Behavior Of Piled – Raft Foundations with Cap Directly In Contact With Soil and Freestanding Pile Cap

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Abstract: The main purpose of the present study is to investigate the behavior of directly in contact with soil piled-raft cap and piled- raft freestanding cap foundations in cohesionless soil. The distributions of load along pile shaft as well as the transferred load to piles tip have been determined. In addition, the group efficiency and pile group's settlement have been obtained. In addition, the loads transferred directly to the soil underneath the pile cap have been obtained. Experimental tests were done under axial loading. A load test was executed for a single pile. The second load test is Piled-raft cap directly in contact with soil for four piles. The third load test is Piled-raft freestanding cap for four piles. In addition, end-bearing load as well as underneath the pile cap were determined. It is concluded that the load transferred to soil underneath Piled-raft cap directly in contact with soil is found to be 7.98% from the ultimate load capacity. However, the load transferred to soil by friction is found to be 88.27% from the ultimate load capacity. In addition, the load transferred to soil at pile tip is found to be 3.75% from the ultimate load capacity. However, the load transferred to soil by friction for Piled-raft freestanding cap is found to be 95.67% from the ultimate load capacity. In addition, the load transferred to soil at pile tip for Piled-raft freestanding cap is found to be 4.33% from the ultimate load capacity. The group efficiency of Piled-raft cap directly in contact with soil is more than that for Piled-raft freestanding cap. In addition, the group efficiency obtained from experimental test results is higher than the theoretical one. The settlement of Piled-raft freestanding cap is more than that for Piled-raft cap directly in contact with soil. Fair agreement is found between the values of settlement obtained from experimental results using Tangent method and by using finite element analysis.
[Elsamny M. Kassem, Abd EL Samee W. Nashaat and Essa. Tasneem. A. **Behavior Of Piled – Raft Foundations with Cap Directly In Contact With Soil and Freestanding Pile Cap.** *Life Sci J* 2018;15(8):45-62]. ISSN: 1097-8135 (Print) / ISSN: 2372-613X (Online). http://www.lifesciencesite.com. 10. doi:10.7537/marslsj150818.10.

Keywords: Freestanding, in contact, Piled-raft, behavior, piles, settlement, cap

1) Introduction

Usually, piles are used in groups to transfer the supported structure load to the underneath soil layers. Pile cap is executed over a group of piles. In addition, raft foundation rested on piles is able to support the applied load with an appropriate factor of safety to reduce the settlement of foundations. However, Erosion is lowering the ground surface under a pile cap and scour is a localized loss of soil around piles as shown in Fig. (1). Erosion and scour have several adverse impacts on coastal foundations. However, as a result, the pile group will be freestanding (i.e. pile cap is not directly in contact with soil). Erosion and scour reduce the impediment of the foundation into the soil, causing shallow foundations to collapse and making buildings on deep foundations more susceptible to settlement. Scouring generally occurs when the velocity of the flowing water increases the limiting value that the soil particles can simply handle as shown in Fig (2).

Thus, it became necessary to study the phenomenon of the behavior of the directly in contact with soil piled-raft and freestanding piled-raft foundation.

Tomlinson (1995) presented the relationship between the load and settlement for a single pile. At the early stage of loading, the pile settlement due to friction load is very small due to elastic shorting in the pile and the surrounding soil [1].

Muthukkumaran, K. et al (2004) introduced the load transferred from a bored cast – in – situ pile socketed 1.5 m into hard rock. The results clearly showed that the frictional resistance shares the maximum load than end bearing resistance [2].

Rai, S. and Singh, B. (2010) discussed the response of the foundation system when piles are added to a load bearing raft. The load carried by the piles decreases with a settlement. Rai, S. and Singh, B. presented an analysis of settlement of piled raft foundation [3].

Tejendra G Tank and S. P. Dave (2011) summarized the analytical approaches for the analysis of combined piled-raft systems. Tejendra G Tank and S. P. Dave found that increasing the pile length decreases the settlement [4].

Alnuiam A., El Naggar H. and El Naggar M.H. (2013) presented an analysis of piled-raft in cohesionless soil by finite element. The effects of pile diameter and spacing on load distribution have been investigated [5].

Basuony G. et al. (2013) presented an experimental program aimed to investigate the behavior of the raft on settlement of the piles. Three different lengths of piles were used in the experiments study [6].

Hussein H. K., Mahmoud R. Q. and Mudhafar K. H. (2013) evaluated the effect of pile spacing on the load settlement behavior of the piled-raft foundation. The percentage of the load carried by piles to the total applied load of the numerical model found to be 42%. [7].

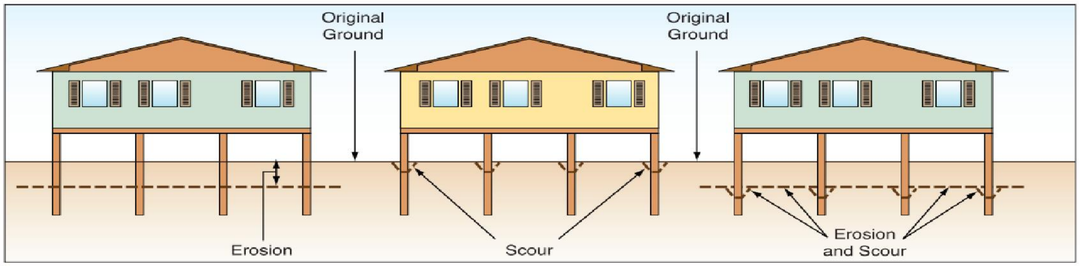


Fig (1). A building subjected to erosion and scour.

Fig (2) Effect of erosion and scour.

Mohammed Y, F., Mustafa A. Y. and Sarmad M. T. (2013) experimentally investigated the behavior of piled-raft system in sandy soil by study. It was found that increasing numbers of piles decrease the settlement [8].

Adel Y. A., Mohamed H. M. and Heba K. M. (2014) performed a finite element modeling for a square piled-raft foundation rested on soil with different stiffness. The analysis contained variation of a number of piles, distribution as well as length [9].

Ashraf A. and Saibaba R. (2014) investigated the behavior of piled-raft foundation. The spacing between piles needs to be wide enough to allow the raft to participate in taking part of the load and using the pile strategically as settlement reducer. Ashraf A. and Saibaba R. found that increasing size of the raft increases carrying capacity. For the piled raft models, the total carrying capacity of the model increased with the increasing of raft size and number of piles in the group [10].

Paravita, S. W. and Daniel T. (2015) analyzed the settlements of the raft foundation and by adding piles. Finite element analysis has been done using PLAXIS 2D. Paravita, S. W. and Daniel T found that, the addition of piles decrease the settlement [11].

Alnos Aly E. Hegazy (2016) investigated piled-raft foundation subjected to general loading as the requirements of design for rafts enhanced with piles. The analysis showed that the stiffness ratios (E_{pile}/E_{soil} and E_{raft}/E_{soil}) and pile spacing (S/D) have significant effects on the piled-raft settlement [12].

The main purpose of the present study is to investigate the behavior of piled-raft cap directly in contact with soil and piled-raft freestanding cap foundations.

2) Experimental Test Program

The experimental research program was to study the effect of the freestanding pile group and directly in contact with soil piled-raft foundation for load sharing of soil around piles and underneath the piled raft groups. The loads transferred to soil underneath the piled- raft directly in contact with soil for four piles and piled- raft freestanding for four piles were measured by a load cell. In addition, the piles were instrumented by five strain gauges along the steel reinforcement to quantity the distribution of loads in the pile. The load and settlement, as well as loads at the pile tip and underneath pile cap were measured. The piles were placed in compacted sandy soil. The test program is as follows:

a) - Single pile – Group (1).

b) - Piled- raft directly in contact with soil for four piles - Group (2).

c) - Piled raft freestanding for four piles - Group (3).

2.1 Characteristics of Piles materials

Used materials and reinforcement as well as concrete dimensions are the follows:

a) Graded sand as fine aggregate in the mix.

b) Crushed stone having sub angular particle shape as coarse aggregate.

c) Ordinary Portland cement.

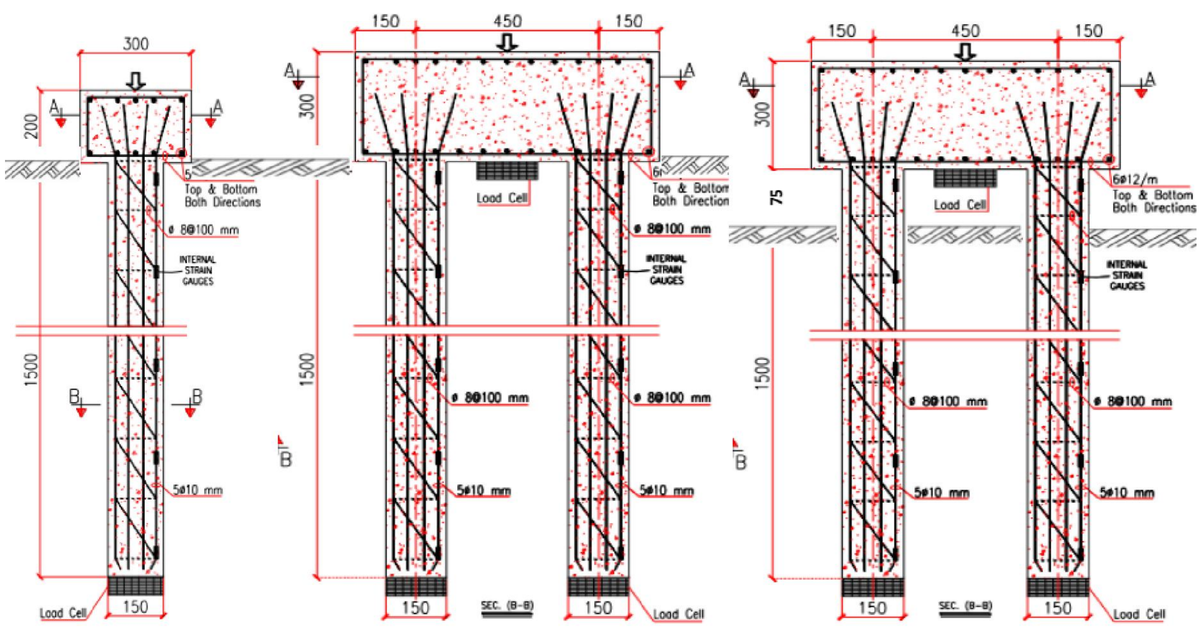
d) Nominal cube strength 2.00 kN/cm^2

e) Clean drinking water free from impurities with a w/c ratio of 0.50.

f) Hot rolled deformed reinforcement steel as reinforcement for the specimens.

2.2 Concrete Dimensions and Reinforcement Details

Nine cylinder precast concrete piles of (150) mm outside diameter with (1500) mm length were executed. Fig (3) shows the details of pile dimensions and reinforcement.



a) Single pile–group (1) b) Piled-raft cap directly in contact with soil -groups (2) c) Piled-raft freestanding cap piles-groups (3).

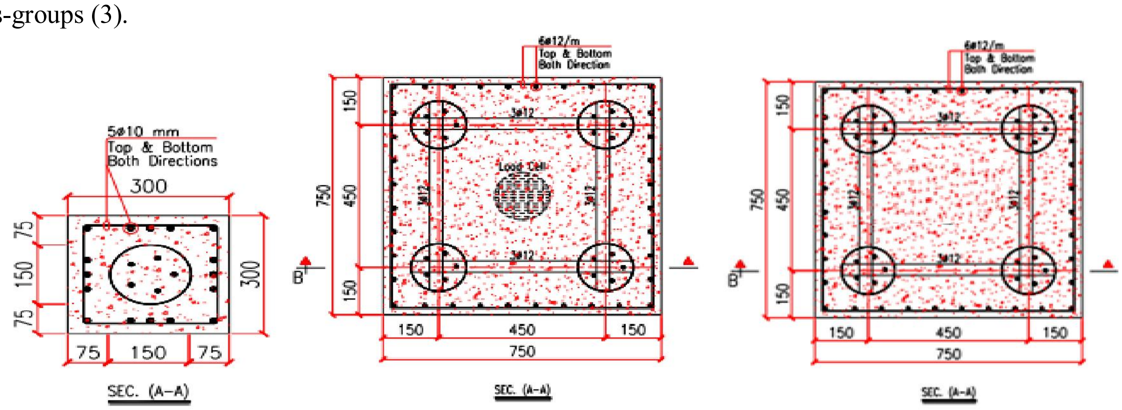


Fig (3). Reinforcement Concrete details for single pile–group (1), Piled-raft directly in contact with soil for four piles -groups (2) as well as Piled-raft freestanding for four piles-groups (3) (all dimensions in mm).

2.3. Reinforcement Details

The longitudinal pile reinforcement consisted of five bars (10) mm diameter with a yield strength 36 kN/cm^2. The spiral stirrups in the piles were formed by (6) mm diameter bars at a spacing of 10 cm. The reinforcement details are shown in Fig (4).

2.4 Strain Gauges

Strain gauges were mounted on the internal steel reinforcement as shown in Fig (4).

2.5 Description of Forms

The used forms were cylinders made of 6 cm steel thickness. The details of which are shown in Fig (5).

Fig (4) Pile reinforcement details

Fig (5). Description of forms.

Fig (6) Casting of pile

2.6 Casting of Concrete

All specimens were cast using a mechanical vibrator as shown in Fig (6). A slump test was taken. In addition, five standard cubes (15×15×15) cm were taken from each concrete patch to define the actual concrete compressive strength. After 24 hours, pile forms were removed and pile specimens were cured with fresh water for 7 days. The cubes were tested after twenty eight days from the date of pile's concrete casting.

2.7 Testing Setup and Procedure

The pile specimens were divided into three groups:

a) The first group is a single pile that denoted (Single pile – Group (1)).

b) The second group is Piled-raft with cap directly in contact with soil for four piles-Group (2).

c) The third group is Piled-raft with freestanding pile cap for four piles - Group (3) (with clear distance 7.5cm =0.5d & d= diameter).

Each pile group was loaded in12 increments according to Egyptian Code, 2001, each increment being maintained time for every increase of load by 25 % test load up to 150 % from theoretical ultimate load and then starts unloading by decreasing load increments by 25 % test load during certain load.

2.8 Loading and Loading Frame

Loading frame manufactured to resist the expected maximum loads that might occur during the test, the details of the frame are shown in Fig. (7). The testing, load was applied using a 100 ton hydraulic jack located at the top of the tested pile or pile group as shown in Fig (8). The loads were simultaneously recorded by an 80 tons load cell as shown in Fig. (9) which was placed at the tip of the tested pile and directly underneath the pile cap. Load cell were connected to a data acquisition system. The data acquisition system used in the present study includes a Laptop computer, a model 8032 Multiplexor (MUX) Data Acquisition System introduced by GEOKON Company and the Lab Tech Notebook software package.

Fig (7) Soil chamber and loading frame

Fig (8) Loading jack and pump

Fig (9) load sell

2.9 Test Procedures

2.9.1 Test Procedures for Single pile - Group (1)

a) Compacted sand was placed in the soil chamber to a depth of about 1000 mm below the pile tip using water content of maximum dry density.

b) A load cell was placed in hole at the center of the pile guided by the frame.

c) Placing the pile over the load cell directly has done taking into consideration centric vertical alignment as shown in Fig (10).

d) Total embedment depth of the pile is 1500 mm after filling with compacted soil layers each has 150 mm thickness using mechanical compactor as shown in Fig (11).

e) The surface of the sand at top was leveled and pile cap shuttering, as well as steel cage were placed then concrete was casted.

Fig (10) Alignment of pile - group (1)

Fig (11) Placing compacted soil around tested pile for single pile- group (1)

Fig (12) Reference beams and dial gauges setup for single pile- group (1)

f) Reference beams were attached around the edge of the cap. Dial gauges were installed on the reference beams (separated from the loading system) to measure the pile head settlement. A hydraulic jack placed between the pile head and the reaction frame as shown in Fig (12).

2.9.2 Test Procedures for Piled- raft cap directly in contact with soil -groups (2) and Piled raft freestanding cap - groups (3)

a) Compacted sand placed in the soil chamber to a depth of about 1.00 m below the pile tip using a water content of maximum dry density.

b) A load cells were placed in hole at the pile tip guided by the frame.

c) Placing the pile over the load cell directly has done taking into consideration centric vertical alignment.

d) Total embedment depth of the pile is 1500 mm after filling compacted soil layers each has 150 mm thickness using mechanical compactor keeping the distance between piles (3diameters from center to center) as shown in Fig (13).

e) Placing load cell underneath the pile cap in case of Piled-raft cap directly in contact with soil-Group (2) only as shown in Fig (14).

f) The surface of the sand at top was leveled and pile cap shuttering as well as steel cage was placed then concrete was casted as shown in Fig (15).

e) Reference beams were attached around the edge of the cap. Dial gauges were installed on the reference beams (separated from the loading system) to measure the pile head settlement. A hydraulic jack was placed between the pile head and the reaction frame as shown in Figs (16) and (17).

Fig (13) Placing piles and keeping the distance between piles (3diameters from enter to center) for Piled-raft cap directly in contact with soil Group (2).

Fig (14) Placing load cell under cap Shuttering, reinforcement and concrete for Piled-raft cap directly in contact with soil Group (2).

Fig (15) Shuttering, reinforcement and concrete casting for Piled-raft cap directly in contact with soil Group (2).

Fig (16) Loading jack, reference beams and dial gauges setup for Piled-raft cap directly in with contact soil-Group (2).

Fig (17) Loading jack, reference beams and dial gauges setup for Piled-raft cap freestanding Group (3).

3) Ultimate Pile Load From Theoretical Approaches

The ultimate capacity for single pile introduced in the present study was determined by several theoretical approaches and by using Egyptian code (2001) [13]. The calculated theoretical ultimate capacity of single pile Q_u is 30 KN and of Piled-raft cap directly in contact with soil- Group (2) and Piled-raft freestanding cap - Group (3) Q_u is 120 KN.

3.1 Loading Method of the Current Study

Loads were applied according Egyptian Code (2001). The tested piles are shown in Table (1).

Table (1). Tested piles

Test No.	Single pile – Group (1)	Piled-raft cap directly in contact with soil for four piles - Group (2)	Piled-raft freestanding capfor four piles -Group (3)
Theoretical Ultimate load (kN)	30	120	120
Test load (kN)	1.50*30=45	1.75*120=210	1.75*120=210
No. of pile	1	4	4
Pile diameter (mm)	150		
Pile length (mm)	1500		

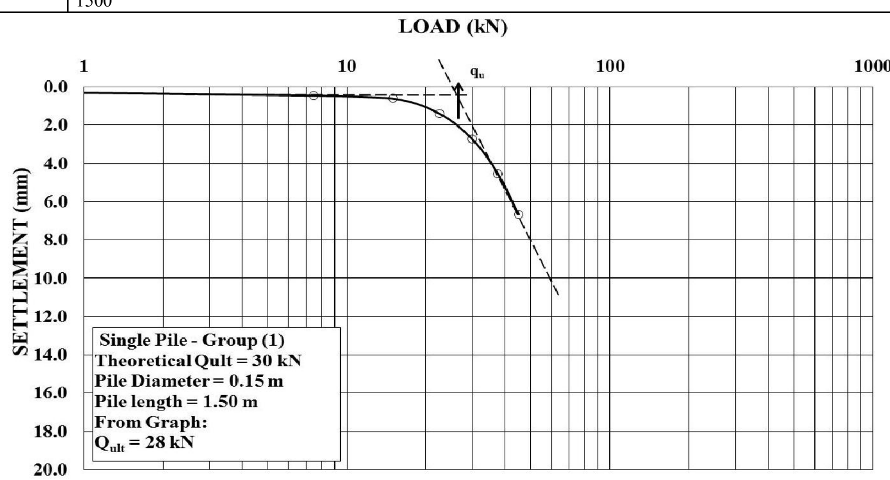


Fig (18). Determination the ultimate load by Tangent method [U.S. Army Corps Engineers, (1991)] for (single pile - group (1)).

Experimental Test Results

The ultimate pile load capacity has been determinate by using modified Chin method (1970) (Egyptian Code, 2001) and Tangent– tangent method (U.S. Army Corps Engineers, 1991) as follows:

4.1 Interpretation of Pile Load Test Results for Single Pile –Group (1)

The ultimate pile load capacity for single pile Group (1) has been determine by using modified Chin method and the Tangent-tangent method from pile load tests readings as shown in Figs (18) and (19).

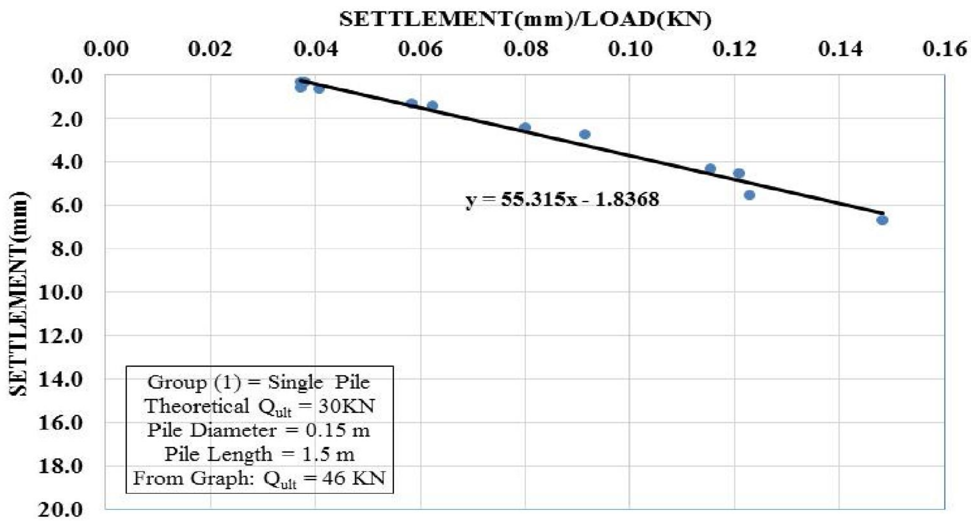


Fig (19). Determination the ultimate load - by modified Chin for single pile - group (1).

4.2 Interpretation of Pile Load Test Results for Piled-Raft Cap Directly in Contact with Soil - Group (2)

The ultimate pile load capacity for Piled raft cap directly in contact soil with four piles - Group (2) has been determine by using modified Chin method and the Tangent-tangent method from pile load test readings as shown in Figs (20) and (21).

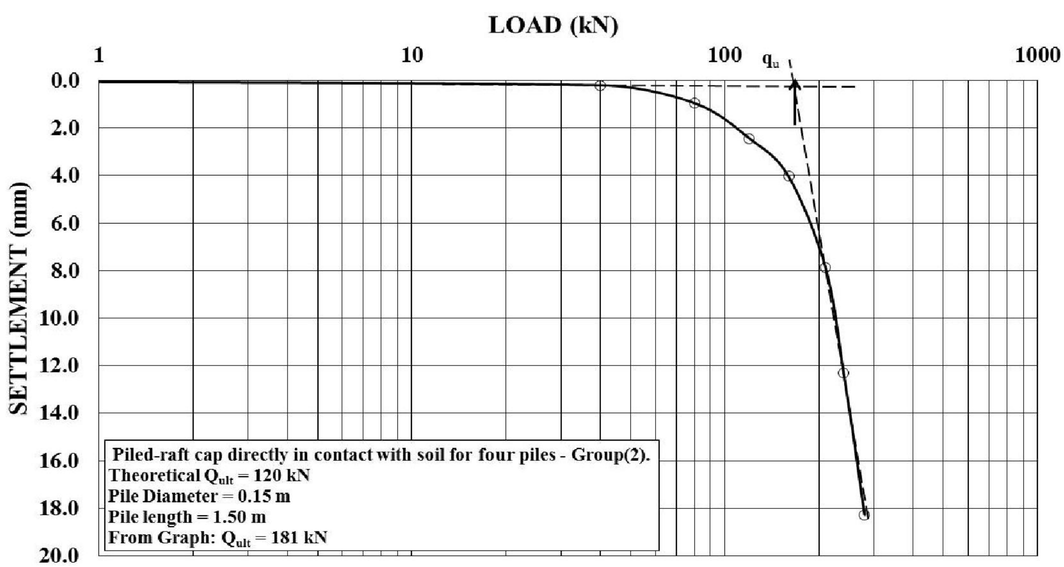


Fig (20). Determination the ultimate load by Tangent method [U.S. Army Corps Engineers, (1991)] for (Piled-raft cap directly in contact with soil for four piles - Group (2)).

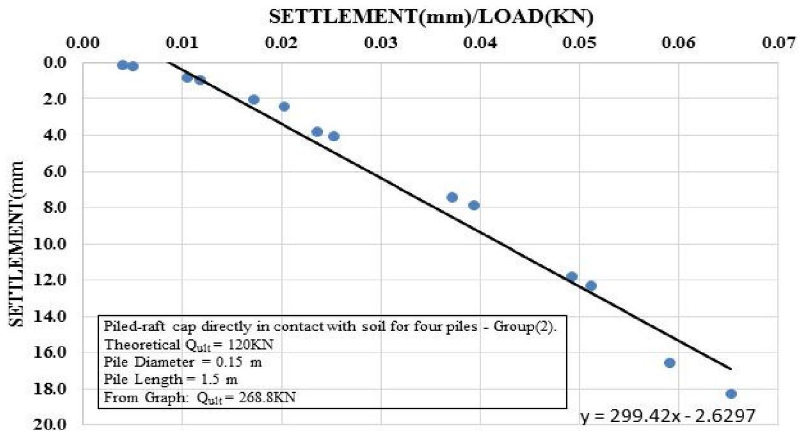


Fig (21). Determination the ultimate load by modified Chin method for Piled-raft cap directly in contact with soil for four piles -Group (2).

4.3 Interpretation of Pile Load Test Results for Piled-raft Freestanding Cap for Four Piles - Group (3).

The ultimate pile load capacity for Piled raft freestanding cap for four piles - Group (3) has been determine by using modified Chin method and the Tangent-tangent method from pile load test reading as shown in Figs (22) and (23).

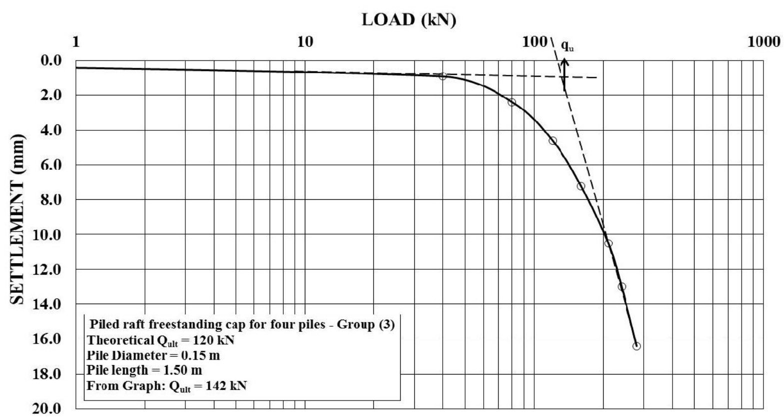


Fig (22). Determination the ultimate load by Tangent method [U.S. Army Corps Engineers, (1991)] for Piled raft freestanding cap for four piles - Group (3).

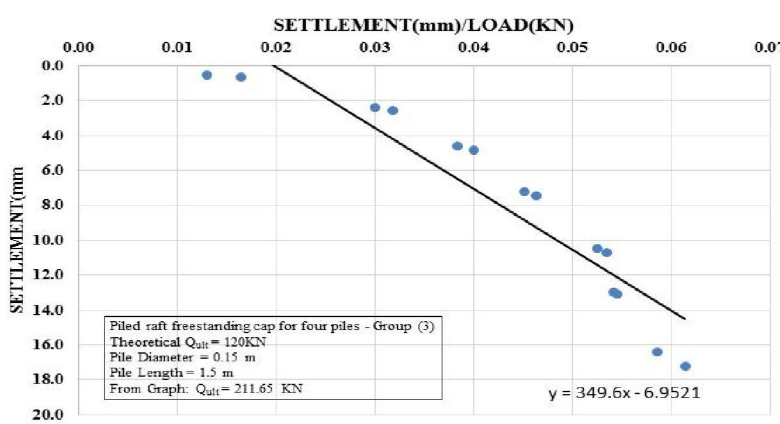


Fig (23). Determination the ultimate load - by modified Chin method for Piled raft freestanding cap for four piles - Group (3).

A comparison between ultimate capacities of piles for single pile - group (1) and single pile inside Piled-raft cap directly in contact with soil-Group (2) as well as Piled-raft freestanding cap - Group (3) from Tangent - tangent method and modified Chin method are shown in Figs (24) to (28).

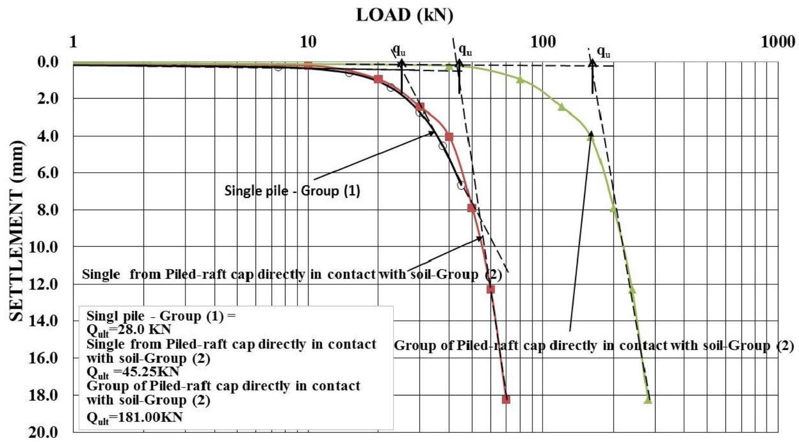


Fig (24). Comparison between ultimate capacities of single pile-group (1) and single pile inside groups Piled-raft cap directly in contact with soil for four piles - Group (2) from Tangent method.

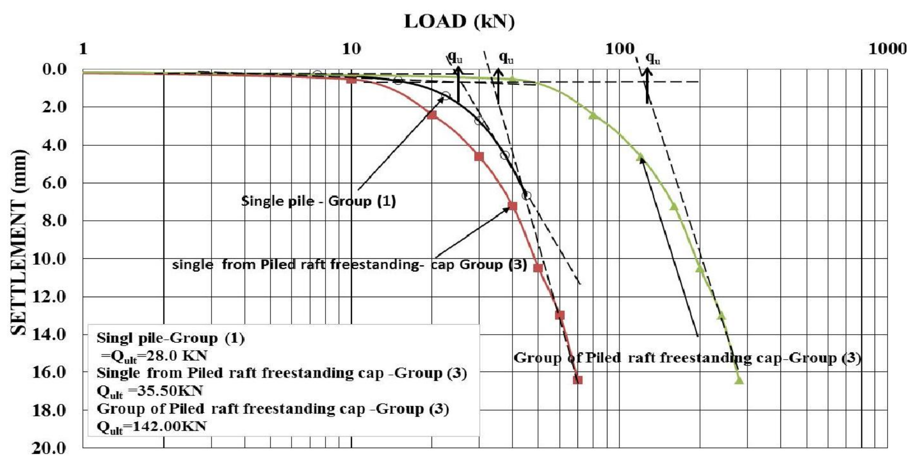


Fig (25). Comparison between ultimate capacities of single pile-group (1) and single pile inside groups Piled-raft freestanding cap four piles - Group (3) from Tangent method.

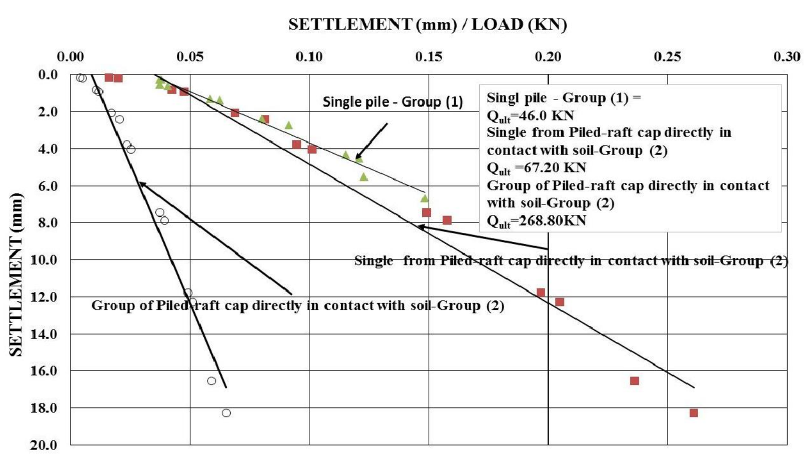


Fig (26). Comparison between ultimate capacities of single pile-group (1) and single pile inside groups Piled-raft cap directly in contact with soil for four piles -Group (2) from modified Chin method.

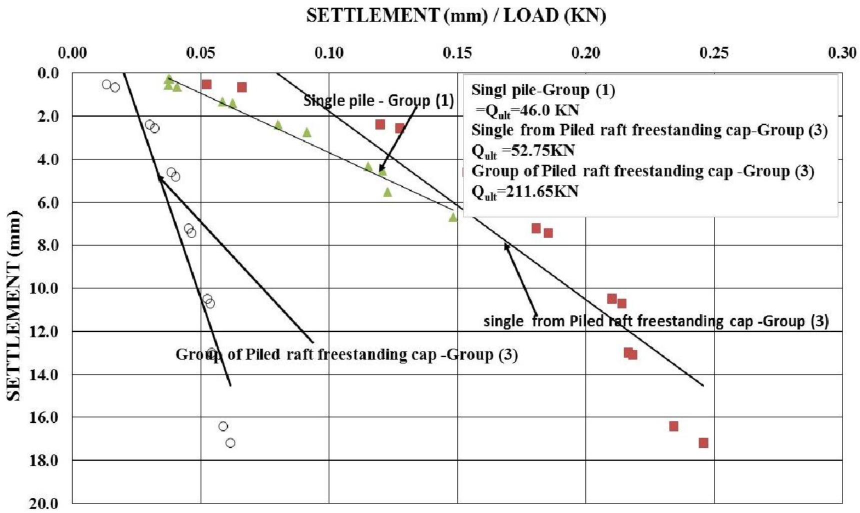


Fig (27). Comparison between ultimate capacities of single pile-group (1) and single pile inside groups Piled-raft freestanding cap four piles - Group (3) from modified Chin method.

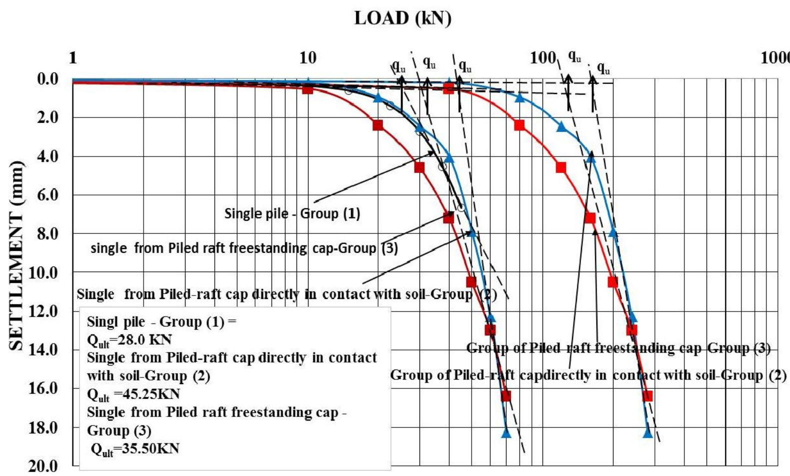


Fig (28). Comparison between ultimate capacities of piles for single pile - group (1) and single pile inside Piled-raft cap directly in contact with soil-Group (2) as well as Piled raft freestanding cap - Group (3) from Tangent - tangent method

However, the values of the obtained ultimate capacities and ultimate capacities of single pile and single pile inside groups from different methods are listed in Table (4).

Table (4). Ultimate capacities of single pile and single pile inside groups.

Group	Methods	Single pile – Group (1)	Piled-raft cap directly in contact with soil for four piles - Group (2)	Piled raft freestanding cap for four piles - Group (3)
Ultimate load (Q_{ult}) from theoretical Methods (kN)	Egyptian code (2001)	30	120	120
Total ultimate load (Q_{ult}) for four piles from experimental Methods (kN)	Tangent method (1991)	28.00	181.00	142.00
	modified Chin method (1970)	46.00	268.80	211.65
Ultimate load of single pile inside groups (Q_{ult}) from experimental Methods (kN)	Tangent method (1991)	28.00	45.25	35.50
	modified Chin method (1970)	46.00	67.20	52.75

From the above-obtained results, it is concluded that the ultimate capacity for Piled-raft directly in contact with soil for four piles - Group (2) is higher than from Piled raft freestanding for four piles - Group

(3). In addition, the obtained values of ultimate capacities from Tangent method (1991) is lower than from modified Chin method (1970).

4) Load Distributions

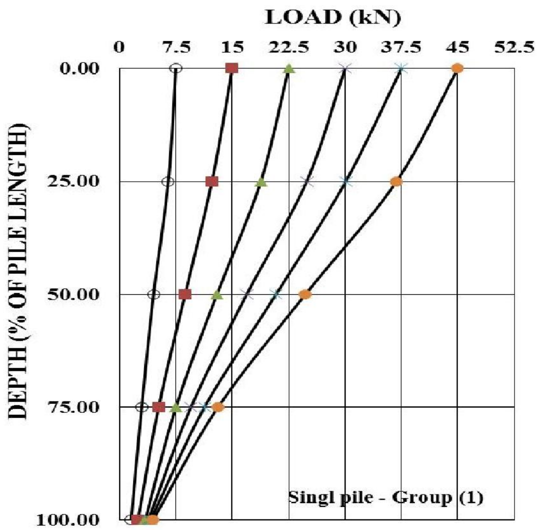


Fig (29) Relationships between test load and each of load increment values distributed along pile shaft for (single pile group - (1)).

The percentage of applied loads transmitted to end bearing and side friction as well as the percentage of the load transmitted to the soil underneath the pile cap have been determined. The relationships between test load and each of load increment values distributed along pile shaft have been determined for all groups as shown in figs (29) to (31). In addition, the distributions of loads around the pile shaft (friction) at ultimate capacity obtained from modified Chin and Tangent- tangent methods are shown in Figs (32) and (33). A comparison between distributions of loads around the pile shaft (friction) at ultimate capacity obtained from modified Chin method and Tangent-tangent methods for all groups is shown in Fig (34). However, the distributions of friction load values along the pile shaft at ultimate capacity are listed in Tables (5).

The loads at-pile tip and underneath pile cap measured by load cell as percentage of pile head load for all groups are shown in figs (35) to (37). Fig (38) shows loads at-pile tip and underneath pile cap measured by load cell as percentage of pile head load for Piled-raft cap directly in contact with soil- Group (2) and Piled-raft freestanding cap - Group (3). The loads transferred by friction around pile shaft and underneath pile cap as well as pile tip are listed in Table (6).

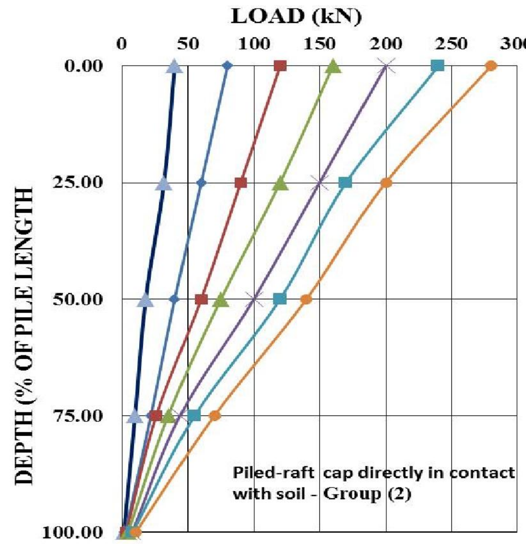


Fig (30) Relationships between test load and each of load increment values distributed along pile shaft for (Piled-raft cap directly in contact with soil for four piles - Group (2)).

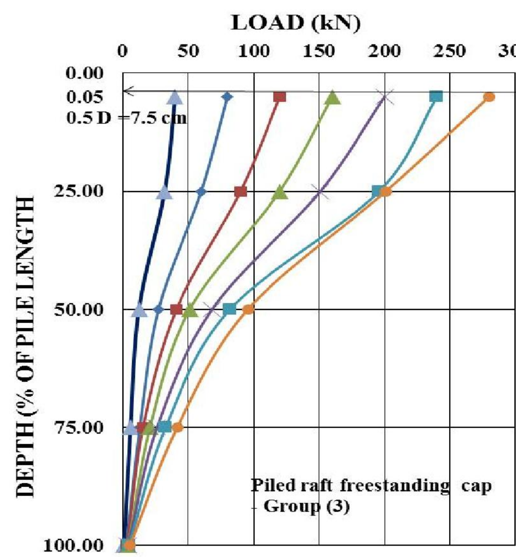


Fig (31) Relationships between test load and each of load increment values distributed along pile shaft for (Piled-raft freestanding cap for four piles - Group (3)).

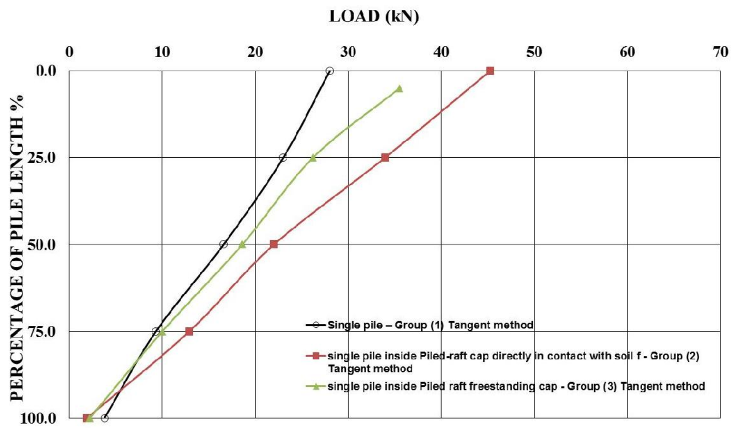


Fig (32) Distribution of loads around pile shaft (friction) at ultimate capacity obtained from tangent-tangent method.

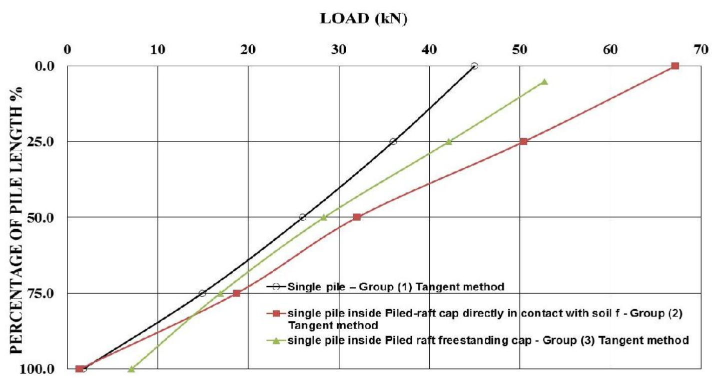


Fig (33) Distribution of loads around pile shaft (friction) at ultimate capacity obtained from modified Chin method.

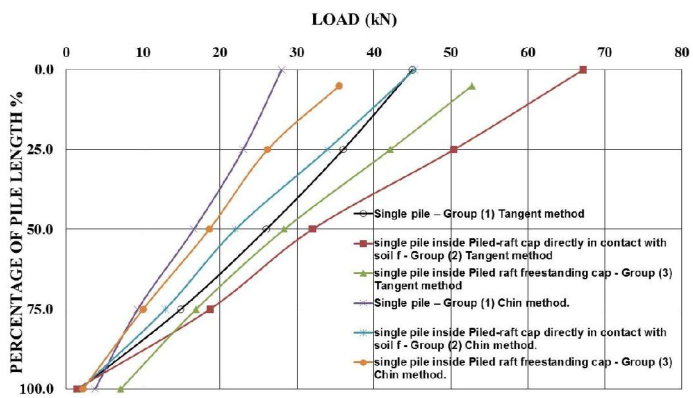


Fig (34) Comparison between distributions of loads around pile shaft (friction) at ultimate capacity obtained from modified Chin method and Tangent- tangent methods for all groups.

Table (5). Distribution of friction load values along the pile shaft at ultimate capacity.

Depth (%)	Load (KN)					
	Single pile – Group (1)		Piled-raft cap directly in contact with soil – Group (2)		Piled raft freestanding– Group (3)	
	Tangent method	Modified Chin method	Tangent method	Modified Chin method	Tangent method	Modified Chin method
0	28.00	46.00	45.25	67.20	35.50	52.75
25	23.40	39.00	34.28	50.40	25.32	42.13
50	16.59	26.00	21.42	31.49	16.83	28.35
75	9.31	14.90	13.03	18.70	9.13	16.9
100	3.77	1.75	1.90	1.37	2.62	7.10

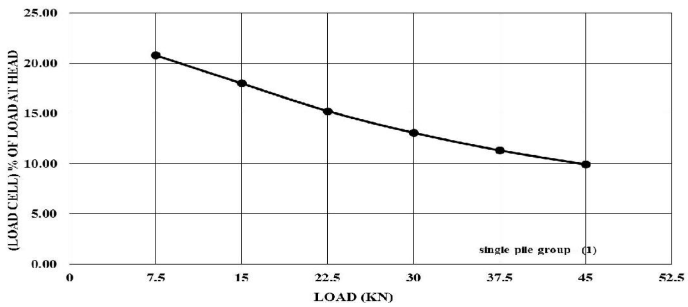


Fig (35) The loads at-pile tip measured by load cell as percentage of pile head load for single pile – group (1).

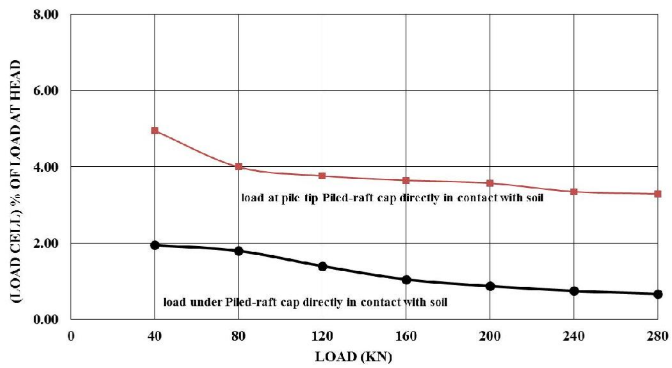


Fig (36) The loads at-pile tip and load underneath pile cap measured by load cell as percentage of pile head load for Piled-raft cap directly in contact with soil- Group (2).

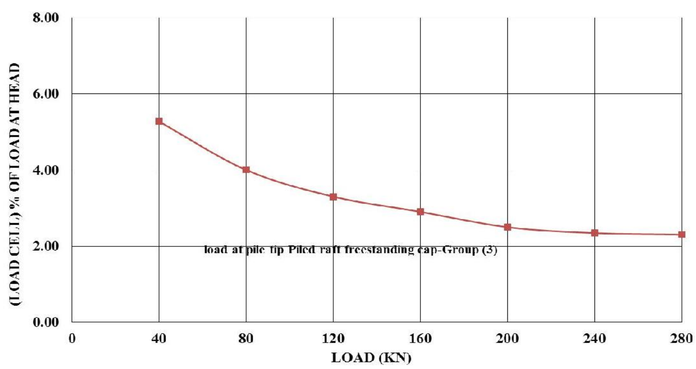


Fig (37) The loads at-pile tip measured by load cell as percentage of pile head load for Piled-raft freestanding cap - Group (3)

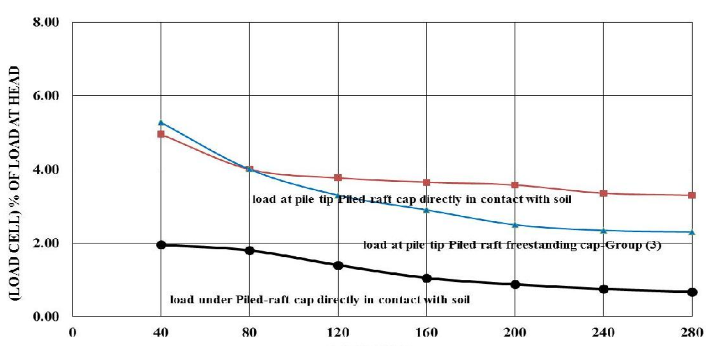


Fig (38) loads at-pile tip and underneath pile cap measured by load cell as percentage of pile head load for Piled-raft cap directly in contact with soil- Group (2) and Piled-raft freestanding cap - Group (3).

Table (6). Load transferred by friction around pile shaft and underneath pile cap as well as pile tip.

Group		Load (KN)		
		Single pile – Group (1)	Piled-raft cap directly in contact with soil for four piles - Group (2)	Piled raft freestanding cap for four piles - Group (3)
The loads transferred as (%) ultimate loads	Q_{ult} (KN)	28.00	181.00	142.50
	Friction around pile %	85.00 %	88.27 %	95.67 %
	Underneath Piled raft %	--	7.98 %	0.00
	At pile tip %	15.00 %	3.75 %	4.33 %

From the above, the load transferred to soil underneath Piled-raft cap directly in contact with soil is found to be 7.98% from the ultimate load capacity. However, the load transferred to soil by friction is found to be 88.27% from the ultimate load capacity. In addition, the load transferred to soil at pile tip is found to be 3.75% from the ultimate load capacity. However, the load transferred to soil by friction for Piled raft freestanding cap is found to be 95.67% from the ultimate load capacity. In addition, the load transferred to soil at pile tip for Piled raft freestanding cap is found to be 4.33% from the ultimate load capacity.

5) Group Efficiency

6.1 Theoretical group efficiency

Murthy (2008) presented the group efficiency factor (η_g) [15]. The group efficiency factor (η_g) is expressed as follow:

$$\eta_g = 1 - \theta \frac{(n-1)\,m + (m-1)\,n}{90\,m\,n}$$

Where:

η_g = Group efficiency;

θ = $\tan^{-1}$ (D/S) in degrees;

D = Pile diameter (m).

S = Pile spacing (m).

n = Number of piles in a row.

m = Number of pile rows.

The theoretical group efficiency (η_g) has been calculated and found to be = 0.80.

6.2 Experimental group efficiency

The group efficiencies have been determined and are shown in Table (7). The group efficiency of piles groups is shown in Fig (39).

Table (7) Values of Group efficiencies.

Group		Single pile – Group (1)	Piled-raft cap directly in contact with soil for four piles - Group (2)	Piled-raft freestanding cap for four piles – Group (3)
Groups efficiency factor (η_g)	Theoretical (η_g) (Murthy, 2008)	---	0.80	0.80
	Tangent-tangent Method excremental	--	1.60	1.25
	Modified Chin method excremental	--	1.43	1.13

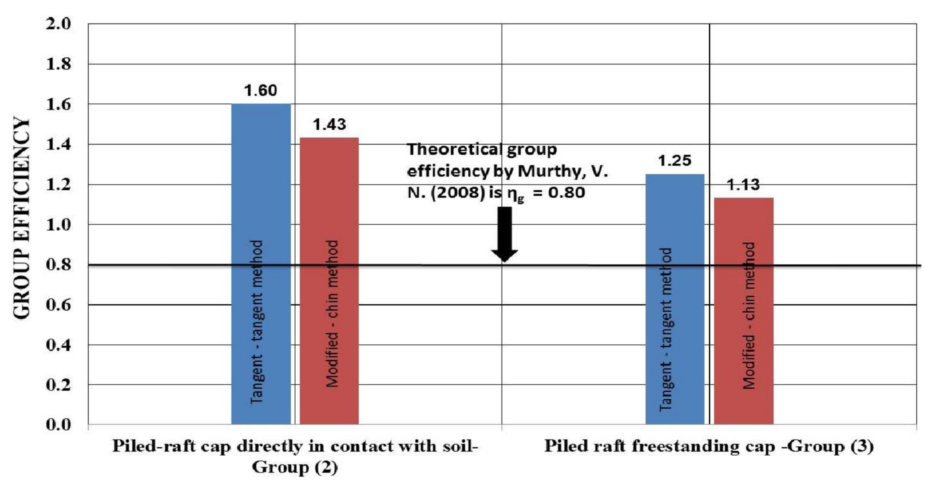


Fig (39). The group efficiency of piles based on experimental results obtained modified Chin method and Tangent method.

From the above, the group efficiency of pile groups found to be ranging from 1.43 to 1.60 for piled-raft cap directly in contact with soil for four piles-Group (2) by using tangent - tangent Method (1991) and Modified chin method)1970). However, the group efficiency was found to be ranging from 1.13 to 1.25 for Piled raft freestanding cap for four piles - Group (3) by using tangent - tangent Method (1991) and Modified chin method)1970).

6) Piles Group Settlement

In the present study, the settlement for single pile - group (1) and single pile inside piled-raft cap directly in contact with soil for four piles-Group (2) as well as Piled raft freestanding cap for four piles - Group (3) obtained from loading tests using Tangent method (1991) and modified Chin method)1970 (are shown in Table (8).

Table (8). Settlement at ultimate capacities of single pile and Piled-raft freestanding cap and piled-raft cap directly in contact with soil.

Group	Settlement (mm)		
	Single pile – Group (1)	Piled-raft cap directly in contact with soil for four piles – Group (2)	Piled-raft freestanding capfor four piles – Group (3)
tangent-tangent Method	2	4.25	6.15
Modified chin method	6.17	13.96	16.65

From the above, it is concluded that the obtained settlement at the ultimate capacities from Tangent method was found to be less that the obtained from modified Chin method. Also, the settlement of Piled-raft cap directly in contact with soil is less than that Piled-raft freestanding cap.

7) Theoretical Analysis

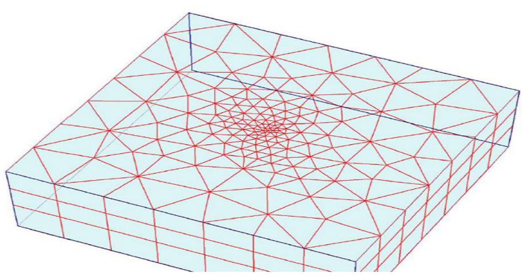


Fig (40). 3D deformed mesh for single pile – Group (1).

Finite element analysis was used for single pile and Piled-raft cap directly in contact with soil as well as Piled-raft freestanding cap. The analyses done by using 3D Plaxis program in which a semi-infinite element isotropic homogeneous elastic material simulates the soil.

Figs (40) and (41) show 3D deformed mesh and vertical displacement for single pile - group (1). Figs (42) to (44) show 3D deformed mesh and total vertical displacement for Piled-raft cap directly in contact with soil - Group (2). Figs (45) to (47) show 3D deformed mesh and total vertical displacement for Piled-raft freestanding cap- Group (3).

The settlement for single pile - group (1) and single inside Piled-raft cap directly in contact with soil as well as Piled-raft freestanding cap obtained from experimental loading tests using Tangent method (1991) as well as modified Chin method)1970 (as well as finite element analysis are shown in Table (9) and Fig (48).

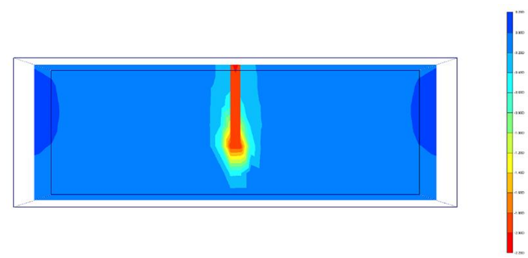


Fig (41). Vertical displacement for single pile – Group (1).

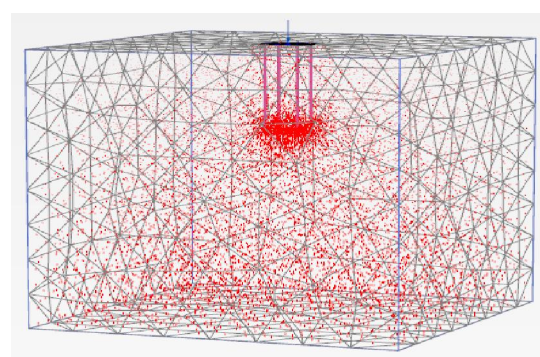


Fig (42). 3D deformed mesh for Piled-raft cap directly in contact with soil - Group (2).

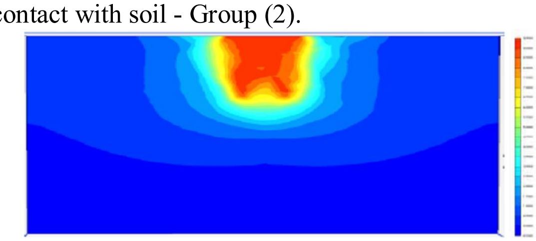


Fig (43). Vertical displacement for Piled-raft cap directly in contact with soil - Group (2).

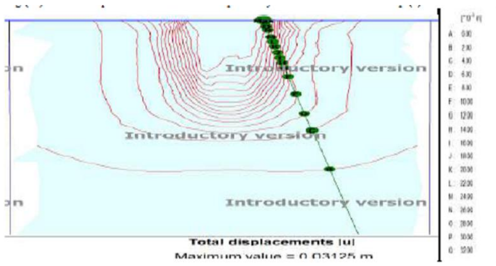


Fig (44). Total displacement for Piled-raft cap directly in contact with soil - Group (2).

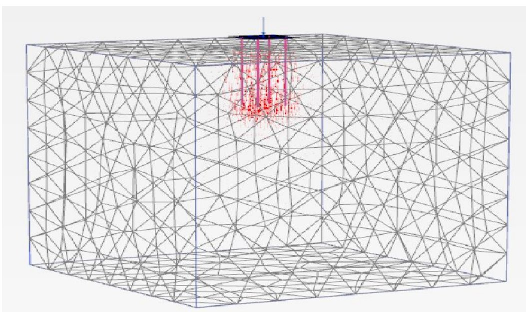


Fig (45). 3D deformed mesh for Piled-raft freestanding cap- Group (3).

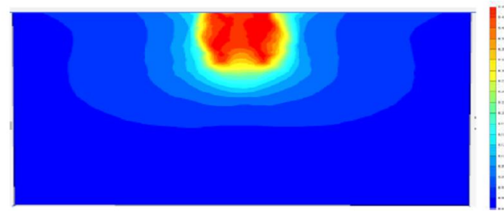


Fig (46). Vertical displacement for Piled-raft freestanding cap - Group (3).

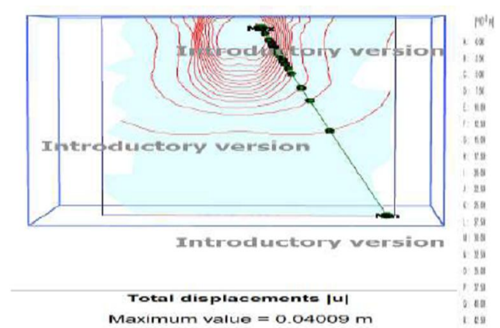


Fig (47). Total displacement for Piled-raft freestanding cap - Group (3).

Table (9). Settlement at ultimate capacities of single pile and Piled-raft cap directly in contact with soil as well as Piled-raft freestanding cap.

Group	Settlement (mm)		
	Single pile – Group (1)	Piled-raft cap directly in contact with soil for four piles – Group (2)	Piled-raft freestanding cap for four piles - Group (3)
Tangent-tangent Method (Experimental)	2.00	4.25	6.15
Modified Chin method (Experimental)	6.17	13.96	16.65
Finite element analysis	1.85	3.13	4.01

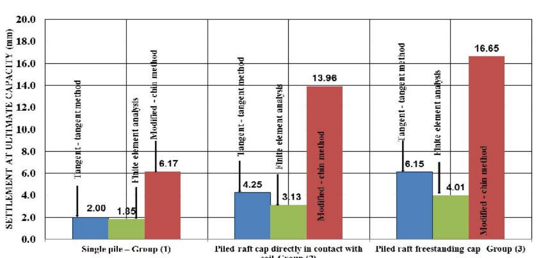


Fig (48). Comparison between settlement for single pile - group (1) and single pile inside Piled-raft cap directly in contact with soil for four piles - Group (2) and Piled-raft freestanding cap for four piles - Group (3) obtained from loading tests by from Tangent method (1991) and modified Chin method)1970) as well as Finite element analysis.

From the above, it is concluded that fair agreement is found between the values of settlement obtained from experimental results using Tangent method and by using finite element analysis.

Conclusions

The following conclusions are obtained:

i. The load transferred to soil underneath Piled-raft cap directly in contact with soil is found to be 7.98% from the ultimate load capacity. However, the load transferred to soil by friction is found to be 88.27% from the ultimate load capacity. In addition, the load transferred to soil at pile tip is found to be 3.75% from the ultimate load capacity.

ii. The load transferred to soil by friction for Piled raft freestanding cap is found to be 95.67% from the ultimate load capacity. In addition, the load transferred to soil at pile tip for Piled raft freestanding cap is found to be 4.33% from the ultimate load capacity.

iii. The group efficiency of Piled-raft cap directly in contact with soil is more than that for Piled raft freestanding cap.

iv.The group efficiency obtained from experimental test result is higher than the theoretical one.

v.The settlement of Piled raft freestanding cap is more than that for Piled-raft cap directly in contact with soil.

vi.Fair agreement is found between the values of settlement obtained from experimental results using Tangent method and by using finite element analysis.

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8/25/2018