ISSN: 2395 - 2180

Available online at http:// www.ijemmr.co.in

International Journal of Engineering, Management & Medical Research (IJEMMR)

VOL - 5, ISSUE - 8, AUGUST - 2019

AN EXPERIMENTAL STUDY ON LOADING CONDITION OF PILED RAFT FOUNDATION

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ABSTRACT

Foundation of many structure like transmission, radio and television towers are subjected to inclined compressive and uplift loads. Additionally, foundation of tall buildings and bridges are also subjected to high lateral loads along with other verticals loads coming for the superstructure. In such cases, to increase the load bearing capacity of such foundation system and to decrease the corresponding vertical and lateral deflection piles may be employed along with raft footing. This paper presents an experimental study of the effectiveness of using short piles either rigidly connected or hinged to the raft (instead of long piles) on the behavior of a loaded raft. The load configuration was designed to simulate rafts under inclined loads. Several arrangements of piles with different lengths and numbers along with the effect of the relative density of the soil and the load inclination with vertical were studied. Test results indicate that the inclusion of short piles adjacent to the raft edges not only significantly improves the raft bearing pressures but also leads to a reduction in raft settlements and tilts leading to an economical design of the raft. However, the efficiency of the short piles-raft system is dependent on the load inclination ratio and pile arrangement. Also, connecting short piles rigidly to the raft gives greater improvement in the raft behavior than hinged piles for case of obliquely loaded pile raft system.

KEYWORDS:

PILED RAFT; SHORT PILES; SETTLEMENT; SAND; INCLINED LOAD.

INTRODUCTION

Raft foundations are widely used in supporting structures when relatively strong layers are present at shallow depth. Sometimes, although the shallow layers of soil have an adequate bearing capacity, a raft foundation can induce excessive settlements. In such cases, piled rafts (raft foundations enhanced with piles) are used. While the loads are assumed to be carried by the raft, piles are included for reducing raft settlement. The piles can be arranged to reduce differential settlement in the raft. The concept of using piles to reduce raft settlement was first proposed by [1] Burland et al. (1977) who placed one pile under each column of a building. Several reports were published on the use of piles as settlement reducers

In traditional pile-raft systems, piles are usually long and connected to the raft. While these long piles are effective in reducing raft settlement, they may lead to significant straining actions (shear forces and bending moments) which affect the structural design of the raft. Due to the increase in their geotechnical bearing capacities, the piles should be enlarged to avoid the structural collapse in their sections. Also, these piles attract high shear force and mobilize high bending moment in the raft leading to an uneconomic design

In this paper, the new concept of using hinged piles is checked experimentally which is provided for overcoming the structural problems of the piled raft. Also, the loading condition is unique. The applied load is being inclined to some certain angle with the vertical axis of the raft. The idea of using short piles below the raft fixed or hinged instead of using only connected long piles was investigated. As these piles were short, their geotechnical capacity is much less than their collapse loads leading to avoiding the problems of high axial stress in piles and high shear forces in the raft due to the pile reactions. However, the effect of using short piles either fixed or hinged on the load settlement performance of the piled raft is not clearly understood. It should also be mentioned that most of the aforementioned papers are parametric numerical studies that have investigated the performance of piled rafts considering either evenly distributed loads or concentrated column loads rather than the case of oblique loads accompanied with overturning moment which is more commonly found in practice.

It has been found that capacity of both raft and piles varied a lot when compared to values predicted from available theories as these theories analyses both the raft and the piles separately if a lateral load is present along with a vertical load.

Therefore, the aim of this study was to gain more understanding about the behavior and the failure mechanism for either fixed or hinged short piles subjected to a combined lateral and vertical loading condition. Loading condition on piled raft foundation resting on sand is kept such that there is both lateral load and vertical load, gradually increasing and acting at a certain angle from the vertical axis of raft. The main objective was to determine and establish experimentally the relationship between the raft behavior and the load inclination condition, the relative density of the sand that the piles are in, and other variable parameters of short piles.

EXPERIMENTAL SETUP

The laboratory model tests were conducted in a test box, having inside dimensions of 120 cm by 120 cm in plan and 100cm in depth. The tank is made from steel with the front wall made of20-mm-thick glass and is supported directly on two steel columns as shown in Fig. 1. These columns are firmly fixed to two horizontal steel beams, which are firmly clamped to the laboratory floor by bolting. The loading system is mounted by a semi-circular I-beam of steel supported by the two columns. It consists of a hand-operated wheel axle loading system and precalibrated load ring. The load was applied by the rotating the axle arrangement fixed with the semi-circular loading frame which is attached to a rigid platform as shown in Fig. 1. The semicircular loading frame was so placed that the load can be applied at the center of the model raft as well as on any position on the raft for applying eccentric load with easy placing of deflection measuring dial gauges. Therefore, the load system consists of two assemblies: the wheel axle applies a gradually increasing concentrated load inclined at fixed inclination as desired and lower semi-circular plunger guide maintains the load alignment. The semi-circular load frame was designed to be detachable at end so that it can be removed during deposition of the sand and returned back, when sand deposition is completed, to the original loading position above the tank. Detailed description of the apparatus developed by the authors is given in detail in Roy et al. (2012)& Roy et al. (2013).

A model strip raft made of mild steel with plunger groove on its top surface has been used. This model was chosen to simulate the raft of several cases of a narrow building subjected to both vertical and lateral loads. The model raft was 200 mm in diameter and 10 mm in thickness. A raft thickness of 10 mm was chosen to simulate rigid rafts which are commonly used in practice. The model raft was positioned on the sand bed such that it lies exactly at the center of the semi-circular load frame. A rough base condition was achieved by fixing a thin layer of sand onto the base of the model raft with poxy glue. The model raft was made with holes threaded internally so that the piles could be put in vertical position at the required spacing of the piles. Model piles with 20 mm and 15 mm outer and inner diameters, respectively, made of hollow steel tubes (E=0.207X106MPa) were used in the study. The piles were 200, 300, and 400 mm in length and the corresponding length-to-diameter ratios of the piles were 10, 15, and 20. The load was applied by fixed amount at a constant rate with the wheel axle arrangement. The load is transferred through the ball bearing accommodated at the top of the proving ring in a hole on its top surface. The desired load through the plunger is measured through the proving ring as shown in Fig. 2. A small seating pressure was applied first for ensuring proper transfer from the loading arrangement tothe model raft through two ball bearings and two rods accommodated in sockets of loading frame and grooves on the top surface of the raft. The sockets on the semi-circular loading frame can be adjusted to a desired angle. Thus, the applied load may be inclined at any desired angle from complete vertical to a purely lateral condition. The inclined alignment of the applied load is maintained by alignment guide mild steel bars attached with the load frame. The plunger is also guided through another semi-circular guide bar fitted at the lower end of the larger semi-circular load frame. Such an arrangement allowed an easy application of static inclined compressive loads on the raft or on the piled raft foundation as it approached failure and eliminated any potential moment transfer from the loading fixture. The settlements of the raft were measured using five 50 mm travel dial gauges accurate to 0.001 mm placed on the raft across section S-S as shown in Fig. 2.

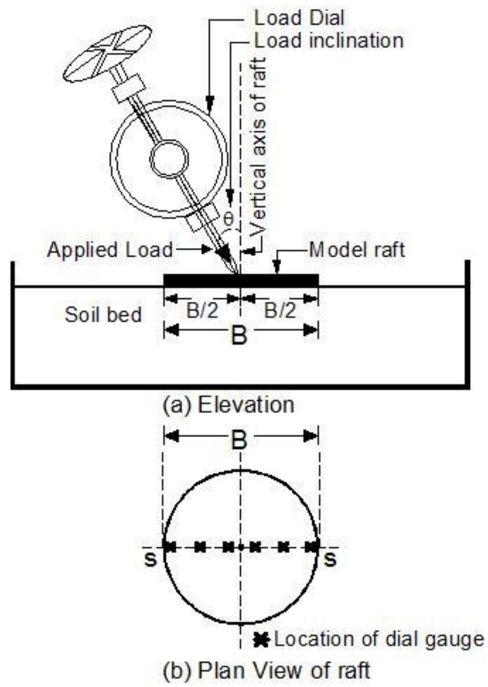

Fig.2. Schematic diagram of model raft and load arrangement

TEST MATERIAL

The sand used in this research is dry brown uniformly graded Mogra sand obtained from sand mines of Hoogly district, West Bengal was used. The sand washed, dried, and sorted by particle size. It is composed of rounded to sub rounded particles. The specific gravity of the soil particles was determined through specific gravity bottle. Three tests were carried out producing an average value of 2.65. The maximum and the minimum dry densities of the sand were found to be 18.5 kN/m3 and 15.1 kN/m3 and the corresponding values of the minimum and the maximum void ratios are 0.305 and 1.43., respectively. The particle size distribution was determined using the dry sieving method and the results are shown in Fig. 3. The effective size D10, uniformity coefficient (Cu) and coefficient of curvature for the sand were 0.45 mm, 1.25 and 0.96

respectively. In order to achieve reasonably homogeneous sand beds of reproducible packing, controlled pouring and tamping techniques were used to deposit sand in 50-mm-thick layers into the model box. Model soil layers 450 mm in height were constructed in layers with the bed level observed through the front glass wall. In this method, the quantity of sand for each layer, this was required to produce a specific relative density, was first weighed and placed in the tank and tamped until achieving the required layer height. The inner faces of the tank were marked at 50 mm intervals to facilitate accurate preparation of the sand bed in layers. The experimental tests were conducted on samples prepared with average unit weights of 16.1, 17.15, and 18.10 kN/m3 representing loose, medium-dense, and dense conditions, respectively. The relative densities of the samples were 35, 55, and 80%, respectively. The estimated internal friction angle of the sand determined from direct shear tests using specimens prepared by dry tamping at the same relative densities were 25°, 35.5°, and 40°, respectively. Secant Young's modulus representing loose, medium-dense, and dense sands derived from a series of drained triaxial compression tests were more or less 12,000, 20,000, and 35,000 kN/m2.

EXPERIMENTAL PROGRAM AND TEST SETUP

An extensive test program was carried out to study the behavior of obliquely loaded model piled rafts resting on sand. The effect of using short piles as structural members either rigidly connected to the raft or hinged with the raft on the ultimate inclined load carrying of piled raft foundation system was examined. Once the setup of the sand bed was completed, great care was given to level the sand surface using special rulers and a water balance so that the top surface of the sand was exactly horizontal. Then, several rows of free standing model piles were installed singly one-by-one using a special guide system which held the piles vertical during the installation. The guide system was initially clamped to the tank from the top. The piles were template through thin weight less synthetic strings into their pre-determined positions.

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RESULTS AND DISCUSSION

Results of more than50number of model tests carried out on model rafts in coheionless soil are reported in this paper. The raft behavior under oblique load (inclination angle is written as θ with the vertical axis of raft) with the inclusion of short piles was studied and discussed. The relative improvement of the raft performance when supported on either a rigidly connected or piles hinged with raft is represented using a non dimensional factor, called the bearing pressure improvement (BPI). This factor is defined as the ratio of the bearing pressure of a piled raft (qpiled) piles either rigidly connected or hinged with the raft, to the bearing pressure of an unpiled raft (qunpiled) at the same settlement level. The raft settlement (S) is expressed in nondimensional form in terms of the raft width (B) as the ratio (S/B, %). Pile to raft area ratio is denoted by Apr. For comparisons of the piled raft response with the different studied parameters, two levels of settlement ratios (S/B), at 1% and 5%, were considered.

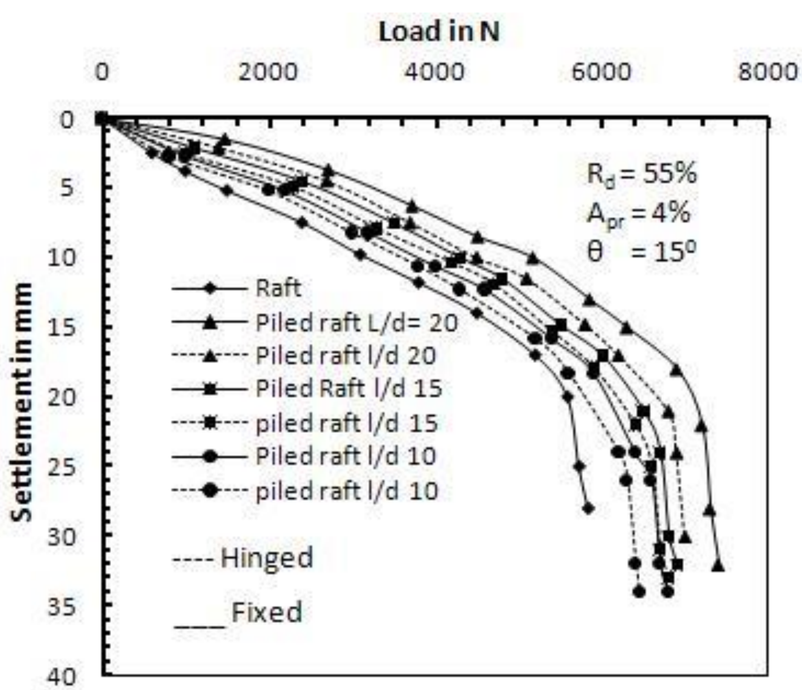

Fig. 6. Variation of load deformation behavior with maximum settlement for different pile lengths

EFFECT OF PILE LENGTH

Fig. 6 shows typical variations of the ultimate load versus maximum settlements of the raft centre under an inclined loaded on raft (θ= 150) for the different pile lengths. The behavior of an unpiled raft is also included in the figure for comparison. The figure clearly shows that the inclusion of piles either rigidly connected or hinged much improves the initial stiffness of the load-settlement curves (the ultimate load carrying much increase at lower rates of settlement). The figure also demonstrates that a pile rigidly connected to the raft has a more significant effect on the ultimate load carrying capacity of raft than that of hinged piles under inclined loaded condition. However, the improvements in the load carrying capacity at the same settlement level are greater with longer piles. The settlements decrease significantly for a pile connected to the raft for the same raft load. For example, comparing the curves of Fig. 6 at the ultimate load of the unpiled case, the value of the settlement decreased from 17.20 mm (unpiled case) to 15.6, 12.1, and 7.95 mm when using rigidly connected piles of L/D=10, 15, and 20, respectively.

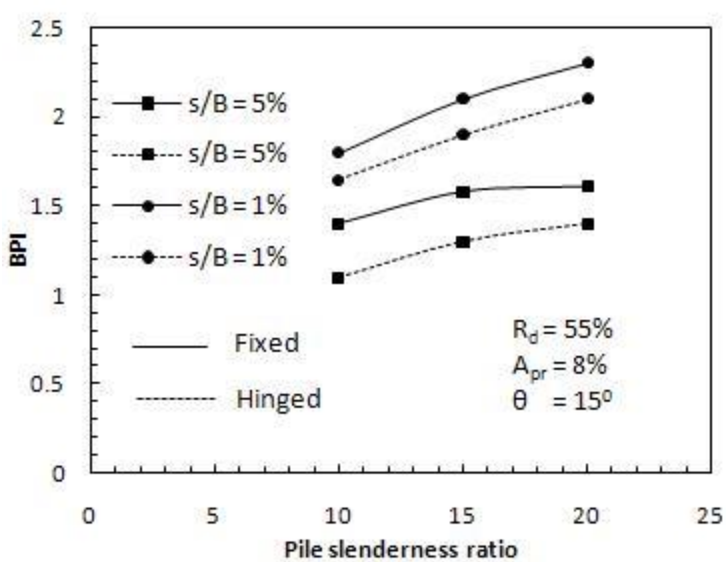

Fig. 7. Variation of BPI with L/d ratio at different s/B ratio

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EFFECT OF PILE NUMBER

Two series of tests were conducted on a raft subjected to load with an angle θ = 150 degree with vertical and resting on medium dense sand using same pile configuration (arrangement 3 in Fig. 5). While the piles were rigidly fixed with the raft in the first series, they were hinged with the raft in the second one (series 15 and 16 in Table 1). Fig. 8 shows the variations of BPI with pile number at different settlement ratios. The figure shows that the rate of BPI initially increases with the increase in pile number.

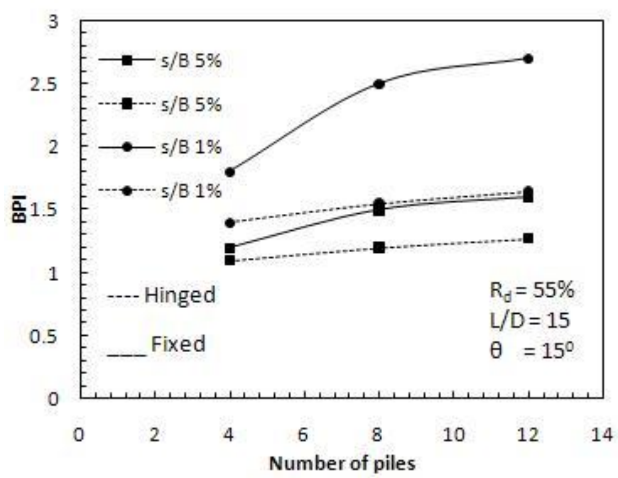

Fig. 8. Variation of BPI with number of piles at different s/B ratio

CONCLUSION

The effectiveness of using vertical short piles under a structural member either rigidly connected to raft or hinged with the raft were studied. Several arrangements of piles in cohesionless soils of different relative densities were investigated. Based on the laboratory investigations, the following main conclusions are drawn:

In case of raft alone lateral displacement is excessive whenever it is acted upon by combined vertical and lateral loads. The inclusion of short piles has a significant effect on improving the load carrying capacity of a piled raft composite as well as it minimizes the lateral displacement of the foundation.

Pile arrangement has significant effect on the raft settlement particularly at higher lateral load levels. However, it seems that the optimum arrangement of piles is dependent on the magnitude of lateral load. Piles placed at the edges of rafts are found to more efficient in reducing the overall settlement in piled raft whenever lateral load is around 20% of vertical load.

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