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Responses of Piled Raft Foundations in Layered Soils Subjected to Eccentric Vertical Loading

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Abstract: ***The concept of raft foundations enhanced with piles (typically named "piled-raft") has received considerable attention in recent years. Raft foundations are widely used in supporting structures when relatively strong layers are present at shallow depth. Sometimes, although the shallow layers of soils have adequate bearing capacity, a raft foundation can induce excessive settlements. In such cases, piled rafts (raft foundations enhanced with piles) are used. The behaviour of piled raft changes significantly in layered soil. It had been seen for piled raft installed in layered soil the reduction in settlement was more pronounced with smaller length of piles, compared to homogenous soil. In this study a parametric investigation were conducted (studying the effects of variation in ratio of load eccentricity to width of footing, ratio of pile length to diameter, pile numbers and arrangement of the piles on the responses of the foundation) to observe the behaviour of piled rafts in layered soils with eccentric loading. Rafts with connected piles and rafts reinforced with unconnected piles were considered.***

Keywords: Piled Raft, Connected, Unconnected, Eccentric load

1. Introduction

Piled raft foundations are widely used nowadays. These are of two types, connected and unconnected. In the first case piles are rigidly connected to the raft; while in the second case there is a thin layer of soil between the raft and the piles. While the loads are assumed to be carried by the raft, piles are included for the purpose of reducing raft settlement, and therefore, the main objective of introducing piles is to control or minimize the total and/or differential settlements of the system, rather than to carry the major proportion of the loads. The behaviour of piled raft changes significantly in layered soil. It had been seen by Vasudev *et al.* [1] for piled raft installed in layered soil the reduction in settlement was more pronounced with smaller length of piles, compared to homogenous soil with pile tip resting on dense sand. Results [2] showed that the piled raft foundation with different pile diameters may be a good solution to reduce total and differential settlements in soils with dense bottom layer. In soft bottom layer, piled raft foundation with different pile diameters did not produce a good result to control maximum and differential settlement. Also, In the areas subjected to high wind or seismic loading, raft foundations are subjected to eccentric loading that may cause the structure to tilt (particularly in the case of a narrow building). Using a piled raft in such a case may increase the stability of the building and may reduce the tilt [3].

A number of studies had taken place exploring the behaviour of piled raft foundations. Wong *et al.* [4] experimentally studied the behaviour of piled-raft foundations with disconnected piles. It was suggested that these piles should be treated as reinforcement to the subsoil, rather than as structural members. Small *et al.* [5] numerically investigated behaviour of piled raft under lateral and vertical loading. The numerical model successfully analyzed a raft either clear of the ground surface or in contact with the ground.. Sanctis *et al.* [6] numerically evaluated the bearing capacity of a vertically loaded piled raft. It was found that the proportion of the total load, taken by the pile at failure, is nearly constant and equal about to unity, with the piles beneath the raft achieving the same capacity as for a free standing pile group. EI Sawwaf, M. [3] did an experimental study of eccentrically loaded raft with connected and unconnected short piles. It was found that the inclusion of short piles has a significant effect on improving the behaviour of an eccentrically loaded model raft supported on sand. Elwakil and Azzam [7] conducted experimental and numerical studies of piled raft system. It was found that as the length of piles and number of piles decreased the load carried by raft increased. Mali and Singh [8] investigated the behaviour of large piled raft foundation on different soil profiles for different loadings. The maximum bending moment and maximum shear force were found to be lesser for varying soil profile and homogeneous soil profile respectively.

In this study an experimental investigation had been conducted to observe the behaviour of piled rafts in layered soils with eccentric loading. Rafts with connected piles and rafts (supported on soil) reinforced with unconnected piles were considered. The principal objective of the study was to investigate the influences of load eccentricity in the load-settlement behaviour of piled rafts in layered soils.

2. Methodology

The laboratory model tests were conducted in a test tank of 1 m x 1m having a depth of 1.2 m. The model footing of 250 mm x 500 mm (50 mm thick) was made of wood. A rough base condition of the footing had been achieved by fixing a thin layer of sand onto the base of the model foundation with glue. The load was applied by an indigenously made screw jack, and measured by a load cell. Settlement of the footing was measured by LVDT. 12.5 mm diameter hollow iron pipes were used to make model piles. The length (l) to diameter (d) ratios of the piles were 10 and 15.

3. Experimental Investigations

Initially the tank was filled with sand (Soil 1). The grain size distribution of the sand is shown in Fig. 1. Its specific gravity was 2.58 and relative density was 58 %. The sand was poured into the tank in 50 mm thick layers. Once the set up of the sand bed was completed, great care was taken to level the sand surface. After the experiments with the piled raft placed in sand were completed, in the next stage a layer of silty clay (Soil 2) of 0.5 m thickness was placed below the sand layer. The specific gravity of this soil was 2.28, liquid limit 41.4 %, plastic limit 25.26 %, plasticity index 16.14 %. The grain size distribution curve of Soil 2 is shown in Fig. 2. Tests were performed with connected as well as unconnected piles (having a gap of 10 mm between the pile tops and the bottom of the plate). The corresponding set up is shown in Fig. 3. The loads were applied without eccentricity, and with e / B (eccentricity to width of footing) ratios of 0.1, 0.2 and 0.3. Each load increment was maintained at a constant value until the model raft settlement had been stabilized.

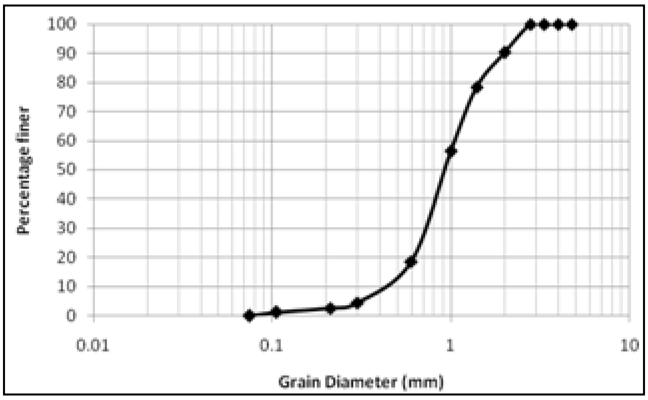

Figure 1: Grain size distribution curve of soil 1

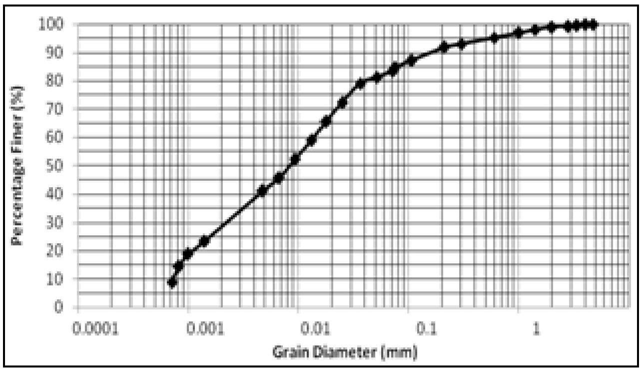

Figure 2: Grain size distribution curve of soil 2

All the experiments were performed with two different l/d ratios (10 and 15) of piles. Three different types of arrangements of piles had been used as shown in Fig. 4. The first arrangement consisted two pile rows (12 piles/ row), the second arrangement consisted of three pile rows (8 piles/ row), and the third arrangement consisted of four pile rows (6 pile/ row). Here, as a representative purpose, some results obtained with the second arrangements have been shown in Fig. 5 to Fig. 8.

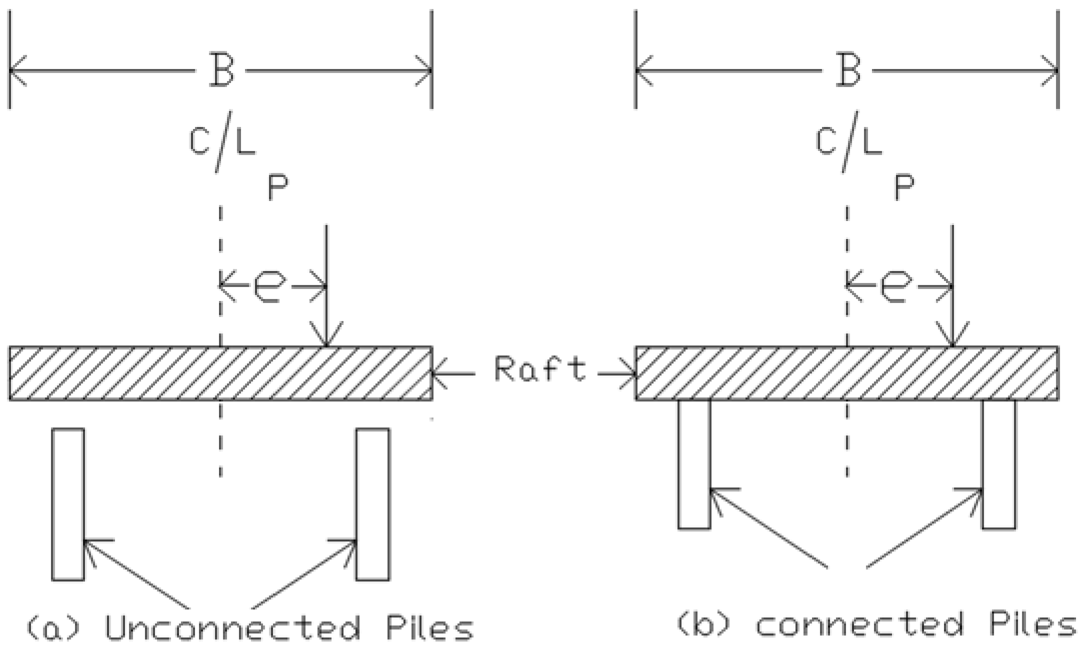

Figure 3: Unconnected and Connected piled rafts

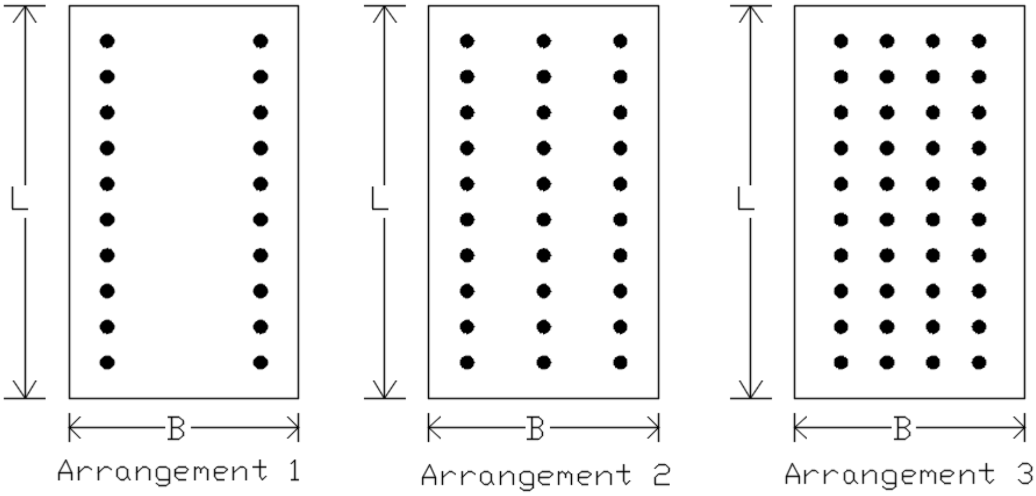

Figure 4: Different arrangements of piles below the raft

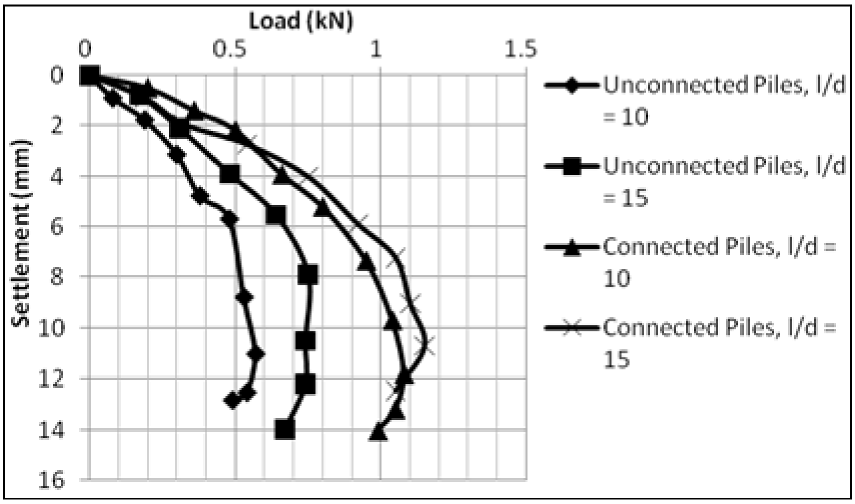

Figure 5: Load - Settlement plots (Single layer, No eccentricity)

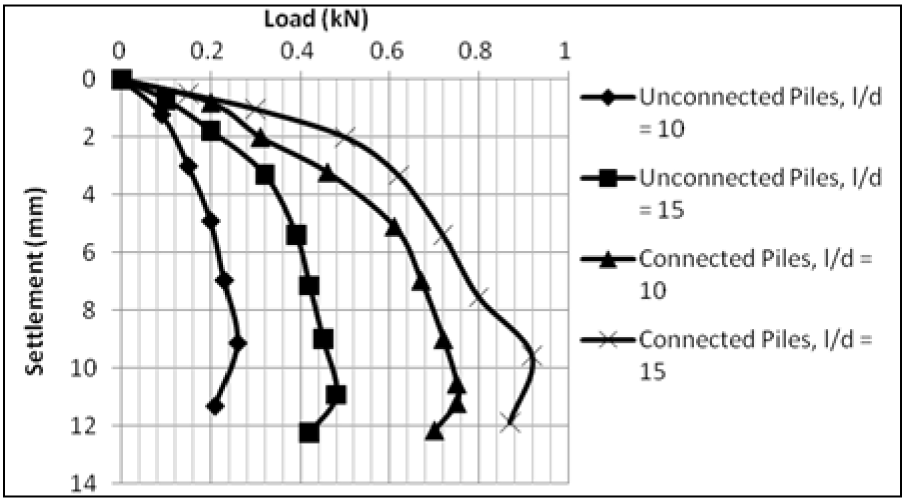

Figure 6: Load - Settlement plots (Single layer, e/B = 0.3)

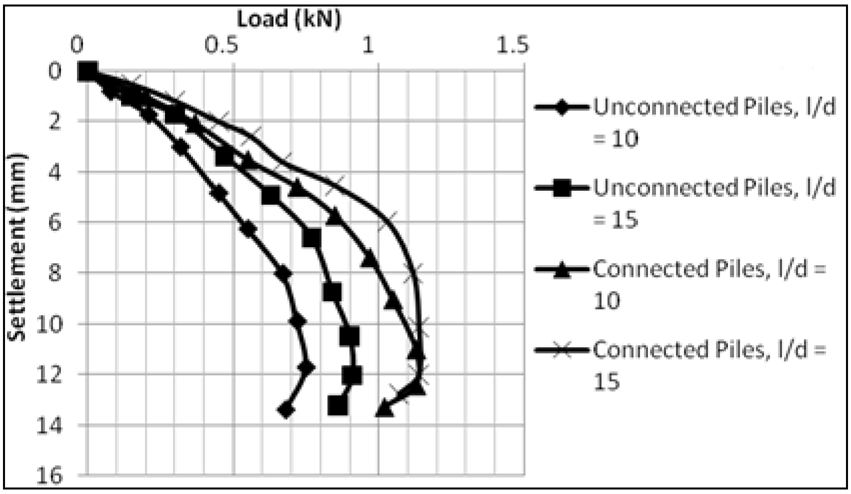

Figure 7: Load - Settlement plots (Two layers, e/B = 0.1)

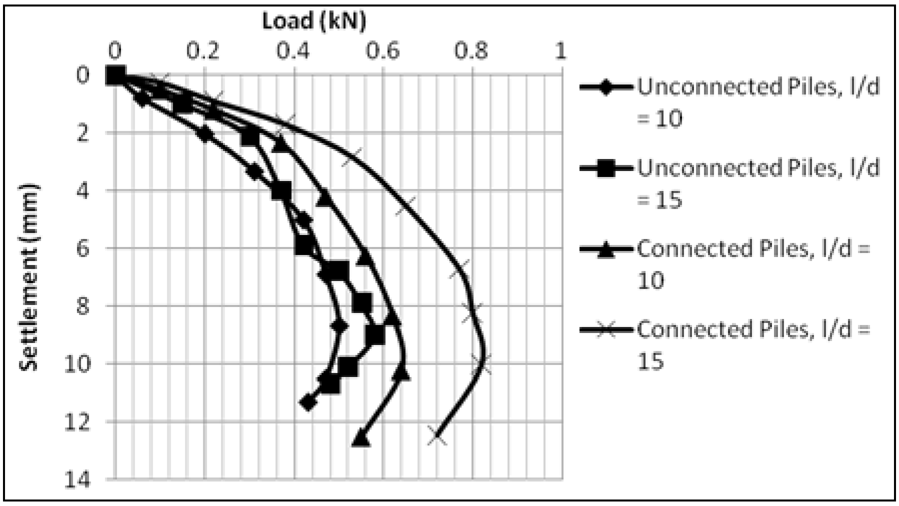

Figure 8: Load - Settlement plots (Two layers, e/B = 0.3)

In all the tests application of loads were stopped, when it was found that the value of load decreased, but the settlement incresed. The results are plotted for single layered as well as two layered soils. Both unconnected and connected piles were cosidered having l/d ratios of 10 and 15. The general nature of load-settlement plots indicates that the connected piled rafts carry more loads (almost 25 to 30 %) than unconnected piled rafts. Also, the load carried corresponding to l/d = 15 is higher than that of l/d = 10 (almost 15 to 20 %).

The effects of different pile arrangements (for two layered soil) may be understood by looking at Fig. 9 to Fig. 12 which display the e/B vs. ultimate load plots (corresponding to l/d = 10 and 15).

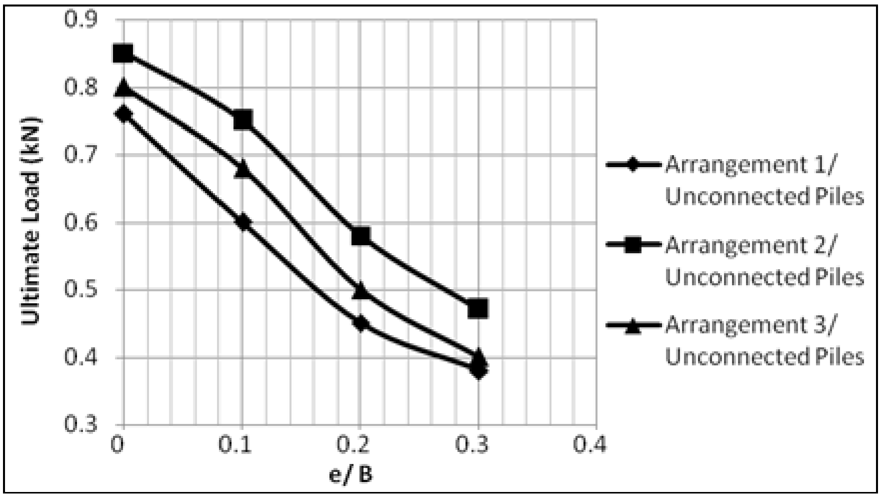

Figure 9: e/B vs. Ultimate load for different arrangements of piles (unconnected, l/d = 10)

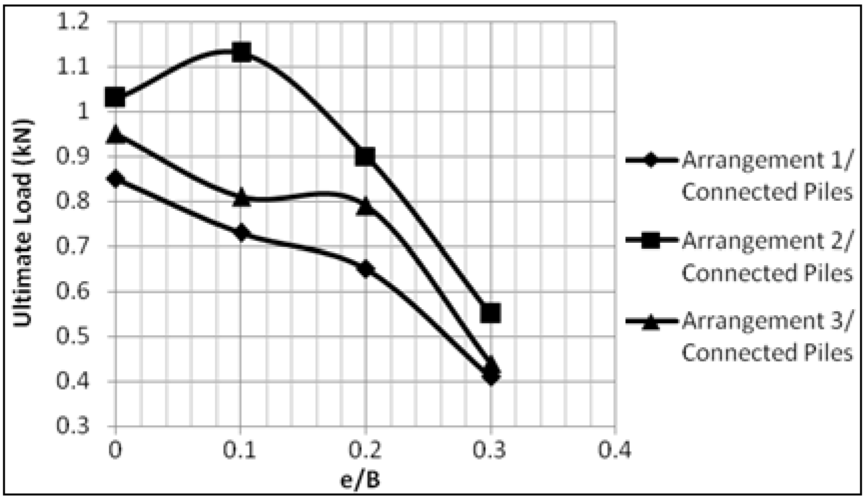

Figure 10: e/B vs. Ultimate load for different arrangements of piles (connected, l/d = 10)

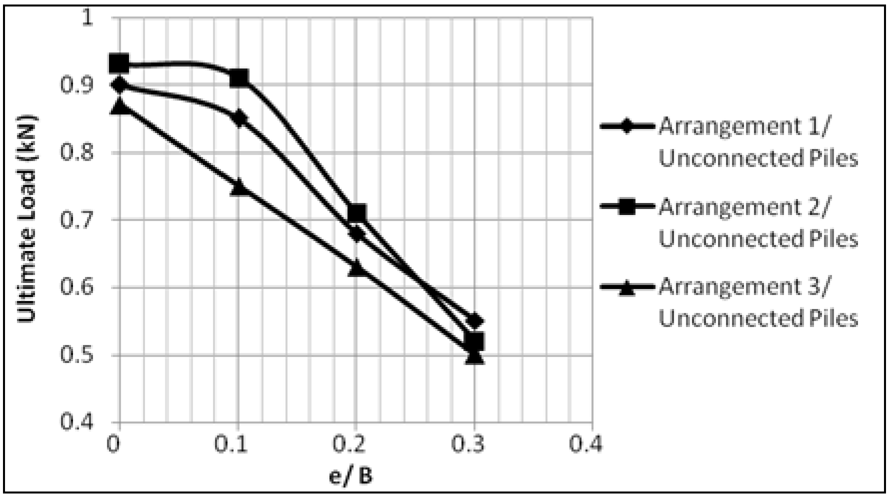

Figure 11: e/B vs. Ultimate load for different arrangements of piles (unconnected, l/d = 15)

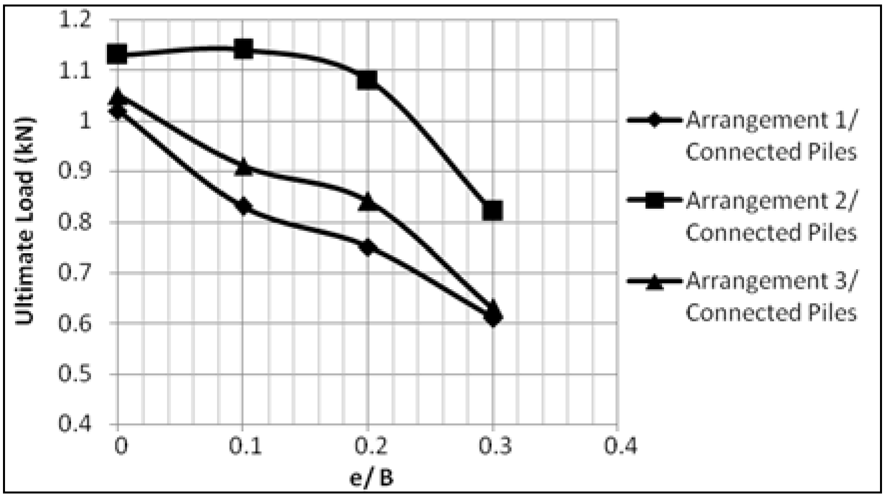

Figure 12: e/B vs. Ultimate load for different arrangements of piles (connected, l/d = 15)

It may be seen in general the second arrangement carries the maximum load. Corresponding to two layered soils, for unconnected piled raft and l/d = 10, the value of ultimate load decreses as e/B increases. For connected piled raft and l/d = 10, the patterns of ultimate load are similar as above corresponding to arrangements 1 and 3; but for arrangement 2 there is an initial increase in the magnitude of the ultimate load followed by a decline (as e/B increases). For l/d = 15, corresponding to the connected piled raft (arrangement 2) the ultimate load initially increases followed by a decrese as the value of e/B increses. For all other cases, there is a decline in the magnitude of the ultimate load with the increment in e/B.

It may be noted here that behaviour of piled raft foundations in layered soil under eccentric loading was not studied before the present research, and the data/ results obtained in this study would enhance the knowledge base of the subject matter.

4. Conclusions

The major conclusions of the present research work are as follows:

1) The general nature of load-settlement plots indicated that the connected piled rafts carried more loads (almost 25 to 30 %) than unconnected piled rafts. Also, the load carried corresponding to l/d = 15 was higher than that of l/d = 10 (almost 15 to 20 %).
2) Out of the three arrangements of piles studied, the arrangement having 3 rows of piles (8 piles/ row) carried maximum loads.
3) Corresponding to unconnected piled raft and l/d = 10, the value of ultimate load decresed as e/B increased. For connected piled raft and l/d = 10, except for arrangement 2, magnitude of ultimate load decrased as e/B incresed. But for arrangement 2 there was an initial increase in the magnitude of the ultimate load followed by a decrease as e/B increased.

4) For l/d = 15, in general, the value of ultimate load carried by the foundation decresed as e/B incresed. But for arrangement 2 in case of connected piles the ultimate load initially incresed, followed by a decline as e/B incresed.

Following are the future scope of research:

1) Number of soil layers may be increased and effects of different arrangements (sequences) of layers may be observed.
2) Instead of concentric load, strip load or uniformly distributed load may be applied.
3) Model piles may be made of materials having varying rigidity, and its effects can be observed.

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