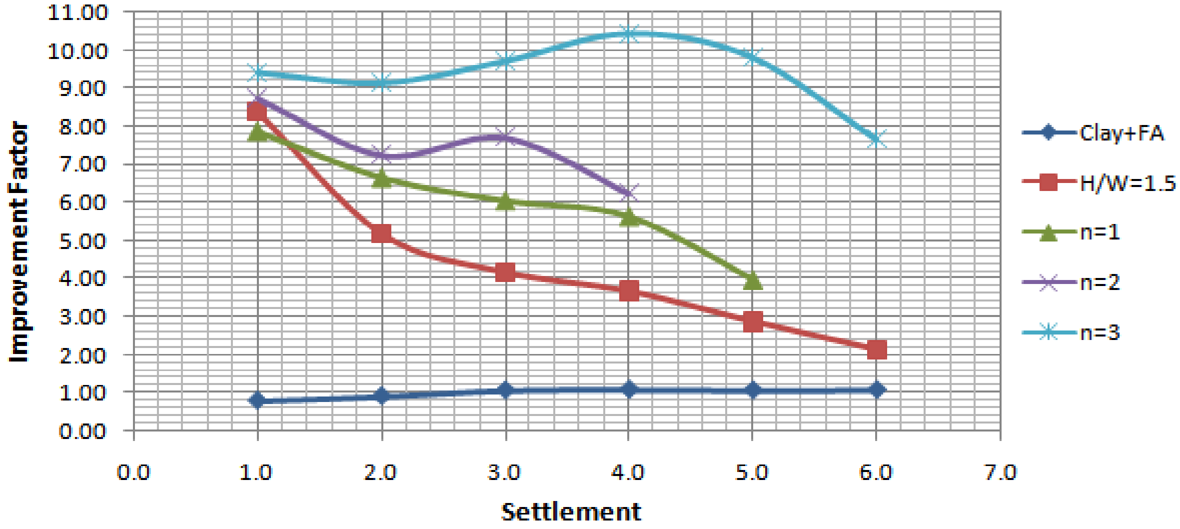


Fig. 17: Variation of IF with number of geogrid layers (n)

9. CONCLUSION

From the optimization of fly ash quantity with clay to model tests investigation, the following concluding remarks may draw.

1. Based on the consistency limits test results, the optimum mix obtained is of 90% clay + 10% flyash, beyond this percentage water content increases.
2. The bearing pressure of clay with 10% fly ash is slightly greater than the clay soil alone. Due to pozzolanic action it may also increase.
3. The bearing pressure of the two layers (sand and stabilized clay) is better than the stabilized clay alone at unreinforced case.
4. The presence of sand on clayey soil improves the load-carrying capacity and decreases the settlement, the thickness of sand layer up to H/W=1.5 effective in settlement perspective.
5. The effect of geogrid reinforcement in sand increases the bearing pressure and decreases the settlement up to two layers of geogrid i.e. n = 2.
6. Bearing pressure ratio is maximum at H/W = 2 for unreinforced case and with three number of geogrid layers. SRR is increases up to H/W is 1.5 for unreinforced case and two number of geogrid layers.

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REFERENCES

[1] Adamska, K. Z. 2008. Laboratory compaction of fly ash and fly ash with cement additions, Journal of Hazardous Materials 151 481–489, Elsevier Ltd.

[2] Alawaji, H. A. 2001. Settlement and bearing capacity of geogrid-reinforced sand over collapsible soil, Geotextiles and Geomembranes 75-88, Elsevier Science Ltd.

[3] Bhuvaneshwari, S., Robinson, R. G. and Gandhi, S. R. 2005. Stabilization of expansive soils using flyash, Fly Ash Utilization Programme (FAUP), TIFAC.

[4] Consoli, N. C., Rosa, F. D. andFonini, A. 2009. Plate Load Tests on Cemented Soil Layers Overlaying Weaker Soil, J. Geotech. Geoenviron. Engg. 135:1846-1856, ASCE/1847.

[5] Das, B. M., Patra, C. R. and Shin, E. C. 2005. Ultimate Bearing Capacity of Eccentrically Loaded Strip foundation On Sand Reinforced with Geogrids, Geotextiles and Geomembranes, 211-218, Elsevier Science Ltd.

[6] Demir, A., Yildiz, A.,Laman, M. and Ornek, M. 2014. Experimental and numerical analyses of circular footing on geogrid-reinforced granular fill underlain by soft clay ActaGeotechnica9: 711–723, © Springer-Verlag Berlin Heidelberg.

[7] Gill, K. S., Choudhary, A. K.,Jha, J. N. and Shukla, S. K. 2013. Large model footing load test on reinforced coalash slope, International Journal of Geotechnical Engineering vol. 7, no.3, 257-265 © 2013 W. S. Maney & Son Ltd.

[8] Hafez, K. M. and Ibrahim, I. 2014. Bearing capacity of circular footing restingon granular soil overlying soft clay, Elsevier B.V. on behalf of Housing and Building National Research Center, 1687-4048.

[9] Jha, J. N., Choudhary, A. K. and Gill, K. S. 2009. Laboratory investigation of bearing capacity behaviour of strip footing on reinforced flyash slope, Geotextiles and Geomembranes, Vol. 28, Issue 4, Pages 393–402, Elsevier Ltd.

[10] Kolay,P. K., Kumar, S. and Tiwari,D. 2013. Improvement of Bearing Capacity of Shallow foundation on geogrid reinforced silty clay and Sand, Journal of Construction Engineering, Volume 2013, Article ID 293809, © Hindawi Publishing Corporation.

[11] Mostafa, A. and Sawwaf, E. L. 2007. Behavior of strip footing on geogrid-reinforced sand over a soft clay slope, Geotextiles and Geomembranes, Volume 25, Issue 1, Pages: 50–60, Elsevier Ltd.

[12] Patra, C. R., Das, B. M. and Atalar, C. 2005. Bearing capacity of embedded strip foundation on geogrid-reinforced sand, Geotextiles and Geomembranes, Vol. 23, Issue 5, 454–462, Elsevier Science Ltd.

[13] Shirvani, R.A. and Shooshpasha, I. 2015. Experimental Study on Load-Settlement Behaviour of Cement Stabilised Footing with Different Dimensions on Sandy Soil, Arab J SciEng 40:397–406, ©The Author(s), Springer.

[14] Thome, A.,Donato, M., Consoli, N. C. and Graham, J. 2005. Circular footings on a cemented layer above weak foundation soil, Canadian Geotechnical Journal 42: 1569–1584, NRC Canada.

[15] Tripathi, R. K. and Yadu, L. K. 2014. Effect on Bearing Capacity Ratio of Strip Footing for Various Granular Fill Thickness and Number of Geogrid Layers in Granular Fill Overlay on Soft Soil, Geo-Congress Technical Papers, GSP 234 © ASCE.

[16] Tripathi, R. K. and Yadu, L. K. 2014. Effect of Depth and Number of Layers of Reinforcement on Bearing Capacity Ratio of Strip Footing Resting on Granulated Blast Furnace Slag Reinforced with Geogrid, Geo-Congress Technical Papers, GSP 234 © ASCE..

[17] Udayashankar, D. 2010. Geotechnical Characteristics of Hubli - Dharwad Black Cotton Soils Mixed With Fly Ash: An Experimental Evaluation, Indian Geotechnical Conference, GEO trendz, IGS Mumbai Chapter & IIT Bombay.

[18] Umesha, T. S., Dinesh, S. V. and Sivapullaiah, P. V. 2009. Control of dispersivity of soil using lime and cement, International Journal of Geology, Issue 1, Vol. 3.

[19] Yadu, L. K. and Tripathi, R. K. 2014. Effect of the length of geogrid layers in the bearing capacity ratio of geogrid reinforced granular fill-soft subgrade soil system, Procedia - Social and Behavioral Sciences 12/2013; 104:225-234, Published by Elsevier.

[20] Yadu, L. K. and Tripathi, R. K. 2013. Stabilization of soft soil with granulated blast furnace slag and fly ash, International Journal of Research in Engineering and Technology ISSN: 2319-1163, Volume: 02 Issue: 02.