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Behavior and Load Sharing of Piled-Strip System in Sandy Soil

Tawfek Sheer Ali 1, Raid R. Al-Omary 2 and Zeyad S. M. Khaled3
1Assistant Lecturer, Department of Civil Engineering, College of Engineering, Kufa University, Najaf, Iraq, PhD researcher in Alnahrain University, Baghdad, Iraq, tawfeeq76@gmail.com, tawfeeq76@yahoomail.com.
2Professor of Geotechnical Engineering, Department of Civil Engineering, College of Engineering, Alnahrain University, Baghdad, Iraq, tosharaid@yahoo.com.
3Assistant Professor of Construction Management, Department of Civil Engineering, College of Engineering, Alnahrain University, Baghdad, Iraq, zeyadsmkhalid@yahoo.com.

Abstract— Probably the most common type of deep foundations is the pile foundation. Piles are defined as relatively long, slender, column-like members. The piles is constructed with a pile cap in most of work of buildings and bridges. The piles in this case are considered carry the load alone and the cap only distribute the load on piles, this system is called piled-raft foundation. The aim of this paper is study the behavior of piled-strip system under a rate of loadings of 1 mm/s as a static loading and presents the sharing between footing and piles in. The sand container is manufactured to contain the soil using inside dimensions of 1 m long, 0.5 m width and 0.6 m depth. The box consists of four steel side frames and a steel base frame which are connected to each other by bolting and welding to form the box frames of the model. Strip footing model is manufactured to represents the pile cap of which encloses the piles under the columns load. The model was made of steel plates welded to transform the load using two v-shaped grooves to house the knife – edge loading blades. To achieve a plane strain condition the dimensions of footing are chosen to have 0.49 m length, 0.135 m width, and 0.2 m height. To achieve the plane strain piles conditions of piles footing, the steel frame with the dimensions of 0.49 m length, 0.4 m depth, and 0.03 m thickness is enfolded by 1 mm aluminum plate. Abrasive papers were glued to give the required roughness to simulate the piles in site. An experimental tests shows that the two capacities of pile, end bearing capacity and skin friction resistance sharing with 75.6% and 24.4% of piles capacity respectively. The results show also that the settlement is smaller for piled-strip system than the piles alone. The results also show that the sharing of footing in capacity with a 33.8% and the piles with 66.2%.

Index Terms— Deep foundation, Piled-raft, Piled-strip, Sharing between piles and footing.

1 INTRODUCTION

Foundations for heavy structures on weak soils are usually on piles and (or) pile-raft systems. These are also called basement raft supported piles or piled basements [1], [2]. When piles are founded on a compressible soil, the pile-raft system settles gradually resulting in a gradual buildup of pressure at the bottom of the raft. Thus, there is a gradual transfer of the total load to the raft and a reduction in the load carried by the piles. The soil beneath the raft (located at a relatively shallow depth) is then compressed, causing a partial load transfer back to the piles. This is a continuous interaction process with the total load being shared by the raft and the piles.

Hooper [3] examined the behavior of piled raft foundation supporting a tower block incentral London. The study was made on the building constructed on piled raft foundation of area 618 m2 with 51 bored concrete piles of length 25 m and diameter 0.91 m. during several years, the field measurements were taken. The analysis was carried out assuming uniformly distributed load on the raft. The instruments used for measurement of pile load, contact pressure and settlement were pile load cell, earth pressure cell and level. The average settlement of the building measured was 18 mm. Based on the field measurements the estimated proportions of load taken by piles and the raft at the end of construction were 60 % and 40 %. It was found that the long term effect of consolidation is to increase the load carried by piles and to decrease raft contact pressure.

Hain and Lee [4] developed an analysis to predict the behavior of a raft-pile foundation system. The analysis considers the system as flexible elastic plate supported on a group of compressible friction piles, and the supporting soil is represented as an elastic homogeneous or nonhomogeneous material. In the analysis, they suggested that the behavior of the piled raft would depend on the relative flexibility of the raft and the relative stiffness of the pile to the soil. Four different interactions between the piles, raft and soil were introduced and thoroughly considered in the analysis. In addition, a 'load cut-off' procedure was introduced to account for the development of the ultimate load capacities of the piles.

Yamashita et al. [5] analyzed a five story building on piled raft foundation of size 24m × 23m with 20 piles of length 16 m and diameter 0.75 m. The results of field observations during construction and analytical study of the same building have been compared. At the time of completion of the building, the settlement measured was 10 to 20 mm and the load shared by piles was 49 %. Analytical simulation of the settlement behavior of the building is presented taking into account the interaction between piles,

ISSN 2229-5518

soil and raft, which are compared favorably with the field observation.

Sinha [6] developed analytical models capable of predicting the settlement of each individual pile in the group under the raft. Accordingly, the differential settlement within the pile raft can be estimated. Three independent models developed to perform; first, the load sharing model that estimates the load components of the raft and the pile group in the system, the second model was to estimate the maximum settlement of the top of the raft and the third model was estimate the differential settlement among the pile-raft-foundation. Parametric studies were performed to observe the influence of raft and pile geometry (e.g length, size, spacing of pile and thickness of raft) on the foundation bearing behavior. The raft bearing contribution and its top deflection pattern under various loading and pile-raft configuration were also investigated. The multiple regression analysis technique, using statistical software MINITAB, along with the theory of solid mechanics was used to develop the analytical models for load sharing, maximum and differential settlement. On the basis of parametric study, the results concluded was that, pile raft increase the load resistance of about 40% than that of individual pile group or mat foundation, Pile spacing more than 7D is ineffective, and at smaller pile spacing, piles take the greater portion of the load and at larger pile spacing; the major load portion is carried by the raft.

2 Plane strain model for piled rafts

The main problem when modeling a piled raft with a plane strain model is the transition from three to two dimensions, i.e. to express a three dimensional problem in a two dimensional model. To do this the "out off"-plane rows of piles are simplified as wall elements, called plane strain piles (illustrated in Fig. 1). The wall element is defined per meter; the normal stiffness, bending stiffness and weight for the piles in the "out off"-plane row of piles are therefore "smeared" per meter

$$EA_{psp} = EA_p \frac{n_{\text{P-row-i}}}{L_P} \qquad (1)$$

Where

EA_{psp} = *Normal stiffness for plain strain pile*

EA_p = *Normal stiffness for one pile*

$n_{\text{P-row-i}}$ = *Number of piles in row i*

L_P = *Raft length in plane*

Analogously, the bending stiffness is inputted as

$$EI_{psp} = EI_p \frac{n_{\text{P-row-i}}}{L_P} \qquad (2)$$

and the weight

$$w_{psp} = w_p \frac{n_{\text{P-row-i}}}{L_P} \qquad (3)$$

The change of cross section when introducing the plane strain piles involves a change in periphery area, which will affect the important shaft resistance and an equivalent shaft resistance is therefore introduced. Since a plane strain pile has a periphery defined by its two sides, the shaft resistance is modified to (Prakoso and Kulhaw) [7];

$$f_{shaft,eq} = \frac{n_{\text{P-row-i}} A_s f_{shaft}}{2L_P} = \alpha_{ar} f_{shaft} \qquad (4)$$

where

A_s = *Shaft area per unit depth*

α_{ar} = *Area ratio*

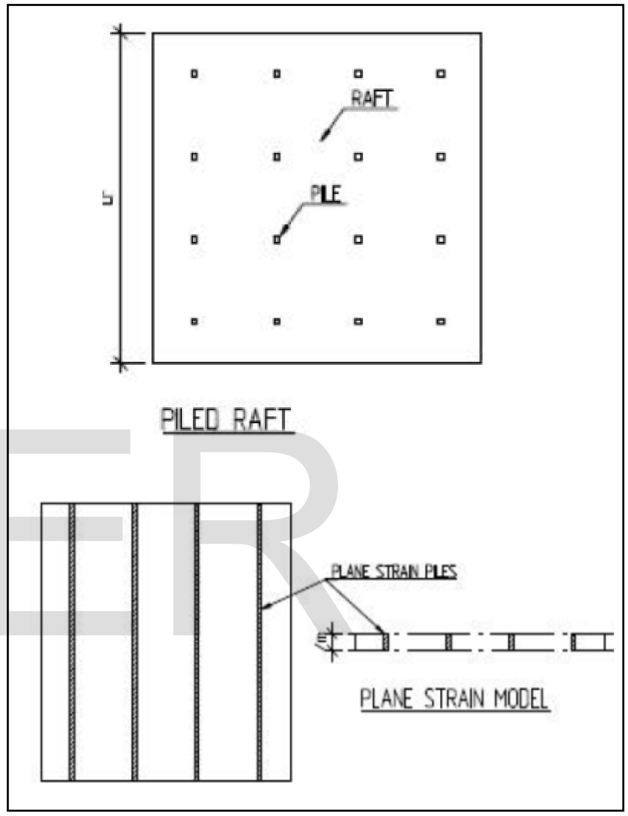

Figure 1 Plane strain model of piled rafts

3 Materials

3.1 Soil Properties and Preparation

The soil used is SP sand with a the chemical and physical properties shown in table 1. sieve analysis carried out its grain size distribution according to ASTM (D422-2007) is shown in Fig. 2. The soil was classified as *SP* type (*Poorly graded sand, gravelly sand, little or no fines*) according to the Unified Soil Classification. ASTM (D4253-2007) and ASTM (D4254-2007) were used to determine the maximum and minimum dry unit weight. The principle for achieving a relative density larger than 70% was used to fill the box of test. To achieve that, the raining technique using a special equipment as shown in Fig. 3 is adopted. The porosity was measured by placing 6 cylindrical density pots under the moving hopper to collect the sand. The inside dimensions of the pots are 80 mm in height and 80 mm in diameter, a pot diameter larger than 3 inches was chosen to satisfy the requirements specified by Kolbuszewski (1948) for free fall

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method. deposition of sand, the pots were carefully collected and the excess sand leveled off using a straight-edge. The pots were then individually weighed. With the known value of the specific gravity, the porosity can be calculated. The calibration was performed twice for the second and third layer of sand deposit before starting the test. A height of dropof (800 mm) was chosen which gave a placing density of 16.7 kN/m³, which corresponds to a working void ratio, porosity and relative density of (e =53.9%), (n = 35%) and (RD = 71.8%) respectively.

3.2 Models Configuration

The sand container was manufactured to contain the soil using inside dimensions of 1 m long, 0.5 m width and 0.6 m depth. The box consists of four steel side frames and a steel base frame which are connected to each other by bolting and welding to form the box frames of the model as shown in Fig. 4. The long side frames and the base are enclosed by steel channel sections of 3 inches width. One of the side frames (1×0.6 m) is made of 3mm thick steel plates and stiffened horizontally using two 2.5 inches channel sections of 6mm in thickness. The base is made of steel plate 3mm thick and stiffened using a grid of solid steel, square 0.5×0.5 inch elements, the distance between each two elements is 100 mm c/c. The two side frames (0.5×0.6 m) are made of 3mm thick steel plates and the bottom supplied by 3 inches channel sections, 6 mm in thickness. The other (1×0.6 m) side is formed from hardened glass plate, 10 mm thickness. The glass plates supported vertically from outside using two 2.5 inches channel sections. Hard plastic strips are placed between the glass plate and the channels to prevent the lateral deflection in the glass during the test. The rate of loadings is 1 mm/s as a static loading using a hydraulic load frame.

Strip footing model is manufactured to represents the pile cap of which encloses the piles under the columns load. The model was made of steel plates welded to transform the load using two v-shaped grooves to house the knife – edge loading blades. To achieve a plane strain condition the dimensions of footing are chosen to have 0.49 m length, 0.135 m width, and 0.2 m height. The footing base is made of a 10 mm thick rigid steel plate as shown in Fig. 5.

To achieve the plane strain piles conditions of piles footing, the steel frame with the dimensions of 0.49 m length, 0.4 m, and 0.03 m thickness is enfolded by 1 mm aluminum plate. Abrasive papers were glued to give the required roughness to simulate the piles in site (Fig. 6).

Table 1: Chemical and physical properties of the soil

The chemical Properties	
SO_3	0.53%
T.D.S	0.73%
Gypsum content	1.15%
The physical properties	
G_s	2.62
γ_{dmin} e_{max}	13.8 kN/m³
γ_{dmax} e_{min}	18.2 kN/m³
γ_{dused}	16.7 kN/m³
e_{used}	53.9%
n_{used}	35%
$Ø_{used}$	40°
$R_{D\ used}$	71.8%
O.M.C	9.8%
D_{60} D_{50}	0.65mm 0.52mm
C_u	3.6
C_c	0.93
m.c	5.3%

Figure 2 Grain size distribution of soil

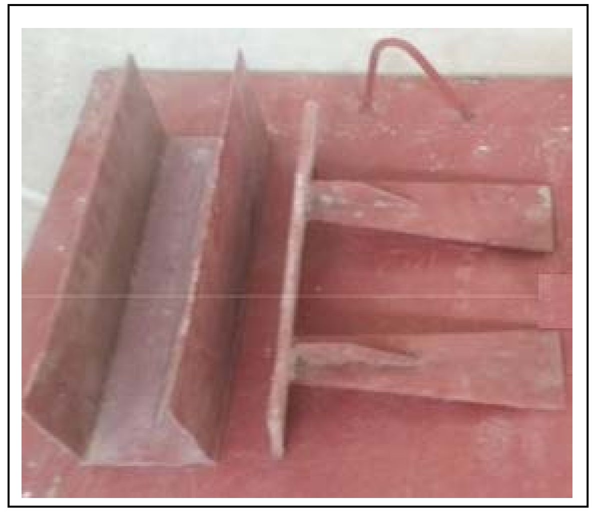

Figure 5 Strip footing model and loading blades

Figure 3 Raining technique equipment

Figure 6 Model of piles

Figure 4 Sand container used in the experimental study

4.Testing and Results

4.1 Piled-Strip system Capacity

The tests using piles under strip footing were performed to simulate the case of plane strain conditions. To achieve the plane strain principle in the analysis and design piles, the piles model were placed under the strip footing in the test box and under a loading frame with rate of loadings of 1 mm/s as a static loading (Fig 7). and the loads-Settlement relation shown in Fig. 8.

Figure 7 Plane strain piles model test under strip footing, (Piled-strip)

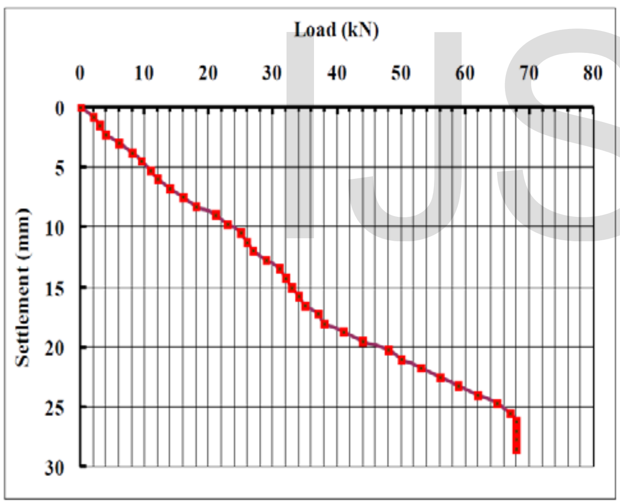

Figure 8 Load-Settlement relationship for piled-strip system

4.2 Skin and End Bearing Piles Capacity

A yield test performed using the plane strain pile model with a gap between the strip and soil to get the capacity of piles only (skin and end bearing), (Fig. 9). The load-settlement curve for this case is demonstrate in Fig. 10. The relationship shows the same behavior of the piled-strip system with a smaller value of load and larger value of settlement because of the exclusion of the area of strip footing.

Figure 9 Details of skin friction and end bearing for piled-strip model test

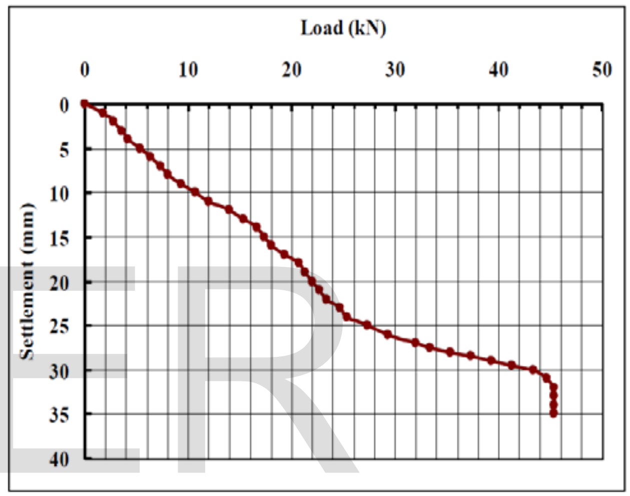

Figure 10 Load-Settlement relationship for skin and end bearing only

4.3 End Bearing Piles Capacity

This test was made to estimate the end bearing capacity of piles model only. To eliminate the skin friction, rubber membranes were applied on the two sides of piles model with the benefit of using silicon grease. This method is successful in eliminating the friction between sand and pile surface. The recorded capacity with a gap between strip and soil represents the end bearing piles capacity only. This technique was developed in the past to eliminate end friction in the triaxial specimen and then was used extensively in plane strain bearing capacity tests [8]. Figures 11 and 12 show the laboratory set up and load-settlement relationship.

4.4 Piled-Strip System Capacity Components

The piles capacity is a combination of end bearing and skin friction. The values of skin friction and end bearing capacity separately was investigated in this study. Figure 13 shows the details of skin friction, end bearing and piled-

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strip.

Figure 11 Details of end bearing piled-strip model test

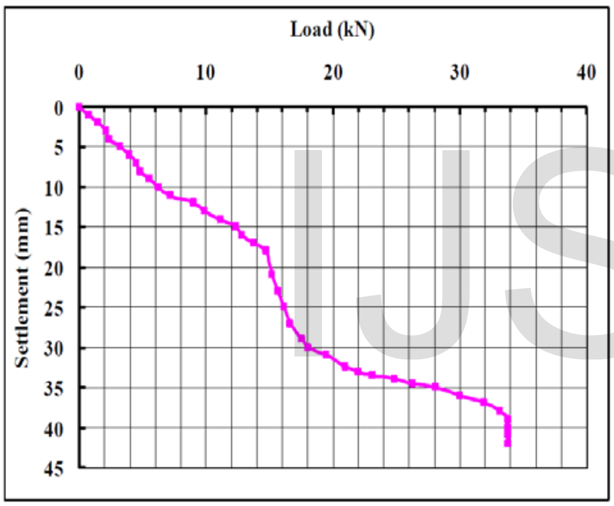

Figure 12 Load-Settlement relationship for end bearing only

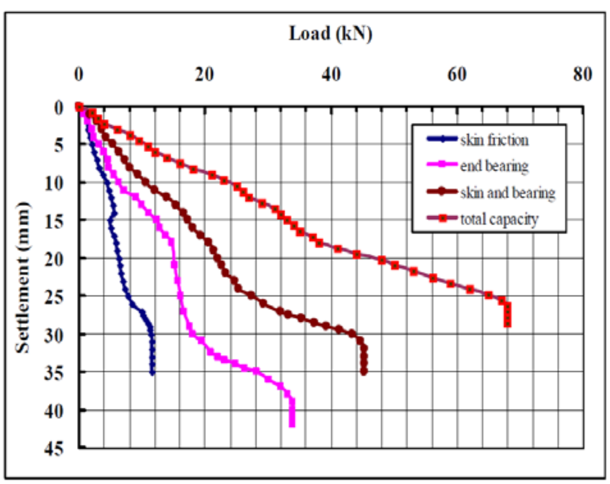

Figure 13 Details of skin friction and end bearing for piled-strip

The procedure for separating these values involves many stages as follows:-

1) Perform the test as a piled-strip system with strip in contact with soil. (Fig. 7)

2) Perform the test as in step 1 except that the strip is placed not in contact with soil using a suitable gap, (Fig. 8). From this step, the capacity of pile alone was measured.

3) Perform the tests in step 2 using a rubber membrane with silicon grease applied on the two sides of the piles model to eliminate the effect of friction.

4) The differences between all values explain the skin friction and end bearing capacity separately.

For example, the following data was taken to represent the calculations.

Pile-Footing system capacity = 68 kN (step 1 above)

Piles capacity (skin and bearing) = 45 kN (step 2 above)

Piles without skin (using rubber membrane) = 34 kN (step 3 above)

Then,
Skin friction = 45 – 34 = 11 kN (step 4 above)

4.5 Load Sharing Between Piles and Footing From Experimental

The experimental results presented above show the values of piled-footing system capacity as well as the values of skin and friction only. Figure 8 shows the values of capacities for piled-strip system which is being 68 kN and 46 kN for skin and bearing only, these values give a load sharing between piles and strip footing of 66.2% for piles and 33.8% for strip footing.

The sharing results for experimental results have a very good agreement with the study of Hooper [3] and Sinha [6].

6 Conclusions

An experimental work of piled-strip system placed in sandy soil is performed. The following conclusions are drawn from the load settlements relations for the capacity components of system and piles separately:

1. The piled-strip system have a lower settlement than the piles alone because of the sharing of strip footing itself in bearing the loads.
2. The end bearing capacity of piles sharing with 75.6% of piles capacity and the skin friction resistance sharing with 24.4% of piles capacity.

3. The load sharing between piles and strip footing of piled-strip system is 66.2% for piles and 33.8% for strip footing.
4. Use of a rubber membranes on the two sides of piles model with the benefit of using silicon grease is a suitable technique to eliminating the friction between sand and pile surface.

REFERENCES

[1] Poulos, H.G. (2001a), "Piled Raft Foundations: Design and Applications", Géotechnique 51, (2): 95-113.
[2] Michael Tomlinson and John Woodward, (2008), "Pile Design and Construction" , 5th Edition, by Taylor & Francis.
[3] Hooper, J.A. (1973), "Observations on the Behavior of a Piled-Raft Systems", Geotechnique, 28 (1): 65-83.
[4] Hain, S. J. & Lee, I. K. (1978), "The Analysis of Flexible Raft-Pile Systems", Géotechnique 28, No.1, 65-83
[5] Yamashita, K., Kakurai, M., Yamada, T., (1993), "Settlement Behavior of a Five Storied Building on Piled Raft Foundation", Proc. of the 2nd Int. Geotechnical Seminar on Deep Found. on Bored and Auger Piles, Guent, Belgium, 350-356 Balkema, Rotterdam, Brooke.
[6] Anup Sinha, (2013), "3-D Modeling of Piled Raft Foundation", M.Sc. Thesis, The Department of Building Civil and Environmental Engineering, Concordia University, Montreal, Quebec, Canada.
[7] Prakoso, W. A., and Kulhawy, F. H., (2002), "Contribution to Piled Raft Foundation Design", Discussion and Closures, J of Geotech. and Geoenv. Engg, ASCE, vol. 128 (8): 707-709.
[8] Al-Omari, R.R., (1984), "Strip Foundation on A Sand layer overlying A Rigd Stratum", Ph.D. Thesis, Strathclyde University, Scotland, UK.