Experimental Study for the Behaviour of Footings on Reinforced Sand Beds Overlying Soft Clay Zone

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Abstract: The aim of the work was to study the efficiency of using reinforcement layers in order to enhance the bearing capacity of soils that are characterized by the existence of localized soft clay zone. Small-scale model experiments using tank were conducted with beds created from well graded sand prepared with different dry densities. Soft clay was embedded at predetermined locations within the sand beds so as to represent localized soft clay zone. Various arrangements of soil reinforcement were tested and compared against comparable tests but without reinforcement. Tests were carried out in order to study the effect of the width and depth of the soft clay zone, the depth of reinforcing layers, the length, number and of reinforcing layers on the soil bearing capacity also,the spacing between reinforcement layers. The results show clearly that the ultimate bearing capacity reduces by up to 70% due to the presence of a soft clay zone. It was also noted that the proximity of the soft clay zone also influenced the bearing capacity. Reinforcing the soil with two layers or increasing the length of reinforcement is not as effective as was anticipated based on previous studies. However, bearing capacity increased significantly (up to 3 times) to that of unreinforced sand when four layers of reinforcement were embedded.

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Key words: Bearing capacity, Ground variability, Soft clay zone, Soil reinforcement; Bearing capacity ratio; Geogrid reinforcement; Reinforced sand;

1. Introduction

In situ stabilization of weak soils has risen markedly, with geogrid reinforcement being one more appropriate method of treatment. Successful applications of geogrids for the reinforcement of sub-base layers over weak and soft soils have led to a practical control of excessive settlement in many geotechnical applications (**Tensar, 1995; British Rail Research, 1998**).Generally, the beneficial influence of geogrid reinforcement on the bearing capacity, settlement and subgrade modulus has been recognized for quite some time. Several laboratory model load tests on geogrid-reinforced sand have been published in the literature (**Guido *et al.*, 1985; Guido and Sweeny, 1987; Khing *et al.*, 1992, 1993;Omar *et al.*, 1993;Yeo *et al.*, 1993; Das and Omar, 1994; Huang and Menq, 1997; Kurian *et al.*, 1997; Gabr *et al.*, 1998;Wayne *et al.*, 1998 ;Alawaji, 2001)**. These model tests were conducted with model square or strip foundations on sand. Primarily, control parameters in these tests were the location of the top layer of the reinforcement measured from the bottom of the foundation, the depth of reinforcement, the number of reinforcement layers and the width of each reinforcement layer. **British Rail Research (1998)** has demonstrated that geogrid inserted in the ballast where tracks lie over soft ground can help extend maintenance intervals. Several case studies describe and illustrate projects in which the geogrids have been successfully used (**Tensar International, 1995**). Among these examples are: a retail development over soft clays with a high water table, a dual carriageway over variable soft clay with saturated sand lenses and trials to evaluate the benefits of reinforcing granular sub-bases over a weak subgrade. Many other recent applications in Asia have been presented in the special session organized by ISSMGE, TC9 (**Ochiai and Otani, 1999**). **Tsukada *et al.* (1993)** found that the settlement response and pressure distribution was directly related to the thickness and configuration of the geogrid-reinforced foundation. More recently, the effects of sand pad over very weak soil have been discussed by **Alawaji (1997)**.

Most of the previous studies investigated the performance of reinforced sand, reinforced cohesive soil or reinforced sand overlying a clay layer of uniform thickness. However, less attention has been given for more practical soils in which local changes in the ground conditions occur e.g. due to the inclusion of localized soft pockets and voids. They occur as a result of natural and/or manmade activities and are often encountered in construction sites. For example, poor supervision and implementation of engineering works would result in poorly filled voids and trenches (**BRE, 2004**) as well as a significant variation in the ground strength in abandoned landfill sites. Furthermore, soft pockets/zones can also be encountered in many virgin soils in the form of e.g.

soft clay plugs within sandy meander belts and in tropical areas due to leaching and deposition of fine clay particles by the infiltration of water (**Prothero and Schwab, 2004**). The size and location of a soft pocket can vary widely and its existence can cause a significant ground distress and might result in intolerable ground movement if appropriate remedial measures are not undertaken. Despite the early efforts by **Binquet and Lee (1975)** to understand the behavior of reinforced soils overlying a soft zone, there is a lack of detailed investigations to quantify the effect of the local variability of ground conditions. In particular, the influence of localized soft zones on the behaviour of subsurface soils under foundation loadings is poorly understood and has hindered the development of a comprehensive analytical model. Unlike soft zones, studies for reinforced ground overlying voids received more consideration (**Giroud *et al.*, 1990; Poorooshasb, 1991; Das and Khing, 1994; Wang *et al.*, 1996; Alexiew, 1998; Sireesh *et al.*, 2009).**

This paper presents the results of some laboratory-model load tests ona foundation to investigate the effects of width and depth of a localized soft clay zone on the ultimate bearing capacity of unreinforced sand beds, the reinforcement configuration including the depth of two reinforcement layers, number of reinforcing layers, and length of reinforcement on the load carrying capacity of the reinforced system also, the spacing between reinforced layers. These factors will be investigated at two different states of soil packing so as to study the influence of soil density and hence soil strength on the behaviour of the reinforced system.

2 Materials

2.1. Sand

A commercially available graded sand were used to prepare the sand bed placed in the container .The average particle size of sand was ranging between 1-4mm. To maintain same unit weight of sand in each test, the required weight of sand in each layer was calculated based on bulk unit weight. The sand was poured in layers. The sand is represented in table1.

2.2. Clayey soils

The properties of clay have been presented in table 2.

2.3. Geogrid

Biaxial geogrid was used as a reinforcement layer. The properties of geogrid reinforcement have been presented in Table 3.

Table 1: Properties of sand.

Parameters	Values
	Sand
Specific gravity	2,7
Maximum dry unit weight	19.2 KN/m³
Bulk unit weight at 65% relative density	17.9 KN/m³

Table 2: Engineering properties of clayey soil

Property	Soil
Classification	CL
Colour	Brown
Liquid limit%	45
Plastic limit%	20
Plasticity index%	25
Optimum moisture content%	18.0
Maximum dry unit weight	17 KN/m³
Specific gravity	2.63
Bulk unit weight at 25%water content	19.2KN/m³

Table 3: Properties of geogrid Netlon C121

Parameter	Value
Aperture size	8x6 mm
Thickness	3.3 mm
Weight	730gm/m²
Tensile strength	768kg/m
Elastic modulus(E)	4500 kg/cm²
Yield stress(fy)	230kg/cm²

3 Testing programme

3.1. Experimental Design

To study the behaviour of unreinforced and reinforced sand beds with the inclusion of soft clay zone, a rectangular tank of 1000 mm x 250 mm size and 500 mm high was used for this study. Steel plate of 100x250 mm and thickness 10 mm was used as footing to apply the load. Dial gauges were used for measuring the settlement of footing during the application of load.

The applied load and settlement of the footing were measured and recorded. The experiments were carried out at two different densities which are 1.45 g/cm3 and 1.70 kg/cm3 so as to represent two practical soil states (loose and dense respectively).

The first test was carried out on sand bed with the soft clay zone without any improvement techniques and the load-settlement behaviour was investigated. Other tests were carried out with geogrid-reinforced sand bed. Fig. 1. shows the schematic diagram of the test setup. Summary of the tests conducted has been presented in fig 2,3,4,5,6 & 7.

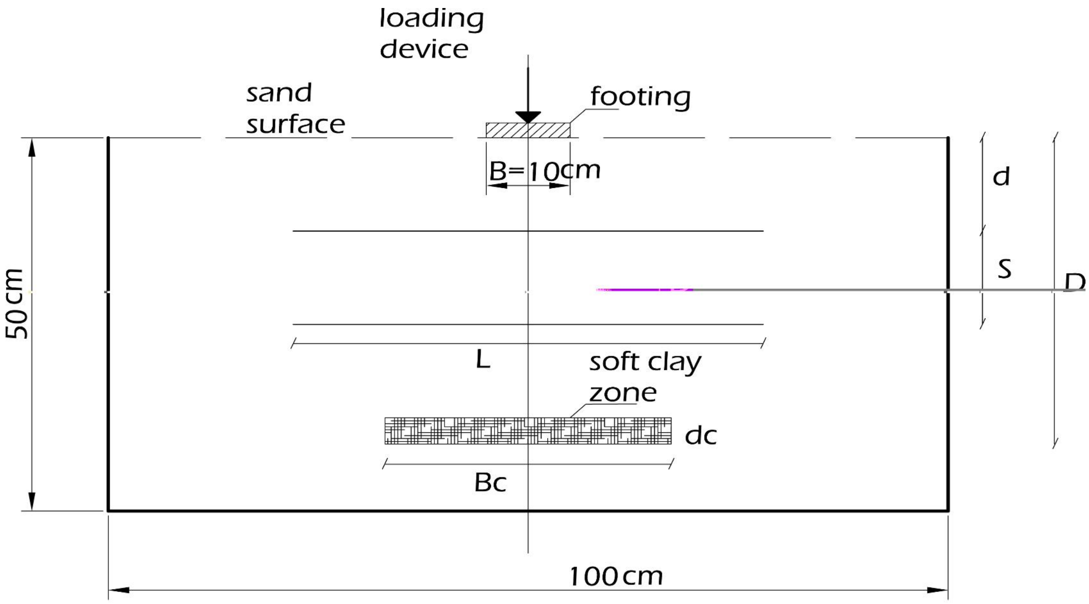

Fig 1. Test apparatus

3.2. Preparation of sand bed

The weight of sand required to form a certain thickness of the bed was determined by knowing unit weight of sand. For different thicknesses of sand, the required weight of sand was calculated and preparation of bed was carried out in layers in order to achieve the required depth of sand bed.

3.3. Preparation of clay bed zone

In all the tests, identical technique was to prepare the clay zone bed. To maintain same unit weight of clay in each test, the required weight of clay in each layer was calculated. Each layer achieved the required thickness.

3.4. Test procedure

Loading was applied through a footing resting on the prepared soil bed and settlement of test bed with or without soft clay zone was measured with the help of dial gauges. Load was applied in equal increments and each increment of the load was maintained until negligible change in the settlement was observed. The settlement due to increment of each equal interval of loading step was observed through two dial gauges having least count of 0.02 mm fixed on the footing. Loading was applied until the total settlement of the footing attained was at least 10% of footing width (B).

4. Results and Discussion

It should be noted that all measured values for the vertical settlement (S) are presented as a function of the footing width (B). In this paper all values for the ultimate bearing pressure values were determined at a vertical settlement of 10% of the footing width . This settlement value was selected because it would indicate practically a failure due to excessive settlement. Results of loading tests on sand beds without the inclusion of a soft clay zone indicated that load-settlement relations were obtained and the ultimate bearing capacity was found to be 70 kPa and 110 kPa for loose and dense sand beds respectively at S/B of 10%.

4.1 Effect of localized soft clay zone width

Experiments were undertaken to quantify the effect of width of a localised soft clay zone on the bearing capacity of unreinforced loose and dense sand beds where dc the thickness of soft clay zone was taken 0.5B (50mm) as illustrated. Fig. 2a and b shows the results of the bearing pressure against settlement ratio for different soft clay zone widths. Also shown are the results of the load-settlement relations for sand beds without the inclusion of soft clay zone. The results clearly demonstrate that the load carrying capacity of a sand bed reduces significantly with the increase in the width of a soft clay zone . In dense sand beds containing a localized soft clay zone, the figure showed a direct dependence on the width of the soft clay zone , Fig. 2b. Localised soft clay zone beneath the footing intercept the failure zone in the sand bed and cause significant transformation in stresses.. With the increase in the footing load, soil arch fails and subsequently a significant portion of the stresses is transferred to the soft clay zone leading to a substantial settlement (**Das and Khing, 1994; Wang *et al.,* 1996; Alexiew, 1998; Sireesh *et al.,* 2009; Mohamed,2010**).

It can be seen that there is a gradual reduction in the load carrying capacity as the width of soft clay zone increases. The results also show that the effect of the soft clay zone is more pronounced in dense sand beds. There is a loss of 70% of the load carrying capacity of dense sand when a localised soft clay zone with a width of 2.0B (200 mm) exists at a depth of 2B (200 mm).

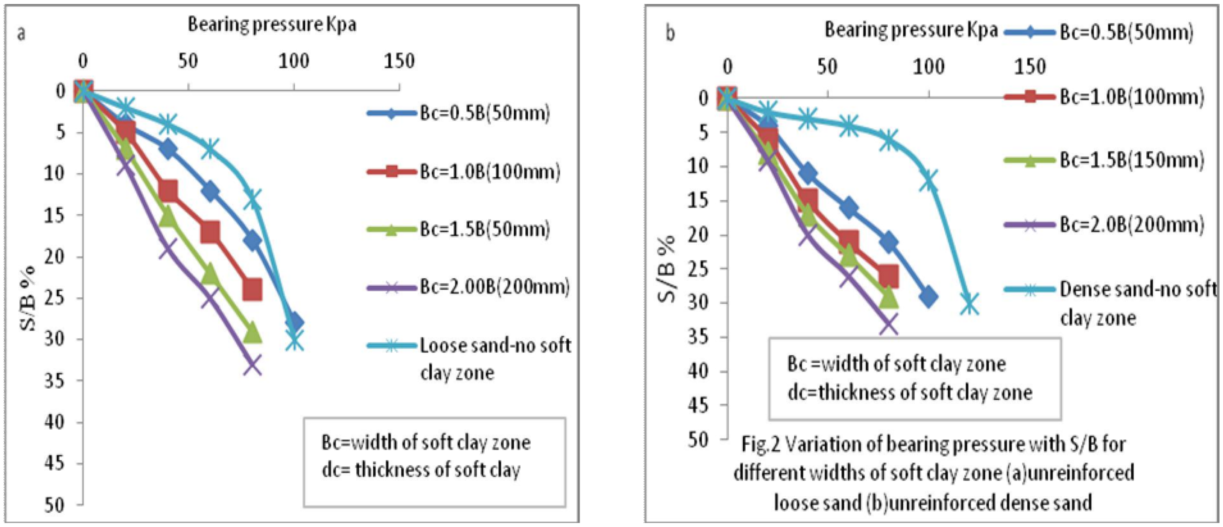

Fig.2 Variation of bearing pressure with S/B for different widths of soft clay zone (a)unreinforced loose sand (b)unreinforced dense sand

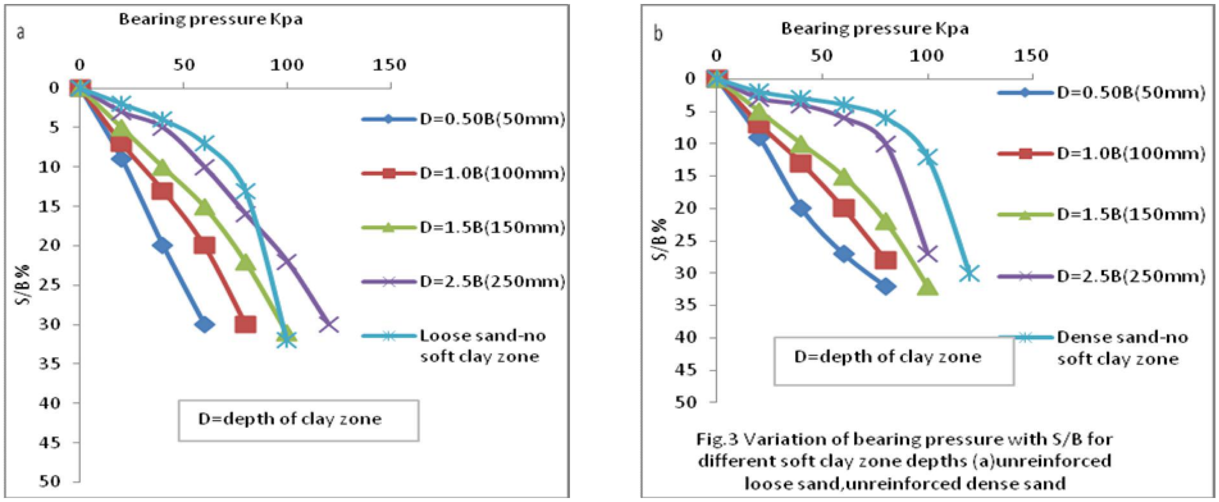

Fig.3 Variation of bearing pressure with S/B for different soft clay zone depths (a)unreinforced loose sand,unreinforced dense sand

4.2 Effect of the soft clay zone depth

The depth of the soft clay zone was 0.5B,1.0B,1.5B&2.0B where B (the width of footing),the width and thickness of soft clay zone was1.0B and 0.5 B respectively .Tests for loose and dense sand beds with soft clay zone at different depths, with 1.0B width are presented in figs.3a&3b respectively. Considerable settlement is observed shortly after applying a relatively small loading increment. The deeper the soft clay zone from footing, the lower its influence on bearing pressure. Unlike the loose sand deposits, the dense sand deposits show larger reduction in the value of the bearing capacity due to the existence of a soft clay zone. For soft clay zone that are within a depth of D=1.5 B (150 mm), a loss of about 50% in the load carrying capacity of dense sand bed is obtained. In this case induced stresses underneath the footing are strongly affected by the presence of the weak clay zone. In dense sand, Fig. 3b, the presence of soft clay zone of width >0.5B (50 mm) and within a depth of 1.5B (150 mm) would strongly affect the ultimate bearing capacity.

4.3 Effect of depth of reinforcement.

These experiments was conducted using two layers of reinforcement with spacing 0.3B &length 3.0B which are placed at different depths to determine precisely the optimal depth of a reinforcement layers. The width and thickness of soft clay zone was1.0B and 0.5 B respectively. Fig. 4a and b shows the variation of the bearing pressure with settlement ratio (S/B) for sand reinforced with two layers and with the inclusion of a soft clay zone. Also shown are the curves for unreinforced sand beds with and without the inclusion of soft clay zone. The results obtained for loose sand beds demonstrate that generally an improvement is achieved by the use of two reinforcement layers. In addition, a slightly higher bearing capacity can be obtained when the depth of reinforcement is placed at a depth of 1.5B (150 mm). In comparison, the dense sand beds showed considerable improvement by the use of two layers of reinforcement as shown in Fig. 4b. However, best enhancement is obtained when the reinforcement layer is placed at an intermediate level 1.0 B, 1.5 B which improves the ultimate bearing capacity to that of the unreinforced sand bed but it does not still recover the full strength of the dense sand without the soft clay zone.

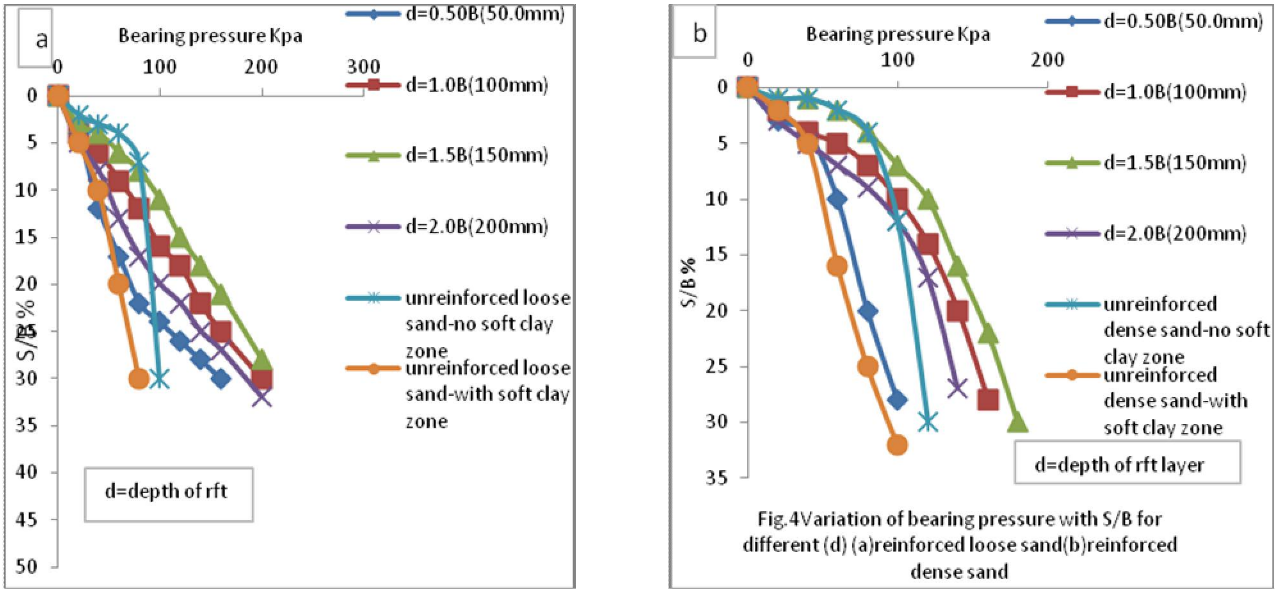

Fig.4Variation of bearing pressure with S/B for different (d) (a)reinforced loose sand(b)reinforced dense sand

4.4. Effect of number of reinforcing layers

The number of reinforcing layers increased gradually from one layer up to five layers while keeping the vertical spacing between layers at 0.3B (30 mm) and length of each layer to be 3B (300 mm) to quantify the efficacy of the increased number of reinforcing layers. The width and thickness of soft clay zone was1.0B and 0.5 B respectively. Fig. 5a and b shows the bearing pressure against S/B for loose and dense sand respectively. The data shows that there is a significant improvement in the load carrying capacity as the number of layers increases. This can be attributed to higher stiffness and confinement for the reinforced region beneath the foundation as a result of the addition of more reinforcement layers and better frictional resistance in the case of dense sand. In both sands, the bearing capacity increased more than three times in comparison to that of the unreinforced sand bed. This indicates that increasing the number of reinforcing layers is the most effective way in enhancing the load carrying capacity. Comparing data for loose sand beds presented in Fig. 5a with those generated for dense sand beds in Fig. 5b illustrates that different characteristics for the load-settlement curves are obtained . In loose sand beds a gradual improvement in the bearing resistance with settlement is experienced up to S/B value of about 15%. In the dense sand, the results indicate that the reinforced dense sand above the localised soft clay zone resists the footing load up to a S/B value of 10%. Over this range of settlement, the whole ground behaves like an elastic material transferring the induced stresses to the sides bridging over the localised weaker zone until the critical bearing pressure is reached. It is clear that there is an increase in the bearing capacity as the number of layers increases up to four layers. The results obtained by using five layers are close to that of four layers.

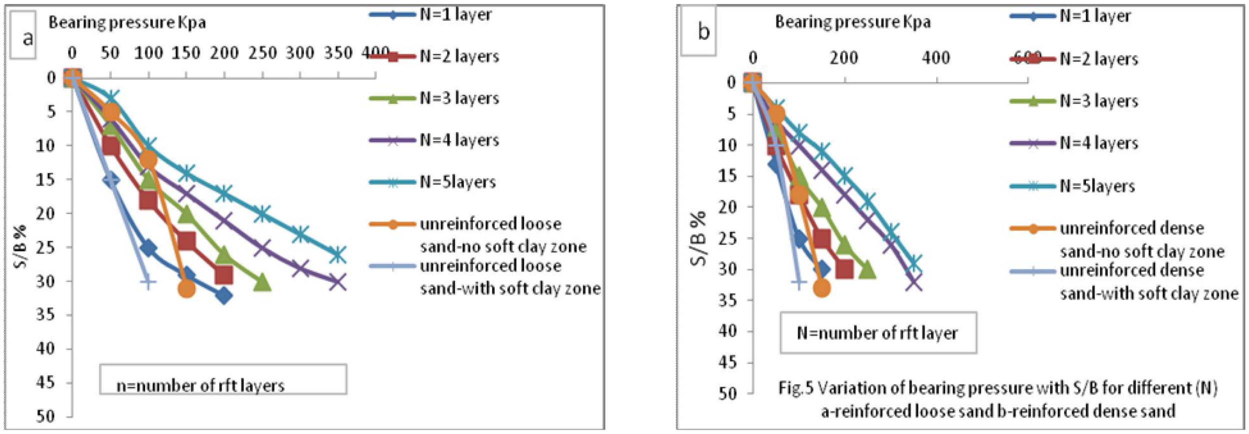

Fig.5 Variation of bearing pressure with S/B for different (N) a-reinforced loose sand b-reinforced dense sand

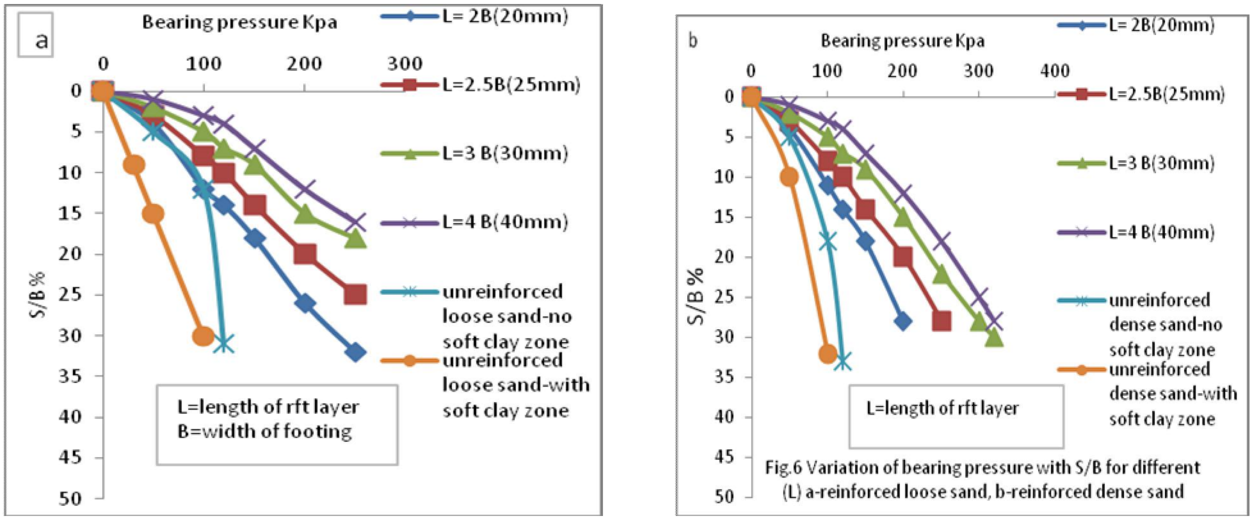

Fig.6 Variation of bearing pressure with S/B for different (L) a-reinforced loose sand, b-reinforced dense sand

4.5 Effect of length of reinforcing layers

In order to investigate the influence of increasing the length of the reinforcing layers on the bearing capacity, experiments were carried out with different lengths of reinforcement in loose and dense sand beds. The width and thickness of soft clay zone was1.0B and 0.5 B respectively. In each experiment two layers of reinforcement were placed at a vertical spacing of 0.3B (30 mm) underneath the model footing and between each other. The effect of length of reinforcement are presented in Fig. 6a and b. Results for the loose sand beds indicates that increasing the length of reinforcement in a loose sand deposit does not provide significant extra enhancement for the soil load carrying capacity. This is primarily due to the weak bond between reinforcing layers and surrounding soil. However, for dense sand, the load carrying capacity improved slightly with the increase in the length of reinforcing layers. There has been an increase of 40% in the bearing capacity measured at a settlement of 15% when the length of reinforcement is increased from 2B (200 mm) to 3B (300 mm).

4.6 Effect of spacing between reinforcing layers

In order to investigate the influence of spacing between reinforcing layers on the bearing capacity, experiments were carried out with different spacing of reinforcement in loose and dense sand beds. In each experiment two layers of reinforcement were placed at a vertical spacing of 0.2B,0.3B,0.4B,0.5B underneath the model footing and between each other. The width and thickness of soft clay zone was1.0B and 0.5 B respectively. The effect of spacing of reinforcement are presented in Fig.7a and b. Results for the loose sand beds indicates that increasing the spacing of reinforcement in a loose sand deposit does not provide significant extra enhancement for the soil load carrying capacity. This is primarily due to the weak bond between reinforcing layers and surrounding soil. However, for dense sand, the load carrying capacity improved slightly with the decrease in the spacing of reinforcing layers. There has been an increase of 35% in the bearing capacity measured at a settlement of 15% when the spacing of reinforcement is decreased from 0.5B (50 mm) to 0.3B (30 mm).

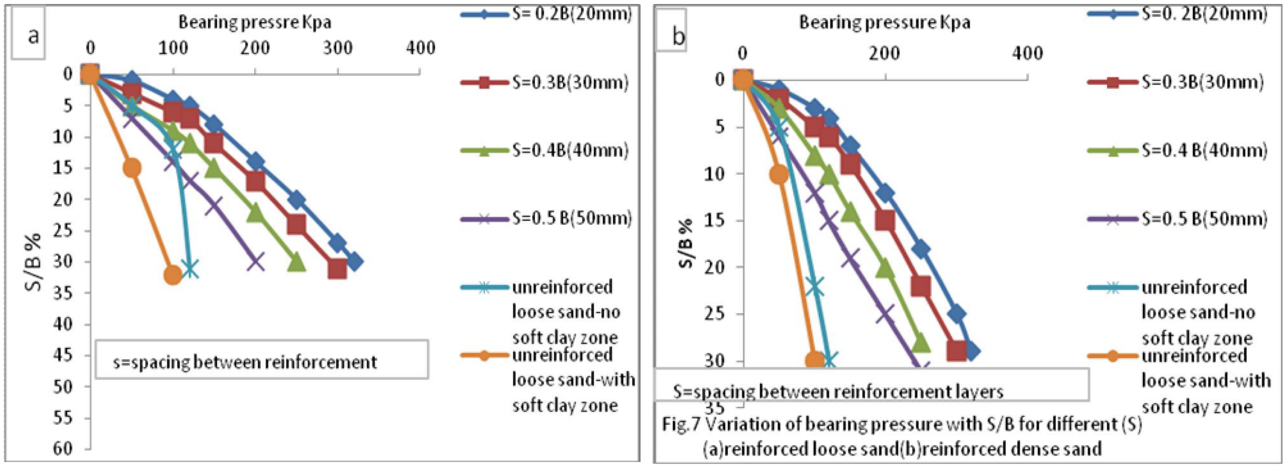

Fig.7 Variation of bearing pressure with S/B for different (S) (a)reinforced loose sand(b)reinforced dense sand

5. Conclusion

_ The existence of soft clay zone has a major impact in reducing the capacity of the soil to resist surface loads. Their impact is directly related to the relative strength of the soft clay zone and surrounding soil.

_ With the increase in the width of soft clay zone the bearing capacity reduces. It was found that for a soft clay zone of similar footing width placed at a depth of 1.0 B, the bearing capacity reduced by 45% in loose sand and 70% in dense sand.

_ Soft clay zone within a depth of 1.5B below the footing or more decreases its influence in decreasing the bearing capacity.

However, best enhancement is obtained when the reinforcement layer is placed at an intermediate level 1.0 B, 1.5 B which improves the ultimate bearing capacity to that of the unreinforced sand bed but it does not still recover the full strength of the dense sand without the soft clay zone.

_ Improvement can be achieved with the addition of two reinforcement layers at any depth. However, better results are obtained with dense sand when the reinforcement layer is placed at an intermediate level 1.0 B, 1.5 B which improves the ultimate bearing capacity to that of the unreinforced sand bed but it does not completely minimise the efficiency of the soft clay zone existence.

_ To improve sand beds overlying soft clay zone a number of reinforcing layers is embeded. The bearing capacity increased by almost three times when the region underneath the footing was reinforced by four layers. This improvement is equivalent to almost doubling the bearing capacity of unreinforced dense sand bed without the inclusion of soft clay zone.

For dense sand, the load carrying capacity improved slightly with the increase in the length of reinforcing layers up to 3.0 B

Increasing spacing between reinforcement in a loose sand deposit does not provide significant extra enhancement for the soil load carrying capacity. However, for dense sand, the load carrying capacity improved slightly with the decrease in the spacing of reinforcing layers to 0.3B.

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