Settlement Behaviour of Disconnected Piled Raft Foundation under Vertical Loading Conditions

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Abstract - *Disconnected piled raft (DPR) foundations have been widely adopted as an effective foundation system where the piles are separated from the raft by a cushion layer, which can limit the shear forces and moments transmitted between the raft and the piles. Thus, DPR foundations may avoid the problem of horizontal forces, such as those from an earthquake or dynamic loads, which damage the structural connection between the pile head and raft. DPR foundation is an economical and efficient system, but the studies based on DPR foundations are limited. A series of static vertical loading tests were carried out on DPR foundation on fine sand using a geotechnical model. Loading tests were carried out by plate load test apparatus. In this paper we discuss the behaviour of interposed cushion layer under vertical loading conditions. The effect of vertical loading on cushion thickness, pile spacing and pile length were presented and discussed. The result showed that most of the vertical forces were carried by raft or interposed layer friction in the DPR foundation. It is observed that with increase in pile spacing and pile depth, DPR foundation was able to bear more load.*

Key Words: Disconnected piled raft foundation, cushion layer, static vertical loading, plate load test.

1. INTRODUCTION

Raft foundations are generally used to support buildings and structures, with or without basements, in dry or high water table conditions. When the shallow subsoil conditions are unfavorable (unsafe bearing capacity or excessive settlements) then load bearing piles are used to transfer the entire load to more competent soil layers. In many cases, the maximum and differential settlements are the controlling factors for the selection of piled raft foundations. The piled raft foundation consists of three load-bearing elements; namely piles, raft and subsoil. According to their relative stiffness, the raft distributes the total load transferred from the structure to the top soil and the connected piles. In conventional design of piled foundations, it was usually postulated that the overall load is supported by the piles. In piled raft foundation systems, the contribution of the raft is taken into consideration to verify the ultimate bearing capacity and the serviceability of the overall system. In conventional piled raft design, the number of piles is normally large and the load carried by each individual pile is relatively small. There is a high safety margin before the piles reach their ultimate geotechnical bearing capacity or structural failure load. The capacity of the piles is generally governed by geotechnical considerations rather than by the compressive strength of the pile material. In addition, the resistance of piles to horizontal forces through suitably designed connections is usually adequate due to the large number of piles used.

1.1 Disconnected Piled Raft Foundation

When settlement reducing piles are designed as structural components, the settlements are often relatively large such that the ultimate geotechnical capacity of the piles is fully mobilized. For an efficient design of rafts with settlement reducing piles, indicated that the geotechnical pile capacity could be assumed to be 80% mobilized under working load conditions. However, when these piles are structurally connected to the raft, as they are in traditional construction, a high axial stress may develop in the relatively small number of piles. Thus the load carrying capacity of these settlement-reducing piles may be governed by their structural capacity rather than by their geotechnical capacity. A high safety factor will then have to be applied in order to avoid structural failure.

In addition, these sparsely arranged structural piles beneath a raft may not provide adequate horizontal resistance to lateral loads. For structures resting on raft foundations in seismically active zones or areas with high wind loads, some building authorities therefore deter the use of settlement reducing piles. Thus the practical use of settlement reducing piles is restricted. As an example, designers in Jakarta, Indonesia, are reluctant to use these structurally connected settlement-reducing piles out of concern that the design would not be approved by the building authorities, in view of potential damage to the connections between the relatively few piles and the raft during an earthquake.

Since the main objective of adding piles to a raft is for settlement control, and thus to achieve an economical design of the foundation, one alternative in the design of these piles is to consider them as stiffeners for the base soil such that the above mentioned problems can be avoided. Hence an alternative method of disconnected piled raft foundation introduced as shown in figure 1.

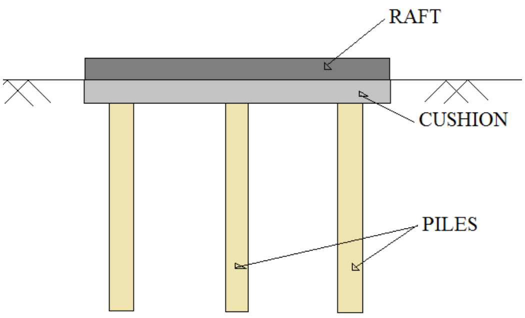

Fig -1: Disconnected piled raft foundation

The disconnected piled raft avoids the problem of horizontal forces, such as those from earthquakes or dynamic loads, that can damage the structural connection between the pile head and raft since such forces can normally be resisted by the friction mobilized along the interposed layer and raft contact as shown in figure 2.

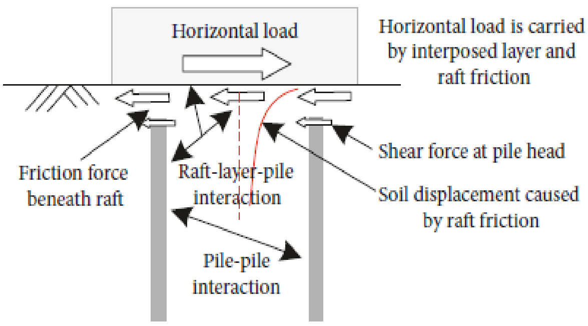

Fig -2: Horizontal load distribution technique

As there occurs a frictional force beneath the raft placed, the horizontal force acting on system may be carried by interposed layer and the raft friction and reduce the chance of structural failure. The friction and load carrying capacity of interposed layer may depend on the cushion material placed. Hence cushion material and the thickness of cushion material may adversely affect the properties of corresponding disconnected piled raft foundation. The settlement and horizontal movement may also depend on raft - interposed layer - pile interaction, pile to pile interaction, and finally on shear force produced at pile head.

2. OBJECTIVES AND SCOPES

To mobilize bearing capacity of subsoil and to modify load transfer mechanism on pile, a cushion layer is provided as an interposed layer between piles and raft. The main objective of this study is to investigate the behavior of disconnected piled raft foundation under vertical loading conditions. This is done by varying cushion thickness, pile spacing and pile depth to find the most appropriate foundation system by comparing its characteristics. The scope of this study is limited with load carrying capacity and effect of piles on different loading conditions.

3. MATERIALS USED

3.1 Sand

The soil used in the study is sand and was collected from IES College of engineering, Chittilappilly. The sand was air dried for conducting all the laboratory tests. Collected sample is shown in figure 3.

Fig -3: Sand

The grain size distribution was found using IS 2720-part 4. Evaluated properties of sand are shown in Table 1.

Table -1: Initial Properties of Sand

PROPERTIES	VALUES
Specific gravity	2.65
Uniformity coefficient, C_u	2.4
Coefficient of curvature, C_c	0.77
Gradation of sand	SP
Max. dry density (g/cc)	1.819
Min. dry density (g/cc)	1.777
Soil friction angle	33°
Permeability (cm/s)	7.29×10^{-4}

3.2 Gravel

Gravel is used in the study as a cushion material for load distribution purpose. Gravels of size 0.5mm to 5mm was chosen and was collected from Amala, Thrissur. Evaluated properties of gravel are shown in Table 2.

Table -2: Basic Properties of Gravel

PROPERTIES	VALUES
Aggregate Crushing value (%)	24
Aggregate Impact value (%)	15.75
Water absorption (%)	2.41
Coefficient of curvature (Cc)	4.75
Uniformity coefficient (Cu)	2.433
Hardness (%)	31.44

3.3 Pile

The model piles were circular hollow pile being hollow mild steel pipe having 16mm outer diameter. Thickness of piles expected to be 1 mm. The tips of the piles were closed. 9 number of piles with 3 different length (320, 360 & 400 mm) were used to study the effect of disconnected piled raft in different loading condition. The length of the piles were chosen in such a way that the depth of the bed below the tip was sufficiently thick so that, bottom rigidity does not affect the pile behavior and pile functions purely as friction pile.

3.4 Raft

Raft modeled to prototype scale of 1/50 were fabricated by using mild steel plate. The thickness of model raft was maintained uniform. Steel raft plate is used with a dimension of 240 mm length, 240 mm width and 25 mm thickness.

3.5 Test Tank

Model tests were performed in a test bed cum loading frame assembly. Test bed was prepared in a model test tank of internal dimensions 750mm length, 750mm width and 800mm depth. The square rigid test tank was fabricated using 1.2mm thick plain galvanized steel sheets forming base and four sides as shown in figure 4.

Fig -4: Test tank

Stiffeners were provided on the outer sides and bottom of test tank to make it rigid. The inside face of the tank was graduated at every 200mm depth intervals to prepare sand bed in layers to achieve correct density of sand in the tank.

4. MODEL TESTING

Large scale model testing are conducted to represent the three dimensional field condition. Effect of deformation extends to a specified distance. 'd' is the diameter of the pile used. The distance of pile from tank wall was kept at 20d, so that tank is not likely to interfere with the deformation zone of soil and hence the test results. For studying the effect of embedment depths, tank height and by considering the parameter spacing between the piles, tank width was selected. Height of the tank was selected as 2 times greater or equal to the embedded length of pile to ensure the insignificant effect of rigid behaviour of pile. Model tests were conducted under axial and loading conditions.

4.1 Filling Test Tank

The test tank was marked at 4 layers with 200mm depth. The quantity of sand was calculated for each layer corresponding to the required relative density. The predetermined quantity of sand was filled in each layer with method of freefalling from a height of 1.5m. The sand were filled in layers up to the level of 400mm height. Piles were kept in correct embedment depth and position. Then filling of sand was continued till it reaches the top surface of piles placed. Then the top surface of sand bed was leveled.

A sand-gravel mixture of 10% gravel in sand was initially placed as the cushion layer with a thickness of 10mm above the piles with in the boundary of raft to be placed. The surrounding portions were filled by sand up to the same height of cushion. Finally, raft plate was placed over the cushion layer.

4.2 Setting Loading and Measuring Devices

After preparing the test tank, the hydraulic jack was clamped to the reaction frame and its hose was connected to the lever system. The load was applied to the disconnected piled raft system by using rigid reaction frame through the hydraulic jack and proving ring. The axial load is directly applied on raft surface as shown in figure 5. A calibrated proving ring of 100kN and dial gauge of 25mm capacity with sensitivity of 0.01mm are used for measuring loads and pile displacement respectively. The proving ring and dial gauge are set to zero before the testing was started.

Fig -5: Axial loading setup

The test was started by applying load using hand operated hydraulic jack. The pile was loaded at a constant loading rate until an ultimate bearing state was reached. The behavior of disconnected piled raft foundation was obtained by plotting the graph between vertical displacement and axial load. Final load at which the disconnected piled raft system stops taking further load is taken as the ultimate axial load capacity of the DPR foundation.

5. RESULT AND DISCUSSIONS

In this study, the axial compressive loading of piles was considered. The loads applied at raft surface and the corresponding vertical displacements were recorded during tests. A cushion material of gravel-sand mixture was used in this study.
Before moving to axial compressive test, a direct shear test was conducted with varying gravel percentage in cushion material to confirm the most appropriate sand-gravel mixture. The concentration by weight of the gravel in the mixtures is varied between 0 and 15%.

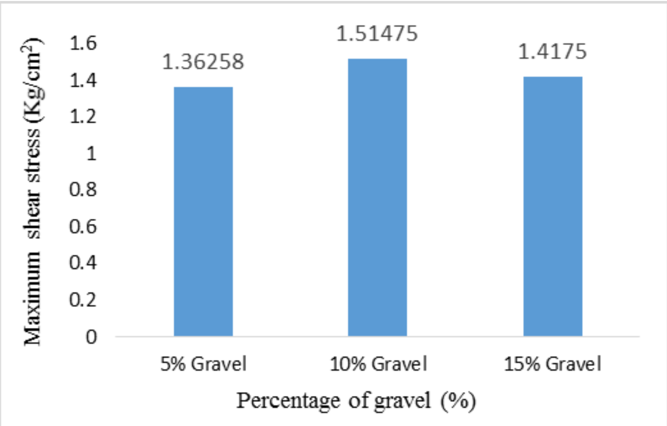

Fig -6: Maximum shear stress vs. percentage of gravel chart

Figure 6 shows a bar graph chart of maximum shear stress obtained from direct shear test using different percentage of gravel (5%, 10%, and 15%) in sand. Shear strain vs. shear stress graph were plotted with varying percentages of gravel in sand-gravel under 50, 100 and 150 kPa loads. Shear stress vs. normal stress graph were drawn corresponding to the maximum stress values from different percentages of gravel. It is observed that, at 10% of gravel content maximum shear stress of the mixture is attained. For further studies the cushion with 10% gravel is considered.

5.1 Load-Settlement relation based on Cushion thickness

Plate load test was initially conducted using varying cushion thickness to study its effect on DPRF. Cushion material of sand-gravel mixture with a constant percentage of gravel (10%) is used all over the study. Figure 7 shows the graph of settlement of disconnected piled raft foundation under three different cushion thickness 10, 15 and 20mm correspondingly.

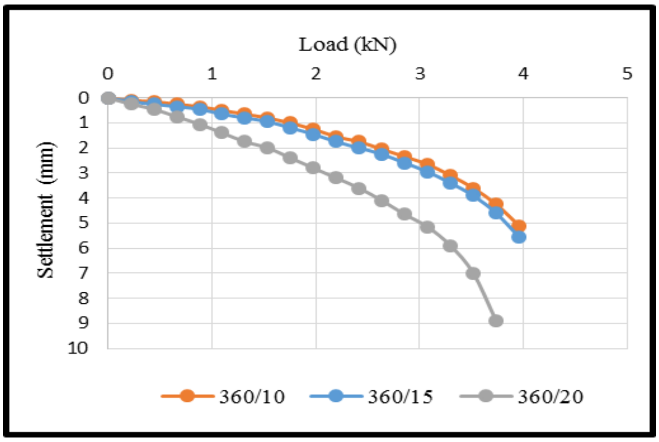

Fig -7: Load-Settlement curve based on cushion thickness

From the graph plotted, for cushion thickness of 10, 15, and 20mm, the maximum settlement of DPRF was observed to be 3.6, 3.9 and 7mm for a load of 3.52kN. From the obtained settlement values, cushion thickness of 10mm DPRF shows a slightly smaller value than cushion thickness of 15mm. The maximum bearing capacity of both foundation system is observed to be having values with slight difference. It is more practical to choose cushion thickness of 15mm, as there occurs 35 percentage more load distribution across the raft and cushion layer. When it comes to a 20mm thick cushion layer, settlement of DPRF is observed to be very high.

5.2 Load-Settlement relation based on Pile spacing

Axial loading tests were conducted on DPRF with varying pile spacing, considering a constant cushion thickness of 15mm. Figure 8 shows the graph of settlement of disconnected piled raft foundation under axial loading with three different pile spacing 4D, 5D and 6D, where D is the diameter of pile used. The diameter of pile was considered constant as 16mm.

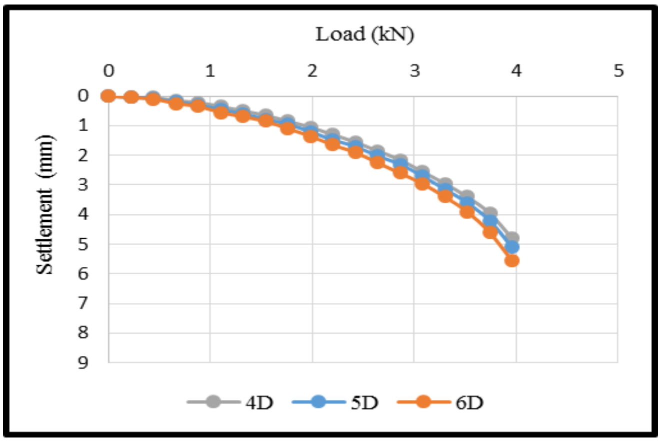

Fig -8: Load-Settlement curve based on pile spacing

For pile spacing of 4D, 5D and 6D, settlement for DPRF is observed to be 3.4 mm, 3.6 mm and 3.9 mm at a load of 3.52 kN. From the load settlement curve minimum settlement is observed when pile spacing of 4D is provided. A slight increment in settlement observed as the pile spacing increases correspondingly from 4D to 6D. Considering the economy and the observed increment in settlement is negligible 6D spacing was further adopted.

5.3 Load-Settlement relation based on Pile depth

Figure 9 shows the graph of settlement of disconnected piled raft foundation under axial loading with three different pile depth assuming a constant cushion thickness of 15mm and constant pile spacing of 6D. Three different pile depth of 320, 360 and 400mm were considered.

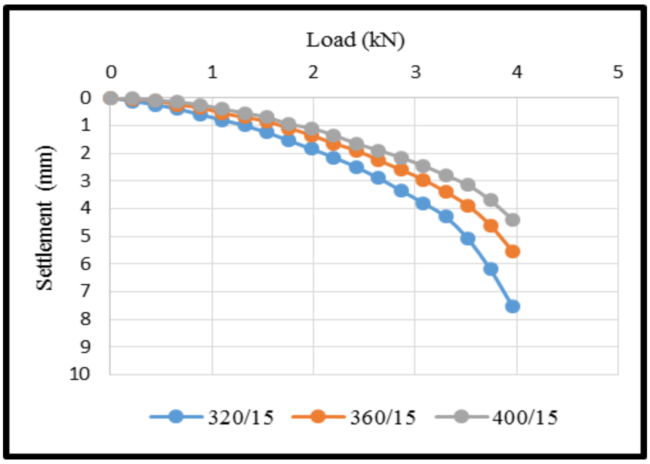

Fig -9: Load-Settlement curve based on pile depth

For pile depth of 320, 360 and 400mm, settlement of DPRF is observed to be 5.1, 3.9 and 3.15mm at a load of 3.52 kN. From the load settlement curve minimum settlement is observed at a pile depth of 400mm and as the pile depth decreases settlement increases correspondingly. Hence it can be concluded that with increase in pile depth, there is a decrease in overall settlement of the foundation.

5. CONCLUSIONS

Disconnected piled raft foundations have the potential to provide an engineered economical alternative for connected piled raft foundation system subject to vertical axial loads. From the model tests conducted, it can be concluded as,

- Maximum shear strength of sand-gravel mixture is attained when 10% of gravel is added.
- Cushion thickness of half the raft thickness is more effective for load distribution with maximum bearing capacity.
- Compared with cushion thickness of 15mm the settlement of cushion thickness 10mm was decreased by 7% and the settlement of cushion thickness 20mm was increased by 44%.
- With decrease in pile spacing, the overall settlement observed to be having a slight increment
- Compared with pile spacing of 6D, the settlement of DRPF of pile spacing 4D and 5D were decreased be 13% and 8%.
- With increase in pile depth, the overall settlement value decreases correspondingly.
- Compared with pile depth of 400mm the settlement of pile depth 320mm and 360mm were increased by 38% and 19%. This may be due to the increase of pile stiffness with increase in pile depth.

DPRF is more applicable in earthquake prone areas, as there occurs a possibility of structural failure for connected piled raft foundation. This foundation technique is more economic as the usage of reinforcement is much less on comparison with CPRF and the number of pile usage can be reduced. DPRF can be considered as an effective pile design to reduce the vertical loading experienced by the pile. The characterization of DPRF has focused on the load transfer mechanism, foundation and soil settlement, bearing capacity, load distribution and bending moments of the pile. DPRF can act to increase the bearing capacity of the ground and reduce settlement while securing bearing capacity.

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