Analysis of piled raft foundation in sandy soil using full scale models

H H Hussein¹, H H Karim² and K T Shlash³

¹ Civil Engineering Department, Wraith Alanbiyaa University, Karbala, Iraq
² University of Baghdad, Formerly Civil Engineering Department- University of Technology, Baghdad, Iraq
³ Civil Engineering Department, Uruk University, Baghdad, Iraq

Email: enghhhpile@yahoo.com

Abstract The conduct of the piled raft foundation system is measured by using different methods. Full scale loading tests were conducted on 18 full scale models consistent with ASTM D1143-07, so as to get actual behavior. The experiment study included carrying out still field load testing for piles fixed in sand soils in Karbala province, these piles are viewed as pioneers within this area. Testing was conducted for Six groups of piles (1×1, 1×2, 3 heaps, 2×2, 5 pile and 2×3). Every group comprised of three states; pile group, just rafts as well as piled rafts, accordingly, a sum of 18 still load testing were done. It was inferred that the piled raft basis diminishes the sum settling as well as prompts increment of the bearing limit more than the piles' groups along with the raft basis. The loading that was shared via the raft basis is approximately (46.3, 28.5, 27.6, 26.4, 25.7 and 25%) regarding the groups of piled raft (1×1, 1×2, 3 piles, 2×2, 5 piles as well as 2×3), individually. The instance of piled raft basis can be taken as the basic state on the grounds that the raft basis has no loading share until the piles' group achieves the completely preparing state. It was seen that the pile achieves this state as the connected loading is in the scope of (40-60%) of the sum burden, after which the raft participates loading share, and afterward it will be failed before pile.

Keywords Piled raft, Full scale, Load testing, Bearing

1. Introduction
The bases of Piled rafts represent composite structure contrasting to classic basis as the construction loading can either be transmitted via the rafts otherwise by piles only. The pile transmits a portion of the constructing loading to the deeper and more severe soil layers, and thus allows reducing the total difference settling within areas by economical technique. Piles can be utilized to a loading degree that could be similar in order of size and load carrying capacity of a single pile similar to or greater than that level [1]. The adopting of piled raft foundations idea for designing the pile group is absolutely not novel in addition was referred to by many researchers, including, [2], [3], [4], [5], [6], and [7], among many others. In the beginning and in view of the restricted accessibility of processing speed and technology saving, the usage of numeric techniques is limited for modest problems. In recent periods and because of the rapid growth in the computer technology, numerical methods such as full three dimensional techniques to solve the complex problems have been utilized.
2. Static Load Tests (Full Scale Model Static Tests)

Field models are known to be costly; therefore, most researchers keep away from conducting such models at sites. In this study, full real tests were executed and applied on Karbala's soils by loading tests on 18 full scale models carried out by the researcher and Al-Tariq lab for piles tests, consistent with ASTM D1143-07, [8], in order to achieve actual behavior.

Six different sets of piled-raft foundations were suggested for the real scale tests in the field. The suggested sets were different in their pile raft dimensions, piles number, and piles configuration. However, all piles were conveyed in a similar way keeping up an ordinary space (multiple times pile width = 0.9 m) amid each two neighboring piles. All sets have a typical pile length of 6 m. In addition, these sets are named with respect to the number of piles in each set. The six sets of piled-raft foundations are listed, as follows:

Set - 1: Foundation 0.9m × 0.9m with thickness of 0.60m and single pile.
Set - 2: Foundation 0.9m × 1.8m with thickness of 0.60m and two piles.
Set - 3: Foundation 1.68m × 1.8m with thickness of 0.60m and three piles.
Set - 4: Foundation 1.8m × 1.8m with thickness of 0.60m and four piles.
Set - 5: Foundation 1.8m × 2.46m with thickness of 0.60m and five piles.
Set - 6: Foundation 1.8m × 2.70m with thickness of 0.60m and six piles.

All the above sets contain three cases (Figure 1) depending on the behavior of the system in carrying the applied loads by sharing each part of the system to resist the loads. The three cases are as follows:

Case one: PRF (Piled raft foundation and the raft is in contact with soil).
Case two: PF (Pile foundation and the raft is not in contact with soil).
Case three: RF (Raft foundation without piles).

![Figure 1. Typical configuration of (a) piled raft; (b) un piled raft; and (c) group piles.](image)

3. Soil investigation of study location.

The site soil profile had been specified according to the geotechnical investigation results on two bore holes with their standard penetrating testing (SPT). The soil stratigraphy includes two major layers. The upper layer includes a thick yellowish to brown sandy silt soil (from 0 to -5) m while the other layer is made of medium thick light brown to brownish yellow sand from (-5 m to -15). The main properties for each soil layer, derived through geotechnical investigations, the evaluation tests of the
situ and laboratory are shown in Table (1). The particle size distribution was determined using the dry sieving method according ASTM D422-2001, specifications, [9], and results are shown in Figure (2).

| Property               | Value       |
|------------------------|-------------|
| Upper layer            |             |
| Very dense dry sand    |             |
| from 0 to -5 m         |             |
| Dry unit weight (Kn/m³)| 20          |
| Angle of friction      | 41          |
| Cohesion (Kpa)         | 0           |
| Lower layer            |             |
| Medium dense dry sand  |             |
| from -5 to -15 m       |             |
| Dry unit weight (Kn/m³)| 20          |
| Angle of friction      | 35          |
| Cohesion (Kpa)         | 0           |

Table 1. A brief of soil features of the study location.

Figure 2. Grain size distribution curve.

4. Output of static load tests
The compressive load was applied using hydraulic jacks possessing a capacity of 500 tons, every jack was put on the head of top and the principal steel beam. A suitable square strengthened solid top was casted on the heading of the testing basis to empower the exchange of the connected loading consistently. What's more, 25 mm thick steel plates were introduced on the top heading.

The settlements versus the vertical applied loads are shown in Figure (3). This Figure illustrates the loading settling conduct of piled raft foundation (PRF), pile foundation (PF) besides raft foundation (RF). The total loads applied for each case are listed in Table (2).
Table 2. The total test loads applied for the different cases in the field.

| Size of Foundation | 0.9×0.9 m (1×1) | 0.9×1.8 m (1×2) | 1.68×1.8 m (3 piles) | 1.8×1.0 m (2×2) | 1.8×2.46 m (5 piles) | 1.8×2.7 m (2×3) |
|--------------------|-----------------|-----------------|---------------------|-----------------|---------------------|-----------------|
| PRF                | 240 tons        | 120 tons        | 180 tons            | 504 tons        | 400 tons            | 480 tons        |
| PF                 | 150 tons        | 120 tons        | 180 tons            | 504 tons        | 400 tons            | 480 tons        |
| RF                 | 120 tons        | 120 tons        | 180 tons            | 320 tons        | 400 tons            | 480 tons        |

Figure 3. Output of static load test.

5. Load carrying capacity of rafts, pile cap and piled raft
The load conveying capacity of the raft, pile cap and piled raft within all groups along with the loading settling conduct of the entire systems using a square pile section of 0.30×0.30 m, was considered. The length of piles is kept constant as 6 m. To simulate the experimental work and ultimate load conditions, loads in the range of 120 to 600 tons have been applied. The next Figures (4) to (9) show that, the settling was plotted contrary to the upright applied loading. These Figures demonstrate the loading settling conduct of piled rafts, pile caps, and rafts for foundations. For all cases, the load-settlement relationships are linear in the beginning because both the piles and soil are still within the elastic ranges.
Figure 4. Loading-settling curve for single pile (1×1) below static load.

Figure 5. Load-settlement curve for two piles (1×2) under static load.

Figure 6. Load-settlement curve for three piles (1×3) under static load.

Figure 7. Load-settlement curve for four piles (2×2) under static load.
From the load settlement behavior for pile groups and piled rafts, it can be observed that the average settlement under any load at the beginning of testing is the same. That means that the total loads in piled raft is firstly carried by piles only without sharing from raft until reaching the piles to their full capacity, then the raft begins to carry part of the loading which was applied.

One could also conclude that the ratio of the fully mobilization of piles is ranging from 40 to 60% of the total load, then the effect of soil under the raft starts to resist the applied loads and sharing the piles group for incrementing the bearing capability of piled raft basis then reduces the total settling.

After the loading capability of the group piles get fully assembled, the loading reactions of the raft show non-linearly and progressively incrementing loading–settling curve and the loading capability of piled raft becomes higher than the pile group and the unpiled raft.

From the above, it can be concluded that the soil beneath raft might be considered "a transitional state" as it starts to share the carrying loads after the piles reach full mobilization. After that the raft contributed in loading share, at that time it would be failed in advance pile. Thus, the soil under raft is considered as "a critical state".

The conduct of loading share could be portrayed utilizing the loading share proportion which speaks to the proportion of loading conveyed by piles to the absolute loading forced on piled raft as pursues, [10]:

$$load\ sharing\ ratio = \frac{Q_p}{Q_{pr}} = \frac{Q_p}{Q_r+Q_p} = 1 - \frac{Q_r}{Q_{pr}}$$

(1)

As:

$Q_{pr}$ = loading forced on piled raft;
$Q_p$ = loading conveyed by piles;
$Q_r$ = loads carried by raft.

6. Assessment of Ultimate Capacity.
There are several standards that define the pile’s failing loading, [11]. Few of such standards are stated below:

![Figure 8. Load-settlement curve for five piles (5 piles) under static load.](image1)

![Figure 9. Load-settlement curve for six piles (2×3) under static load.](image2)
The bearing limit can be taken at break mark of two fascinating straight lines of various inclines in the wake of plotting the loading settling relation in log-log plot. This break mark stands for failing, [12] and [13].

Failing was stated as the loading conforming to displacement of 10% of the width of the model foot (otherwise pile width), [14].

The crossing of the two tangents of loading-settling curve is the base for defining the failing, whereas the second can be tangent to the lower flatter ration for that curve, [15].

The loading-settling curve is hyperbolic, fit as a fiddle, once the failing burden is drawn nearer. Every loading worth can be separated by its comparing settling esteem and the subsequent worth can be plotted against the settling, the plotted worth falls on a straight line. The reverse slope of such line represents the Chin-Kondner Extrapolation of the final loading, [16].

\[ Qu = \frac{1}{C_1} \]  
(2)

Where:
- \( Qu \): the ultimate loading
- \( C_1 \): the slope of the straight line

Once testing the preceding suggestions in addition to inspecting the conduct of the loading-settling relation for the piles of the current study, it was noticed for all cases that Butler and Hoy (1977) suggestion could be employed for stipulating the final load of the piled raft and piles group. From Figures (4) to (9), it can be noted that the load carried by piles increases with the increase in number of piles in the group for all the studied groups. The loading conveyed via piles to the sum loading carried out on piled raft also increases with increasing the piles’ amount within the groups, whereas the group of (2×3) registered the maximum piles capability by 75% of the entire applied loading, as shown in Table (3).

**Table 3. Loading share amid raft foundation along with pile groups from static field tests.**

| Case | Ultimate capacity of piled raft (tons) | Ultimate capacity tons Load shared (%) |
|------|---------------------------------------|----------------------------------------|
|      |                                       | Piles       | Piles       | Raft         | Raft         | Raft         | Raft         |
| 1    | 162                                   | 8 7         | 53.7%       | 4            | 4            | 4            | 4            |
| ×    |                                       | 7 5         |             | 6            | 6            | 6            | 6            |
| 1    |                                       |             |             | 3%           | 3%           | 3%           | 3%           |
| 1    | 105                                   | 7 3         | 71.4%       | 2            | 2            | 2            | 2            |
| ×    |                                       | 5 0         |             | 8            | 8            | 8            | 8            |
| 2    |                                       |             |             | 6%           | 6%           | 6%           | 6%           |
7. Conclusions

1. The basis of piled raft reduces the entire settling, leading to increment in the bearing capability more than the piles’ groups as well as the raft basis. For the case (2×2), as an example, the settlement at 300 tons is 30, 10, and 5 mm at the raft, pile group and piled raft system, respectively.

2. The loading that was shared by the raft basis is approximately (46.3%, 28.6%, 27.4%, 26.4%, 25.7% plus 25%) for groups of the piled raft (1×1, 1×2, 3 piles, 2×2, 5-pile group and 2×3), correspondingly.

3. The raft basis does not have load sharing in piled raft system until the piles’ group arrives at the entirely mobilizing state.

4. It can be noticed that the piles arrived at the entirely mobilizing state once the applied loading lies in the range of (40-60%) from the entire loading.

5. The case of piled raft basis can be as the critical state due to the cap contributed in loading share when the piles’ group arrives at the entirely mobilizing state then it will fail before pile.

References

[1] Hartman F and Jahn P 2001 Boundary Element Analysis of Raft Foundations on piles Mechanical Vol. 3 pp 351–366 (Kluwer Academic Publishers. Netherlands).

[2] Hooper J 1973 Observations on the Behavior of a Piled-Raft Foundation on London Clay Proc. Inst. Civ. Engrs., 55(2) pp 855-877

[3] Davis E and Poulos H 1980 Pile foundation analysis and design (Wiley).

[4] Burland J B Brooms B B De Mello V F B 1977 Behavior of foundations and structures In Proceedings of the 9th International Conference on Soil Mechanics and Foundation Engineering, Tokyo, Japan, Vol. 2 pp 495-546

[5] Prakoso W A and Kulhawy F H 2001 Contribution to Piled Raft Foundation Design Journal of Geotechnical and Geoenvironmental Engineering. Vol. 127 No. 1. pp 17-24

[6] Reul O and Randolph M F 2003 Piled Rafts in Over Consolidated Clay Comparison of In situ Measurements and Numerical Analyses”, Géotechnique, Vol. 53, No. 3, pp 301-315

References
[7] Katzenbach R, Arslan U, Motormen C and Reul O 1998 Piled Raft Foundation Interaction between Piles and Raft (*Darmstadt Geotechnics*, Darmstadt Univ. of Technology, No. 4) pp 279-296

[8] ASTM D1143-2007 Standard Test Method for Piles under Static Axial Compressive Load (American Society of Testing and Materials)

[9] ASTM D422 2001 Standard Test Method for Particle Size-Analysis of Soils (American Society of Testing and Materials)

[10] Junhwan L, Donggyu P and Keunbo P 2014 Estimation of Load-Sharing Ratios for Piled Rafts in Sands That Includes Interaction Effects (*Computers* (Impact Factor: 1.65). 01/2015; 63.DOI: 10.1016/j.compgeo.2014.10.014)

[11] Fellenius B H 2006 Basics of Foundation Design (Electronic Edition. [www.Fellenius.net]) p 275

[12] De Beer E E 1968 Proefondervindelijke Bijdrage Tot De Studie Van Het Grensdraag Vermogen Van Zand Onder Funderingen Op Stalk (*Tijdshrift der Openbar Verken van Belgie*, No. 6, 1967 and No. 4, 5)

[13] Winterkorn H F and Hsai-Yang F 1975 *Foundation Engineering Handbook* (Van Nostrand Reinhold Company, New York)

[14] Terzaghi K 1947 *Theoretical Soil Mechanism* (John Wiley, New York)

[15] Butler H D and Hoy H E 1977 *The Texas Quick – Load Method for Foundation Load Testing* (user’s manual, FHWA – ip 77 – 8, December)

[16] Chin F K 1971 Discussion Pile Tests Arkansas River Project ASCE, *J. SMFD*, Vol. 97, SM6 pp 930-932