ABSTRACT: The model of footings of six different sizes has been placed at surface of the soil bed in model testing tank. The tests have been conducted on unreinforced soil at both dry and liquid limit conditions, and reinforced (i.e., open weave at internal spacing of 1.0 cm) soil at liquid limit of the layered soils in three phases, i.e., silty-sand soil at top, sandy-silt soil at middle and clayey-silt soil at bottom, and sandy-silt soil at top, clayey-silt soil at middle and silty-sand soil at bottom, and clayey-silt soil at top, sandy-silt soil at middle and silty-sand soil at bottom. The effects of different arrangement of soil layers, width of footings, width and spacing of geotextile mat, load-settlement behaviour, bearing capacity ratio have been studied. The ultimate failure loads are of 12.16 to 46.06 kN without reinforcement and of 0.94 to 10.04 kN with reinforcement (spacings of 1.0 cm) for all three conditions. The load has been increased enormously with reinforcement (spacings of 1.0 cm and 2.5 cm) as compared to unreinforced condition. The load bearing capacity of the soil increases and depends on the arrangement of the layers with geotextiles, and maximum size of rectangular footing shows better results.

KEYWORDS: Footings, layered soil, load-settlement behaviour, reinforcement, geotextile.

1. INTRODUCTION

Introducing reinforcement inclusions within the soil is an effective and reliable technique in order to improve the engineering properties of soil. Reinforcement of the soil is specified as a method for improving the mechanical properties of the soil such as shear, compression, hydraulic conductivity and density. The soil usually had the low tensile strength characteristics and was mainly dependent on environmental conditions (Ling et al. 2003). It had been found that geocell enhances the footing performance on sandy soil and the optimum width of geocell mattress was around 4 times the width of footing (Kumar and Sridhar 2014). The number of layers was not significant difference on bearing capacity when the ratio of the depth of the topmost layer to footing dimension was greater than 0.2 (Marto et al. 2013). The studies had been carried out on geocell reinforced sand over soft clay bed and found that geocell reinforcement increased the load carrying capacity of soft soil (Balamaheswari and Hamparuthi 2011). Model tests indicated that reinforcing of subsoil after replacing the top layer of soil with a well-graded soil was beneficial as the frictional resistance increased due to soil reinforcement. It increased ultimate bearing capacity of footing upto 3 to 4 times, if thickness of top layer of existing weak soil equal to width of the footing was replaced by well-graded sand layer (Kumar et al. 2007). Effect of position of middle stiff layer had also been studied; the closer the middle stiff layer to the ground surface, the lesser the displacement (Maheswari and Madhab 2005). A detailed parametric study had been carried out on the soil-strip footing system and this revealed that the factors of safety were strongly dependent upon only the coefficient of variation of the elastic moduli of soil layers (Maheswari and Kumar 2011). Experimental and numerical simulation had been made on square and rectangular footing supported by sand bed with or without geosynthetic reinforcement (Madhabi and Amit 2009).

2. MATERIALS

2.1 Soils and Geotextile
Three types of soil have been considered, i.e., silty-sand, sandy-silt and clayey-silt soils which are locally available. The physical and engineering properties of each soil have been found out by ASTM standards and tabulated in Table 1. Square grid open weave geotextile mats with an internal spacings of 1.0 cm and 2.5 cm consist of a series of interlocking cells which contains and confines the soil within its pockets, and of width 4 cm and thickness 0.2 cm with cross knitting of fibres has been used.

3. EXPERIMENTAL SET-UP
3.1 Model Testing Tank and Footings
The series of load tests have been conducted on square footing of sizes 100 mm×100 mm, 120 mm×120 mm, 150 mm×150 mm and rectangular of sizes 100 mm×120 mm, 120 mm×150 mm, 150 mm×200 mm with a thickness of 6 mm resting on unreinforced and reinforced layered soils in testing tank of size 400 mm×400 mm×600 mm which is made up of steel sheet in two adjacent sides and white perspex sheet of thickness 10 mm is used in other two adjacent sides.

4. EXPERIMENTAL PROGRAMME
4.1 Soil Bed Preparation and Tests
In the load tests, soils used at dry condition and at liquid limit with a uniform thickness of 100 mm for each type of soil at each layer. In case of reinforced soil layers the reinforcements are provided in between two layers.

The load tests on model square and rectangular footings have been carried out under the Compression Testing Machine in laboratory. The settlement of the footings has been noted by applying load incrementally at a rate of 2.5 mm/minute through a proving ring of 25 kN (at liquid limit) and 50 kN (at dry condition) to measure the load on the footings and a dial gauge is properly placed to measure the uniform settlement of footings due to applied load up to 40 mm. Same has been repeated for each tests of the three phases, viz., Phase-I: silty-sand soil at top, sandy-silt soil at middle and clayey-silt soil at bottom, Phase-II: sandy-silt soil at top, clayey-silt soil at middle and silty-sand soil at bottom, and Phase-III: clayey-silt soil at top, sandy-silt soil at middle and silty-sand soil at bottom. The spacing of geotextile mat is provided with internal spacings of 1.0 and 2.5 cm for each footing of three phases.

Fig. 1 Load vs. settlement curves for footings at dry condition with unreinforced soils for Phase-I

Fig. 2 Load vs. settlement curves for footings at liquid limit with unreinforced soils for Phase-I

5. RESULTS
The tests have been carried out on layered soil bed at liquid limit placed with or without geotextile. The behaviour of load vs. settlement for square and rectangular footings for unreinforced dry soil and reinforced soil at liquid limit are shown in the Figures 1 to 3. At dry condition, bearing capacity does not differ as much as liquid limit for a particular footing in all three phases. It has been found that for Phase-I, Phase-II and Phase-III conditions the ultimate failure loads are within the ranges of 15.85 to 46.06 kN, 12.16 to 44.92 kN and 13.27 to 42.07 kN without reinforcement at dry condition, and of 3.32 to 10.04 kN, 1.92 to 7.25 kN and 0.94 to 4.95 kN with reinforcement (internal spacing of 1.0 cm) at liquid limit respectively for all the footings.
6. DISCUSSIONS

6.1 Effects of Different Arrangement of Layers on Bearing Capacity of Square and Rectangular Footings on Layered Soils

Figures 1 to 3 represent load vs. settlement of square and rectangular footings of all sizes. In these cases though Phase-I condition has taken higher load for the same settlement, but the Phase-II and Phase-III also took higher load which is not much smaller than Phase-I condition. Both at dry and liquid limit conditions, the relative performance of sandy-silt soil is better than other two types of soil of the present study. At dry condition the performance of square and rectangular footings for all three phases does not differ as much as liquid limit condition. The bearing capacity of soil for each phase has been higher at the dry condition as compared to that at liquid limit. Similar trend was found by Maheshwari and Kumar (2011) and reported at dry condition, clayey soils have quite good bearing capacity compared to other soil.

Fig. 4 Typical BCR vs. S/B ratio (%) for footings on square grid open weave geotextile mat at spacing 1 cm for Phase-I

The plot of bearing capacity ratio (BCR) vs. the settlement to width (S/B) ratio for square and rectangular footings for each of three phases of reinforced layered soil bed has been shown in Figure 4 for Phase-I. For square and rectangular footings, as the width of footing increases the BCR decreases for reinforced soil for each of the three phases. From the figure, as S/B ratio increases, the BCR also increases for any size of footings in all the three phases. Bazne et al. (2015) observed similar trend and concluded that with the increase in width of footing, BCR decreased.

Fig. 5 Comparison of bearing capacity for spacing of 1.0 cm and 2.5 cm on square grid open weave geotextile mat for square footing of size 120 mm × 120 mm at different S/B ratio for Phase-II

Fig. 6 Comparison of bearing capacity for spacing of 1.0 cm and 2.5 cm on square grid open weave geotextile mat for square footing of size 120 mm × 120 mm at different S/B ratio for Phase-III

6.2 Effects of Width of Square and Rectangular Footings on Bearing Capacity Ratio (BCR)

6.3 Effects of Spacing of Geotextiles on Bearing Capacity of Layered Soils of Three Phases for Square and Rectangular Footings

Geotextiles have been placed in between the two layers of soils with square grid open weave mat for two separate internal spacings of 1.0 cm and 2.5 cm. Figures 5 to 7 show the bearing capacity vs. spacing of geotextiles curve, which indicates that load carrying capacity of soils have been increased significantly as the spacings have been decreased from 2.5 to 1.0 cm. As size of footing increases the rate of bearing capacity also increases. For 150 mm × 200 mm footing of Phase-
I and 100 mm×100 mm footing of Phase-III, the increase in bearing capacity have been maximum and minimum respectively. Kumar et al. (2007) observed similar trend and reported that with the increase in spacing of geotextiles the load carrying capacity had been decreased for the same amount of settlement.

6.4 Comparison between Square and Rectangular Footings
Figure 8 shows that for same amount of settlement, rectangular footings can bear more loads compare to square footings. Hence, bearing capacity for rectangular footings is higher than the square footings. Bearing capacity for rectangular footings are 2.2–10.75%, 5.7–17.08% and 7.0–23% higher than that of square footings for same S/B ratio.

![Fig. 8 Typical diagram for comparison of bearing capacity between square and rectangular footings for Phase-II](image)

Fig. 8 Typical diagram for comparison of bearing capacity between square and rectangular footings for Phase-II

4. CONCLUSIONS
Based on the results and discussions made above, the following conclusions may be drawn:

- If width of size of footing increases and open weave geotextiles mat square grid spacing decreases, then bearing capacity increases for all three phases.

References