BEHAVIOUR OF A STRIP FOOTING RESTING ON ANCHORED GEOSYNTHETIC REINFORCED SAND BED

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Abstract: This paper presents the results of laboratory study that has been conducted to investigate the load–settlement behaviour of strip footing resting on anchored geosynthetic reinforced sand bed. This is achieved by conducting a series of plain strain model test with strip footing. The effect of the breadth of reinforcement, number of reinforcement layer, depth of first layer of reinforcement, provision of end anchors have been examined. The load and corresponding settlement were measured. The results have been presented in the form of bearing pressure versus footing settlement curve. It is observed that increase in number of layer of reinforcement increased the ultimate bearing capacity. Increase in breadth of reinforcement also increased the bearing capacity, till the breadth touches the boundary zone of stress distribution beneath the footing. Provision of end anchors improved the bearing capacity of reinforced sand bed system if it is placed within the zone of stress distribution beneath the footing.

Keywords: anchor, bearing capacity, geogrid, load test, reinforcement, settlement

INTRODUCTION

The basic concept of soil reinforcement is to impart apparent tensile strength to the soil, which is otherwise weak in tension. This mechanism effectively spreads the load over the entire mass and eliminates the need for large spread footing or piles.

It has been well recognized that multiple horizontal layers of high strength geotextiles or geogrids can reinforce the soil beneath footings, piers, rigid walls, high way and airport pavement, trafficked areas and embankments. The rational behind this principle follows the work of Binquet and Lee (1975). They found definite improvement, which was further evidenced by cost saving in an economic analysis. However, when corrosion was considered, the economic benefits where essentially lost. With non corroding and non biodegradable geosynthetics as the reinforcement, the problem of corrosion is eliminated. This classical work reported by Binquet and Lee (1975) triggered lot of interest in this area of research and motivated several hurdles posed by conventional metallic reinforcement. Krishnaswamy (2005) reported bearing capacity of circular and strip footing on a reinforced soil bed containing horizontal layers of tensile reinforcement with end anchors. Visakan (2006) conducted the laboratory model test to study the behaviour of geosynthetic reinforced sand-foundation system with end anchors and so many researchers carried out their research on reinforced soil.

The present study deals with load-settlement behaviour of a strip footing resting on an anchored geosynthetic reinforced sand bed improving the bearing capacity and reducing the settlement. The soil below the footing is subjected to tension, and hence reinforcement is more effective, while the soil beyond the footing subjected to compression and hence reinforcement is not effective. Anchors are provided in reinforcement member to mobilise the maximum passive resistance (k_p). Model studies were carried out using mild steel plates of size, 150mm x 750mm x 20mm to represent a strip footing. Locally available dry river sand used along with the aluminium angles have been used as anchoring system and polypropylene geogrid namely Netlon CE 121 was used as the reinforcement.

EXPERIMENTAL PROGRAMME

Material used

The locally available river sand has been used in the investigation. The properties of sand as follows: G = 2.57, effective grain size (D_{10}) = 0.27mm, uniformity coefficient (Cu) = 2.44, maximum dry unit weight (γ_{dmax}) = 17.51kN/m^3 and minimum dry unit weight (γ_{dmin}) = 14.11kN/m^3, IS classification = SP. High strength polypropylene Netlon CE 121 geogrid is used as the reinforcement. The properties of geogrid as follows: Aperture shape – Diamond, Aperture size = 8mm x 6mm, thickness at joints = 3.1mm, weight = 730±73gm/m^2 and load at 10% of extension = 6.8 kN/m. Aluminum angles of size 12.7mm x 12.7mm x 1.7mm have been used as anchorage system. The angles are coupled to the reinforcement using screws and nuts.

Testing programme

The model tests were performed in a well stiffened rectangular steel tank size of 820mm x 1060mm x 760mm. Load tests were conducted on the footing using a hydraulic jack. A schematic diagram of the loading assembly is shown in Figure 1.

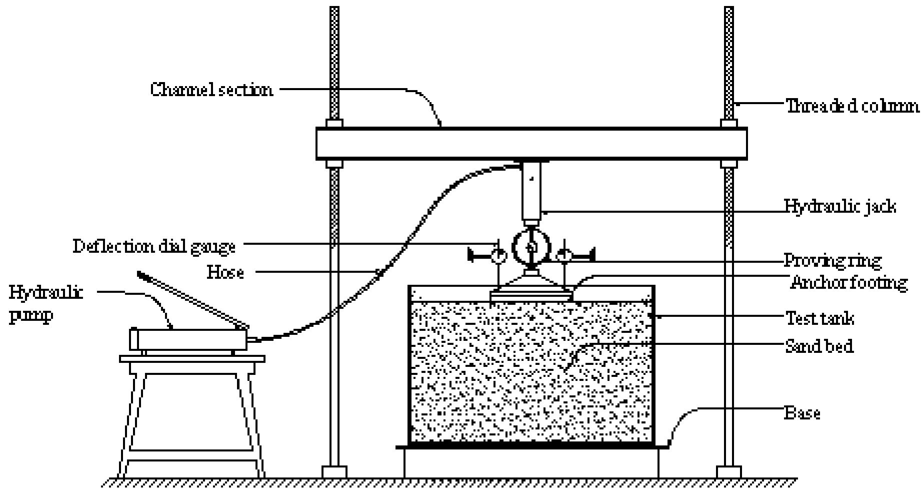

Figure 1. A schematic diagram of the loading assembly

The controlled pouring has been adopted for the preparation of uniform sand bed of required relative density I_D =63% for all test. This technique is employed to achieve the reproducible density. The applied load was measured with the pre-calibrated proving ring arrangement which was directly connected to the footing and attached to the hydraulic jack. Displacement of footing was measured using a settlement dial gauge having 50mm run which is placed on the model footing.

DISCUSSION ON TEST RESULTS

Effect of reinforcement on bearing capacity

Effect of depth of first layer of reinforcement

To understand the effect of the depth of first layer of reinforcement on ultimate bearing capacity values, the bearing pressure-settlement behaviour of a footing resting on a single layer of reinforcement placed at a depth of 0.25B and 0.50B was investigated. The ultimate bearing capacity of unreinforced sand bed is 90kN/m^2. The provision of first layer of reinforcement from the bottom of the footing (u) = 0.25B showed ultimate bearing capacity of 172kN/m^2 and 184kN/m^2 for breadth of reinforcement (Br) = 1.5B and 2.5B respectively. For the depth of first layer of reinforcement 0.50B, the ultimate bearing capacities observed is 144kN/m^2 and 136kN/m^2 for breadth of reinforcement 1.5B and 2.5B

To better understand the effect of depth of first layer of reinforcement on ultimate bearing capacity values, the same is plotted against the ratio of depth of first layer of reinforcement from the bottom of the footing (u/B) in Figure 2. It is observed that as the depth of first layer of reinforcement increases from u/B = 0.25 the ultimate bearing capacity decreases. However, the rate of decrease in ultimate bearing capacity is more for Br = 2.5B.

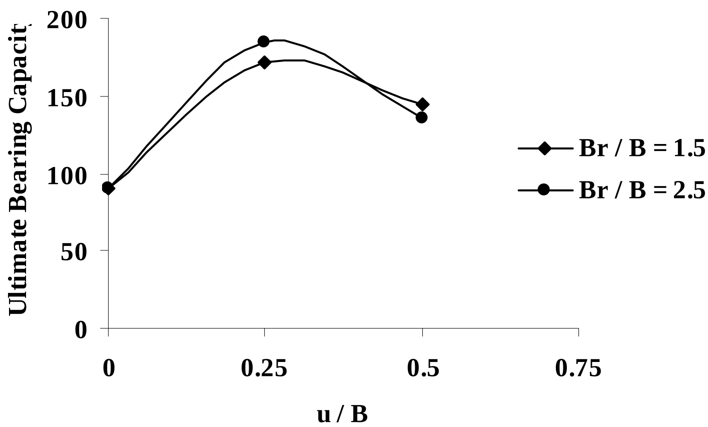

Figure 2. Variation of ultimate bearing capacity with u / B ratio

Effect of breadth of reinforcement on bearing capacity

Figure 3 shows the bearing pressure-settlement plot of strip footing resting on unreinforced and reinforced sand bed of relative density 63%. The breadth of reinforcement of 1.5B, 2.5B and 4.0B are used to reinforce the sand bed. From Figure 3, it is seen that the initial portion of bearing pressure versus settlement curve for various breadth of reinforcement overlaps on each other. However, the final portions of the curves deviate from each other and exhibit increase in ultimate bearing capacity with increase in breadth of reinforcement. The provision of single layer of reinforcement of breadth (Br) 1.5B showed ultimate bearing capacity of 172kN/m^2. For the reinforcement of breadth 2.5B and 4.0B the ultimate bearing capacity observed are 184 kN/m^2 and 191kN/m^2 respectively.

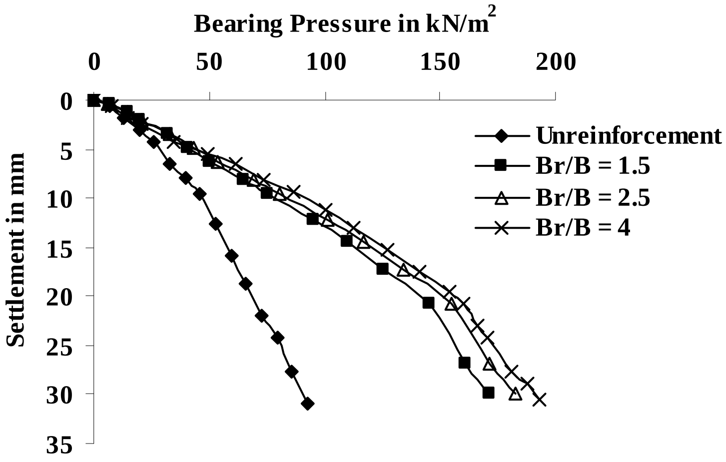

Figure 3. Bearing pressure versus settlement for various Br/B ratios. (N=1)

To better understand the effect of breadth of reinforcement on ultimate bearing capacity values, the same is plotted against the ratio of breadth of reinforcement to breadth of footing (Br/B) in Figure 4.

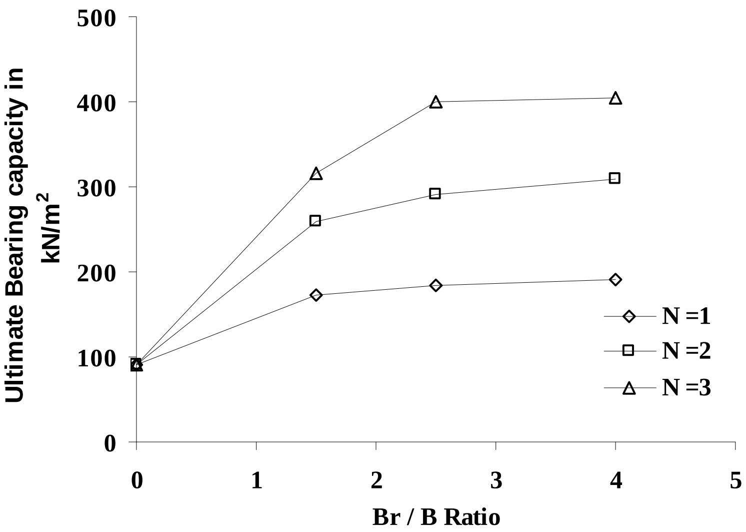

Figure 4. Variation of Ultimate Bearing Capacity with Br/B ratios (I_D=63%)

It is observed that as the breadth of reinforcement increases the ultimate bearing capacity also increases. However, the rate of increase in ultimate bearing capacity is more for Br = 1.5B. As the Br/B increases to 2.5 the rate of increase is reduced. Beyond Br = 2.5B, the rate of increase is marginal. The improvement in bearing pressure for breadth ratio of 1.5 when compared to unreinforced sand is 91%. The same for breadth ratio of 2.5 is 112%. Bearing capacity ratio (BCR) is calculated for each case to understand the effect of breadth reinforcement on bearing capacity. The bearing capacity ratio is defined as the ratio of ultimate bearing capacity of reinforcement system with or with out anchor to ultimate bearing capacity of unreinforcement system.

$$\mathrm{BCR} = \frac{q_R}{q_u} (\mathrm{or}) \frac{q_{RA}}{q_u} \tag{1}$$

Where, q_u = Ultimate bearing capacity of footing on unreinforced sand

q_R = Ultimate bearing capacity of footing on reinforced sand without end anchors

q_{RA} = Ultimate bearing capacity of footing on reinforced sand with end anchors

Figure 5 plot the bearing capacity ratio for reinforcement of various Br/B ratios placed in sand bed of relative density 63%. It is observed from Figure 5 that for the breadth of reinforcement up to 2.5 times the breadth of footing, the rate of increase in bearing capacity is much higher. Further increase in breadth of reinforcement also resulted in increase in bearing capacity, but at lesser rate.

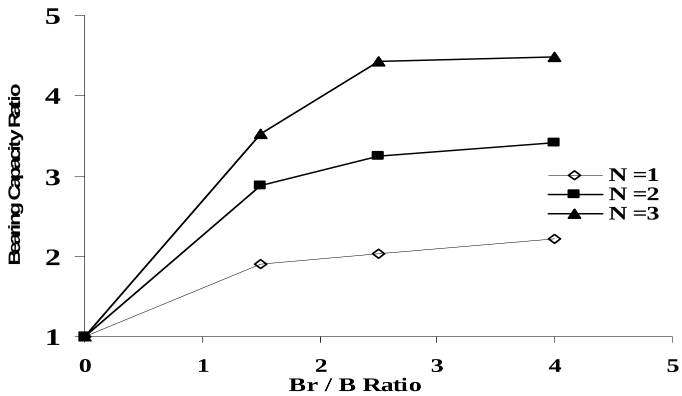

Figure 5. Variation of BCR with Br/B ratios (I_D=63%)

Effect of Number of layers of reinforcement (N) on bearing capacity

The number of reinforcement layers of N =1, 2 and 3 are used to reinforce the sand bed. Vertical spacing (h/B ratio) between the reinforcement layers is maintained as 0.25 for all the test. Figure 4 exhibits increase in ultimate bearing capacity with increase in number of layers of reinforcement. The provision of single layer of reinforcement (N=1) showed ultimate bearing capacity of 172kN/m^2 for Br/B=1.5. The same for two layer and three layer system (N=2 &3) the ultimate bearing capacity observed are 259kN/m^2 and 317kN/m^2 respectively.

The improvement in bearing capacity for single layer reinforcement when compared to unreinforced sand is 91%. The same for two layers and three layer systems are 188% and 252% respectively. Table 1 presents the ultimate bearing capacity of multi layered reinforced sand bed at various Br/B ratios.

Table 1. Ultimate Bearing Capacity of multi layered reinforced sand bed at various Br/B ratios

Description	Ultimate Bearing Capacity kN/m^2		
	Br/B = 1.5	**Br/B = 2.5**	**Br/B = 4.0**
N = 1	**172**	**184**	**191**
N = 2	**259**	**292**	**308**
N = 3	**317**	**399**	**404**

Effect of reinforcement with end anchors on bearing capacity

The previous section brought out the effect of breadth of reinforcement in enhancing the bearing capacity of sand bed. This section deals with the role of end anchors provided in reinforcement on bearing capacity of sand bed. Experiments were conducted on sand bed reinforced by providing end anchor of height (2a) = 25.4mm. The breadth of reinforcement used is 1.5B and 2.5B. The experimental results of reinforcement with end anchors are presented and discussed in the following sub-sections.

Effect on breadth of reinforcement with end anchors on bearing capacity

Figure 6 shows plot the bearing capacity with settlement response of footing resting on end anchored reinforced sand at relative density of 63% breadth of reinforcement used are 1.5B and 2.5B.

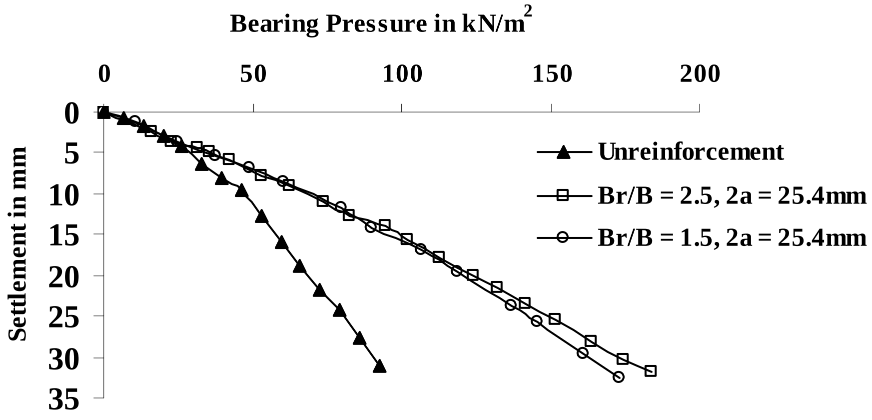

Figure 6. Bearing pressure versus settlement for end anchor reinforced sand bed of various Br/B ratio (N=1)

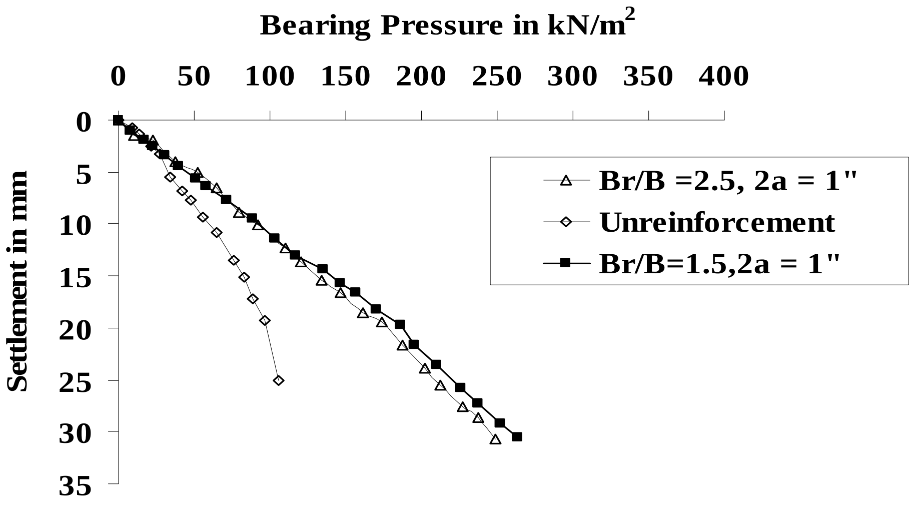

Figure 7. Bearing pressure versus settlement for end anchor reinforced sand bed of various Br/B ratio (N=2)

The ultimate bearing capacity for single layer reinforcement with end anchor is found to be 163kN/m^2 and 164kN/m^2 respectively for breadth of reinforcement (Br) of 1.5B and 2.5B. For single layer of anchored reinforced sand bed the increase in breadth of reinforcement from 1.5B to 2.5B has no influence on the bearing capacity. For two layer reinforcement it is 249kN/m^2 and 244kN/m^2 respectively for breadth of reinforcement (Br) of 1.5B and 2.5B and it is shown in Figure 7. For two layers of reinforcement it is seen that as the breadth of anchored reinforcement increases beyond 1.5B, the ultimate bearing capacity decreases.

Variation of ultimate bearing capacity with breadth of reinforcement for strip footing resting on plain and end anchored reinforced sand bed at relative density of 63% for breadth of reinforcement (Br) of 1.5B is plotted in Figure 8. It is observed that as the breadth of reinforcement increases the ultimate bearing capacity also increase for reinforcement without end anchors. The provision of end anchors in the reinforcement considerably influence the ultimate bearing capacity for reinforcement of breadth up to 1.5B. For further increases in breadth of end anchored reinforcement, the bearing capacity decreased considerably when compared to sand bed reinforced with plain reinforcement.

It is quantified that provision of two layer reinforcement with end anchor contributed 177% increase in ultimate bearing capacity compared to the unreinforced for breadth of reinforcement (Br) 1.5B. When the breadth of reinforcement (Br) is 2.5B, its contribution is 171%. When compared to the plain reinforcement, the provision of end anchors contributed 4% and 20% decrease in ultimate bearing capacity for breadth of reinforcement (Br) 1.5B and 2.5B respectively.

This is due to the fact that, as the depth of first layer of reinforcement from the bottom of the footing (u/B ratio) decreases, surcharge load on the anchor gets reduced. While applying downward vertical compressive load, the end anchored reinforcement layer tries to rotate upward and it is exposed at the surface because of insufficient surcharge. The schematic diagram of the failure mechanism of reinforcement with end anchor for u/B = 0.25 is shown in Figure 9.

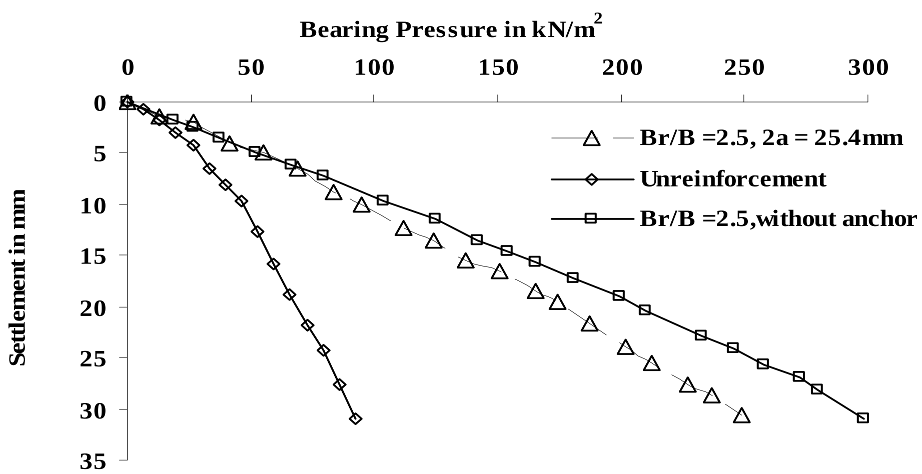

Figure 8. Bearing pressure versus settlement for reinforced sand bed with and without end anchors (u/B = 0.25, N=2)

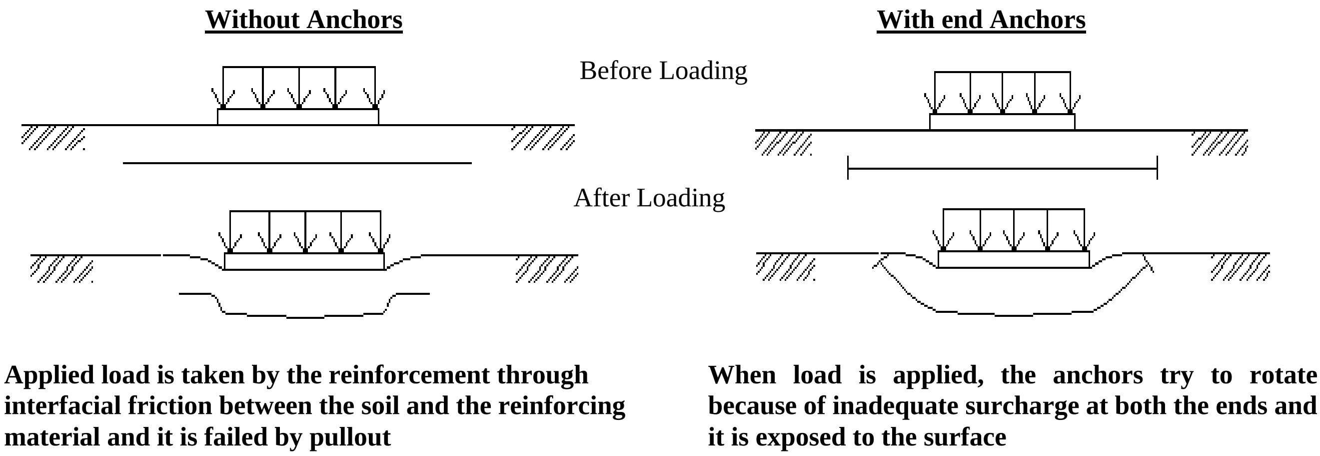

Figure 9. Failure mechanism of reinforced and bed with and without end anchors for u/B = 0.25

The ultimate bearing capacity of reinforcement with end anchor placed at a depth of u/B = 0.25 is found to be 160kN/m^2 and 152kN/m^2 for breadth of reinforcement Br =1.5B and 2.5B respectively. From Figure 4.10 it is observed that, the provision of end anchors of u/B = 0.5 contributed 11% increase in ultimate bearing capacity compared to the same with u/B = 0.25 for breadth of reinforcement 1.5B and 12% for breadth of reinforcement 2.5B.

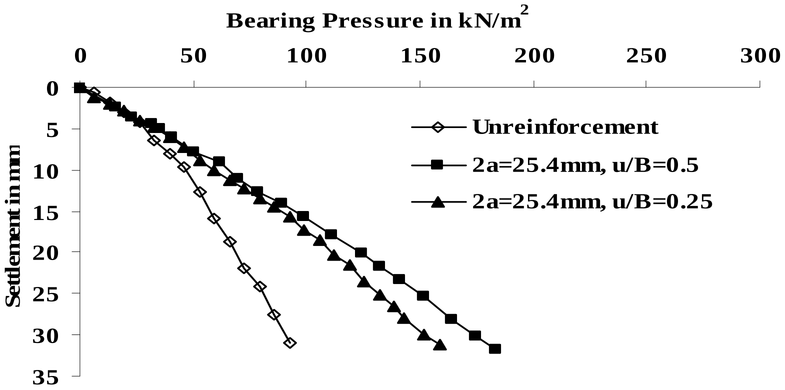

Figure 10. Bearing pressure versus settlement for reinforced sand bed with end anchor of u/B = 0.25 and u/B = 0.5 (Br/B=2.5, N=1)

CONCLUSIONS

Based on the experimental and proposed theoretical analysis, the following conclusions are drawn:

1. As the depth of first layer of reinforcement from the bottom of the footing (u) increases the ultimate bearing capacity decreases. By increasing the u/B ratio from 0.25 to 0.5, the ultimate bearing capacity is decreased by 19% for breadth of reinforcement Br = 1.5B when compared to unreinforced case. Similarly for Br = 2.5B the percentage decrease in ultimate bearing capacity is 34%.
2. Reinforcement of various breadths placed at a depth of first layer of reinforcement u/B = 0.25 and vertical spacing between two layers h/B = 0.25 of relative density 63% revealed that increase in breadth of reinforcement let to an increase in bearing capacity. This increase in bearing capacity is significant up to a reinforcement of breadth 2.5 times the breadth of footing.
3. The provision of increased number of layers of reinforcement in sand bed increases the ultimate bearing capacity. For single layer reinforcement, the improvement in ultimate bearing capacity is 91% when compared to the unreinforced sand bed. Similarly for two layer and three layer system are 188% and 252% respectively of breadth of reinforcement 1.5B.
4. The effect of provision of end anchors for breadth of reinforcement (Br) 1.5B and 2.5B of 25.4mm height anchor placed at u/B = 0.25 resulted 177% and 171% increase in ultimate bearing capacity compared to the unreinforced. However this provision decreased the ultimate bearing capacity by 4% and 20% for breadth of reinforcement 1.5B and 2.5B when compared with plain reinforcement. The reduction in ultimate bearing capacity is due to the rotation of reinforcement at the end anchors because of inadequate surcharge over the end anchors.
5. The provision of end anchor enhances the ultimate bearing capacity by increasing the depth of first layer of reinforcement (u). By increasing the u/B ratio from 0.25 to 0.50, the ultimate bearing capacity is increased by

11% and 12% for breadth of reinforcement (Br) 1.5B and 2.5B respectively when compared to plain reinforcement.

REFERENCES

Binquet, J. and Lee, K.L., 1975. Bearing Capacity Tests on Earth Slabs. Journal of the Geotechnical Engineering Division, ASCE, Vol. 101, No. GT 12, pp. 1241-1255.

Krishnaswamy, N. R., 2005. Behaviour of Reinforced Soil – Foundation Systems. Proceedings of Geopredict, pp. 1-27.

Visakan, R., 2006.Behaviour of Geosynthetic Reinforced Sand – Foundation System With Anchors. Proceedings of Indian Geotechnical Conference, Vol. 2, pp. 587 – 590.