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Effect of Pile Spacing on Load Sharing of Pile Raft Foundation under Different Loads

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Abstract: The present study is mainly based on the determination of the effect of spacing between piles and load underneath pile cap. Furthermore, the distribution of load on pile after redistributed of load from soil. The program consisted of installing four piles (Lp=1.5m, D=0.15 m) with various spacing where (Sp=3D, 4D, 5D and 6D) and the piles supported a square steel plate (1.20 X1.20) m and the plate support I-beam to ensure the load distributed uniformly from the hydraulic jack to dense compacted sand piles put in a soil chamber, subject to compressive axial loading. The displacement, strains along the piles as well as transferred loads to soil underneath piles cap were measured simultaneously. Also, finite element package of a PLAXIS 3D version 2013. (A finite element code for soil analysis) has been done for the experimental program to compare between the theoretical and experimental result. The obtained experimental test results indicated that the increasing pile spacing increase the load carried by soil by ratio from (8.3% to 27.5%). The ratio from (35% to 48%) of the load carried by soil redistributed to pile. So, the Soil carried (5.5% to 14%) from the total load applied to pile after redistributed of load from soil, ultimate load for the pile group (four piles) decrease by increasing spacing between piles.

[El-Samny, M.K., Ezz-Eldeen, H.A, Elbatal, S. A. and Kamar, A.M. **Effect of Pile Spacing on Load Sharing of Pile Raft Foundation under Different Loads.** *J Am Sci* 2020;16(9):33-54]. ISSN 1545-1003 (print); ISSN 2375-7264 (online). http://www.jofamericanscience.org. 3. doi:10.7537/marsjas160920.03.

Keywords: Effect; Pile; Spacing; Load; Sharing; Foundation

1-Introduction:

The sharing load for the piled raft foundation between the raft and the piles is influenced by a number of factors, but to differing degrees.

Some Researches show the effect of spacing between piles on load sharing in piled-raft foundation

Cooke (1986) reported model test results on the foundations for the piled-raft. He contrasted the piled-raft foundations behavior with that of un-piled raft and free-standing piled group. He noticed that the distribution of loads between piles in piled raft foundations depending on the number of piles and their spacing. He noted that settlement is greater at the center of the raft foundation than at the edges of the raft.

Ismael, N. F. (2001) studied the effect of a group of piles in the cemented sands soil field-testing program. The program consisted of two piles group each group consisting of five piles subjected to single-pile axial load tests in the tests of tension and compression. The pile spacing of the piles in the groups from (2D to 3D). It was found that 70% of the load navigates along the pile shafts in side friction which was uniform. Also, it was found that the calculated group efficiency of the pile was 1.22 and 1.93 for the two-and three-pile diameter pile spacing, respectively. Increasing the piles capacity in groups is mainly due to increased skin friction along the shafts of the piles. Despite the interference of the shear zones, the side friction stays surprisingly bigger for pile groups compared with individual piles.

Kwon, ohkyun (2007) investigated the behavior characteristics of a piled raft through model tests. The model that has been conducted was piled raft with varying pile length, pile spacing, type of group and density of soil. The experimental findings were contrasted with those of DEFPIG, the method of Phung and the traditional conventional analytical method, we can draw the following conclusions, at the initial loading stage, the piles take up a significant portion of the total load, but a substantial portion of the total load (up to 30 % more) is transferred after yielding by the raft.

The raft load-sharing ratio depending on the spacing of the pile, length of the pile, relative sand density and level of settlement. As the spacing of the pile becomes wider and the length of the pile becomes longer and the relative density decreases, the LSR gets larger but the differences are not great.

Zkaria Mohamed Omeman (2012) studied the effects of pile, raft and soil interaction factors by using very precise elements, namely the triangular 15-node element. Through contrasting the findings with the test results and other numerical models found in the literature, the model was making sure. A simple model for forecasting the settlement and the sharing load among the piles and the raft was developed using the numerical model. The impact on the performance of piled-raft foundations like pile length, pile spacing, of some significant design parameters. Studies also included raft width, raft thickness, raft stiffness, pile diameter, and pile stiffness. The influence of certain significant soil properties not well known in the literature, like the elasticity modulus, the ratio of Poisson, the angle of friction, the angle of dilatation and the unit weight, was also examined. The impact of such parameters on the load-settlement relation at small and large settlements and on the load sharing among the piles and the raft was studied in terms of their influence. At small settlement, the impact of the selected parameters on the load-settlement relation was contrasted with those at large settlements.

Kiyoshi, Y. et al. (2014) studied the behavior of sharing load between raft and piles based on the monitoring of eleven structures. For three of the structures, foundation behavior during the Tohoku Earthquake was monitored. No changes in sharing load were noticed after the earthquake for the investigated buildings and the load carried by piles ratio to the effective load decreased when pile spacing increased.

Ragheb, A. M., et al. (2015) applied the closed form equation proposed by Kyujin Choi (2014) on the case of friction piles embedded in soft/medium clay. The load sharing ratio was calculated in case of different studied parameters and the relationships between the piled raft settlement and load sharing ratio were achieved and plotted. The studied parameters included were cohesion, number of piles, piles length, piles spacing and piles diameter. It was found that the load sharing ratio is directly proportional to number of piles, piles length, piles spacing and piles diameter. Also, it was concluded that the cohesion of soil surrounding the piles has a little effect on the value of load sharing ratio.

Elsamny et al [(2017)-a] examined the ultimate capacity, settlement and efficiency in sandy soil for pile groups. An experimental program was carried out to research effectiveness of the group. However, under axial compression load, the experimental program composed of testing single pile, pile groups of two, three and four piles in sand. The spacing among the piles was keeping three pile diameters. Group efficiency of pile groups (2, 3 and 4 piles) has been found to increase with an increasing number of piles.

Elsamny et al. [(2017)-b] examined load shearing among soil and pile raft cohesion-less soil. An experimental program was performed to research the distribution of loads applied to the lower sections of formed soil as well as to pile raft. However, under axial compression load, the experimental program composed of testing individual pile, pile groups of two, three, four, five and six piles in sand. It was observed that the percentage of the ultimate capacity of the transferred single pile load at the tip of the pile = 13.5 %.

Elsamny et al. [(2017)-c] theoretically and experimentally investigated the settlement of single pile and pile groups. An experimental program was carried out to research pile-raft settlement. It has been found that settlement is growing with the number of piles growing. From theoretical calculations, the values of settlement were obtained greater than those obtained from the experimental program.

Maharaj, D.K. et al. (2017) studied a single pile with equivalent size of raft has been taken from an infinite piled raft. One fourth of piled raft with equivalent area of raft has been taken from a single pile with equivalent area of raft. The soil, pile and raft have been discretized as eight nodded brick elements. It has been found that at smaller spacing the load taken by a pile is more than that of the raft. At larger spacing the load carried by pile decreases. For the same spacing to diameter ratio the load carried by pile increases with increase in length of pile.

Elsamny et al. (2018) examined the impact of group effectiveness as well as the load distribution of friction along the pile shaft that the load transferring to the pile tip and the load transferring to the soil below the pile cap were presented in pile groups in cohesion less soil. In axial compression three test groups were conducted. The first group load test was conducted on a single pile. The second group is four caps of piles resting on soil. The third group is four non-rested pile caps on the soil. It has been found that the group effectiveness of pile groups cap of four pile resting on soil is more than that pile group cap of four pile non-rested on soil.

Elsamny et al. (2018) investigated using the finite element method the redistributed of load from soil to pile. The program for the analysis comprises of a piled 25-pile raft. Seven groups make up the analysis. The soil beneath piled raft moves from the load it holds to piles 30 % to 85 %. The spacing of the piles has a major impact on the distribution of loads between the piles and the soil, while the groundwater has no impact. Load eccentricity has a minor impact on the sharing of loads among the piled and the soil. Even so, growing the eccentricity on the piles produces more negative skin friction.

Elsamny et al. (2020) presented the impact of the pile length on the sharing of load among piles and soil and distribution of stress under soil before and after redistributed of load from soil to pile under six piles their diameters are fixed (D = 0.6 m) and the spacing between piles is fixed (Sp = 3D)

and they have various length (Lp = 34D, 36D, 38D and 40D). The piles subjected to eccentric load (0%, 5%, 10%, 15% and 20%) from centroid in X-direction. Raft on piles the thickness of raft is (t = 1.0D). Finite element package of a PLAXIS 3D version 2013. (A finite element code for soil and rock analysis) has been used to determine the stress under pile and soil before and after redistribution of load on pile from soil, percentage load carried by pile and soil, settlement under piles and distribution of load among pile length. It was found that Pile Length have a great effect on load sharing as increasing pile length increase load carries by pile.

2-Experimental Program:

The experimental program was carried out to research the impact of pile spacing on the sharing of loads between piles and soil, distribution of loads between piles and soil underneath pile-raft foundation and the redistribution of load from soil to pile. In this experimental program sixteen instrument model concrete piles were used in this program. Their length was constant (1.50 m) and diameters (0.15 m) and spacing between each pile various from (3D to 6D). The piles were tested in a set up under axial load. Loads of the pile head, displacement was simultaneously calculated. In addition, the load underneath the pile cap (raft) transferred directly to soil via the pile cap (raft) was calculated. Also, the load redistribution from soil to pile has been calculated. The program comprised of installing test piles in dense sand, positioning piles in a soil chamber that is prone to axial load. Nevertheless, the testing was carried on four piles have different spacing and subjected to vertical load at centroid. The test program carried out was as shown in table (1).

Table (1) Investigated Experimental Program

No.	NUMBER OF PILES	LENGTH OF PILES	PILE DIAMETER	PILE SPACING
1	4	1.5m	0.15 m	3D
2				4D
3				5D
4				6D

2.1. Testing program

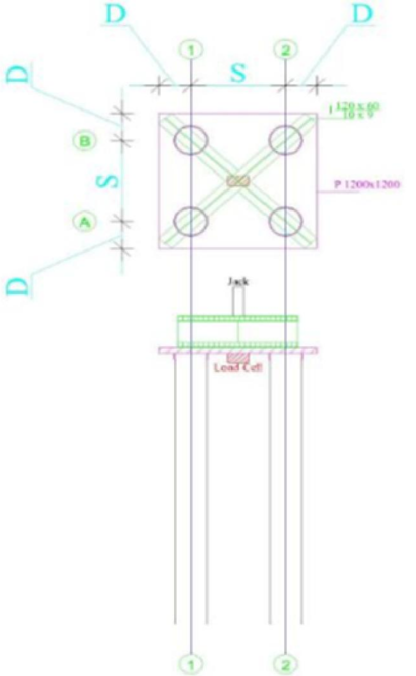

Fig. (1) Four piled-raft foundation model with pile cap subjected to axial load

Consists of four piles, height of each pile (LP=1.5m) and diameters are constant (DP=0.15m) and the piles supported a square steel plate (1.20 X1.20) m and the plate support I-beam to ensure the load distributed from the hydraulic jack to piles. The piles have different spacing (Sp=3.0D, 4.0D, 5.0D and6.0D) and subjected to vertical load at centroid as shown in Fig (1).

2.1.1. Soil Profile

Important para important parameters for the predictive effort are the density and internal friction angle of the sand which have been calculated. Modified proctor test was carried out on the sample of sand. The materials properties for the used soil layers were selected as shown in table (2).

Table (2) Soil Layers Properties

Parameters	Name	Sandy soil	unit
unsaturated soil weight	ɣunsat	18.25	kN/m3
saturated soil weight	ɣsat	17	kN/m3
Poisson ratio	ʋ	0.25	-
Cohesion	c	0	KN/m2
Friction angle	Ø	36	°

2.1.2. Pile used Materials

The following are the concrete dimensions and the descriptions of pile reinforcement:

a. Graded sand was used to form a fine aggregate.

b. Crushed stone is coarse aggregate used in the concrete mix.

c. Clean fresh water free from is utilized to mix pile concrete.

d. For all experimental work Portland Cement BS EN 197-1-CEM 42.4N is utilized in concrete.

2.1.3. Reinforcement Concrete Details

A total of sixteen precast concrete (150) mm outer diameter cylinders with a length of (1500) mm were fabricated. Four piles with different spacing having pile and head dimensions in addition to reinforcement are shown in Fig (2).

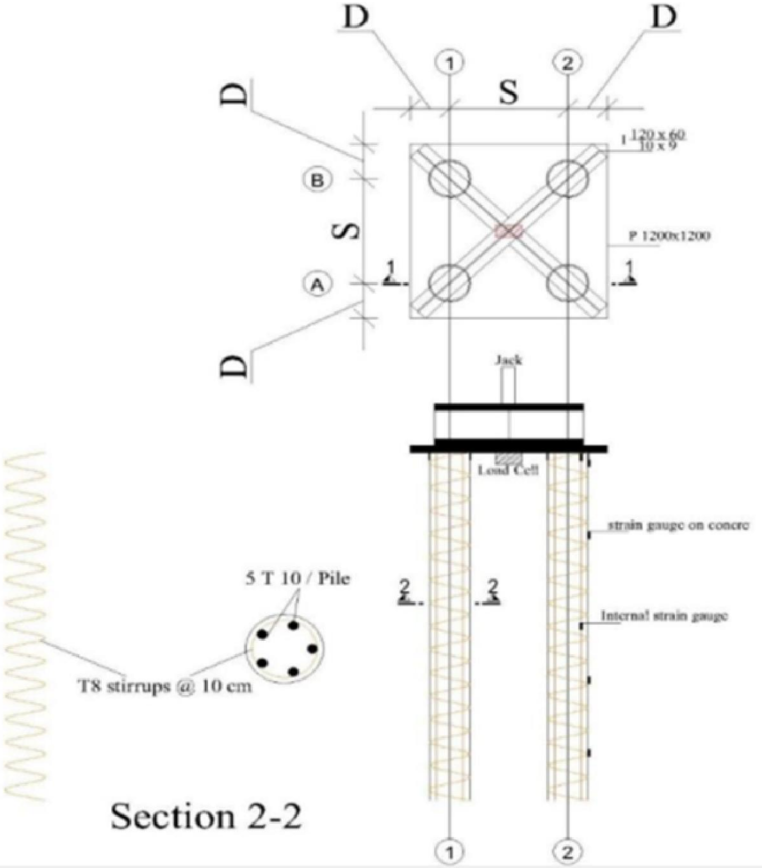

Fig. (2) Concrete dimension and reinforcement for four piled-raft foundation model with pile square steel plate (cap)

2.1.4. Casting of Piles

Figures (3) depict all of the cylindrical piles casted in tubes (forms). A mechanical vibrator was utilized and curing all the cylindrical piles.

Fig (3) Description of forms and Casting of piles

2.1.5. Strain Gauges

The strain gauges were used for internal measurement. TOKYO SOKKI KENKYUJO CO. LYD has fabricated the strain gauges used. The model used was PFL-30-11-3L with a resistance of 120.4 ± 0.5% Ohms at 11ºC, and a gauge factor of 2.13 ± 1.0%. A copy of the manufacture specification is enclosed as shown in Fig (4). And the strain gauge used for outer measurement for concrete as shown in fig (5) and (6).

Fig (4) Internal strain gauges

Fig (5) strain gauges on concrete

Fig (6) strain gauges installation on concrete piles

2.2. Ultimate Capacity of Pile

The capacities of the theoretical piles were estimated using Egyptian code (2001) for single piles. The ultimate theoretical capacity estimated for the single pile Qu=30KN, and the estimated ultimate theoretical capacity of four piles Qu=120KN.

2.3. Testing Setup and procedure

Tests for piles were split into two groups

[1] The first group is single pile was axially loaded.

[2] The second group four piles with different spacing also were axially loaded by the followings:

The piles are four piles subjected to vertical load in centroid. According to the 2001 Egyptian Code, each pile group was loaded in 12 increments, each increment being held for a certain period for every increase of load by 25 % test load up to 150 % from theoretical ultimate load and then start unloading by decreasing load increments by 25 % test load during certain load. Table (3) shows the increment of loading according to Egyptian Code, 2001. The measurements of load at top of piles as well as strains in the pile were recorded at the top and load cells for load underneath the pile cap as well as strain along pile length through system for data acquisition. For settlement calculation, the dial gauge readings were recorded at the start and the end of each loading increment.

Table (3) Load Increment and Minimum Interval Time For Each According The Egyptian Code (2001)

	Load %	Time	Load (kN)
Loading	25	1.00 hr	30.00
	50	1.00 hr	60.00
	75	1.00 hr	90.00
	100	3.00 hrs	120.00
	125	3.00 hrs	150.00
	150	12.00 hrs	180.00
Unloading	Load %	Time	Load (kN)
	125	15 min.	150.00
	100	15 min.	120.00
	75	15 min.	90.00
	50	15 min.	60.00
	25	15 min.	30.00
	0	4.00 hrs	0.00

2.3.1. Loading Frame

Loading frame was designed to withstand the projected maximum loads which could happen during the test, the details of frame are shown in Fig. (7).

Fig (7) Soil chamber and loading frame

2.3.2. Loading Jack

The test load was applied utilizing a hydraulic jack of 100 tons positioned at the top of the checked pile or piles group as shown in Fig. (8)

Fig (8) Loading jack and pump

2.3.3. Load Measurements

The load applied by the hydraulic jack was read simultaneously by a 40 tons load cell as shown in Fig. (9) Which was placed underneath the pile caps directly and connected to the data acquisition system.

Fig (9) Load cells

2.3.4. Data Acquisition System

The system used for data acquiring 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. The specifications of data acquisition system are enclosed as Figs. (10)

2.3.5. F

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Fig (11) Sand cone test

The pile's gross embedded depth was 1.50 m after the mechanical compactor used to fill compacted layers with 15 cm of sand in soil chamber. However, the pile cap's vertical displacements were calculated by dial gauges with a precision of 0.001 cm as seen in Figure (12).

Fig (12) Mechanical compactor and setup f for group (1) – (single pile)

2.3.6. Pile Load Test of Group (2) – Four Piles with variable spacing

The piles were embedded in the compacted layers of sand such that the total embedment depth of the pile was 1.50 m after filling the soil chamber with 15cm of sand using mechanical compactor. However, the vertical with accuracy of 0.001 cm and the spacing between piles variable from (3D to 6D) as shown in fig. from (13) to (19).

Fig (13) Placing piles and keeping the distance between piles (4-diameters from center to center) – group of four piles

Fig (14) Placing load cell under the cap - group of four piles

Fig (15) steel plate and I-beam

Fig (16) steel plate (with different diameters from center to center) – group of four piles

Fig (17) Placing piles and keeping the distance between piles (5-diameters from center to center) – group of four piles

Fig (18) Placing piles and keeping the distance between piles (6-diameters from center to center) – group of four piles

Fig (19) Reference beam and dial gauges setup for – group of four piles

3. Experimental Result

Figures from (20) to (23) show the determination of the ultimate capacity by Tangent- Tangent, Modified Chin, Brinch Hansen and Butler & Hoy methods for single pile where (Lp=1.5m, D=0.15m)

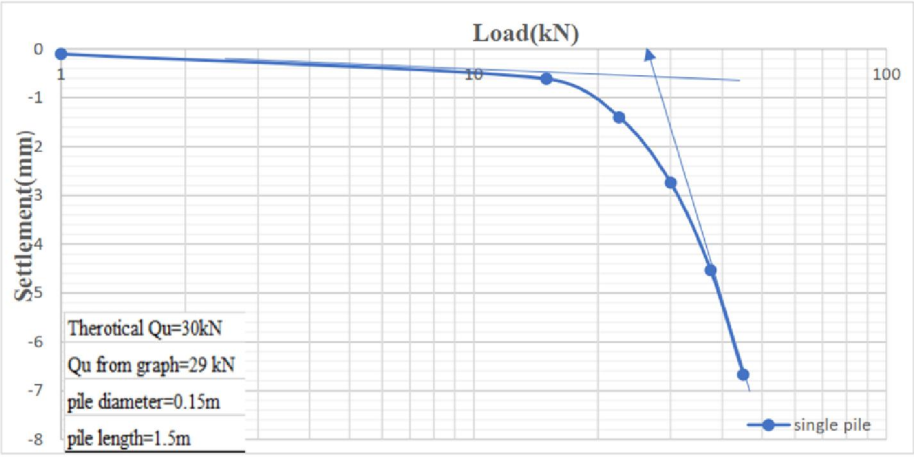

Fig (20) Determination the ultimate load by tangent method, (U.S. Army Corps Engineers, 1991) for (group (1) – single pile)

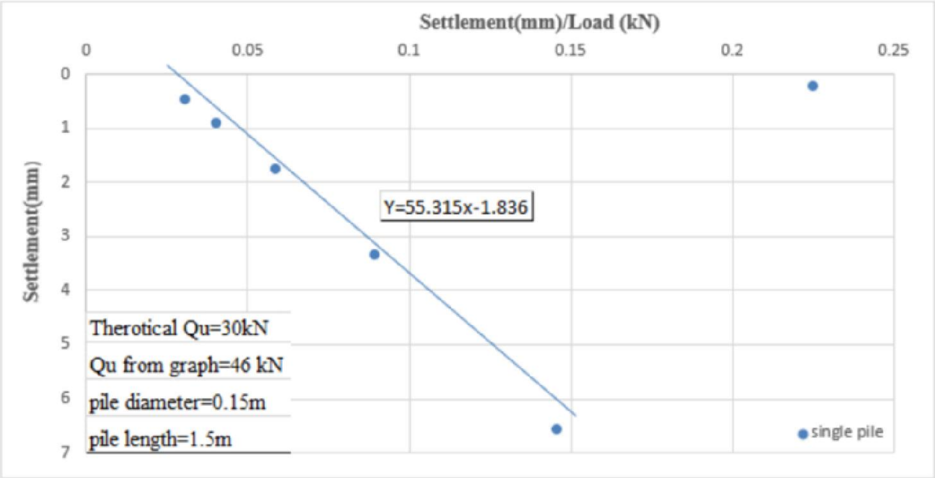

Fig (21) Determination of ultimate load by Modified Chin method, (Egyptian Code, 2001), (group (1) - single pile)

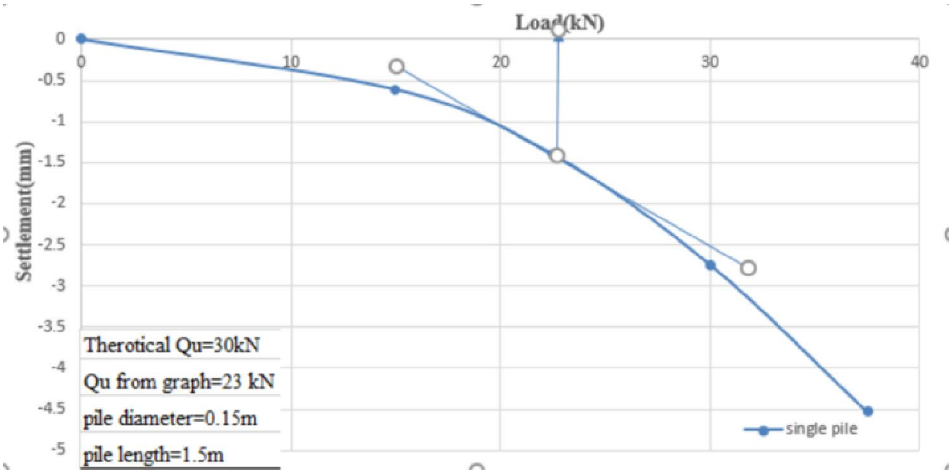

Fig (22) Determination of ultimate load by Brinch Hansen method (1963), (Egyptian Code, 2001), (group (1) - single pile)

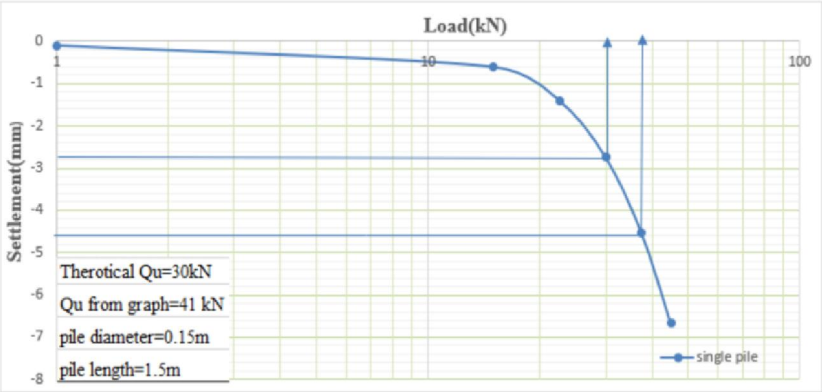

Fig (23) Determination of ultimate load by Butler and Hoy tangent method, (U.S. Army Corps Engineers, 1991), (group (1) - single pile)

Figure (24) displays a comparison of Qult obtained from pile load test with theoretical calculations for Group (1) – (single pile).

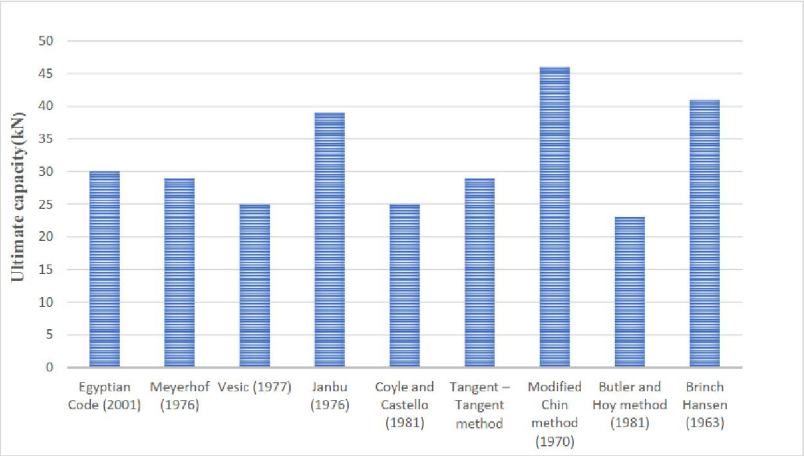

Fig (24) Comparison of Qult from pile load test with theoretical calculations group (1) – (single pile)

Figure (25) displays the determination of the ultimate capacity by Tangent and Butler for four piles where (LP=1.5m, D=0.15m, Sp=3D)

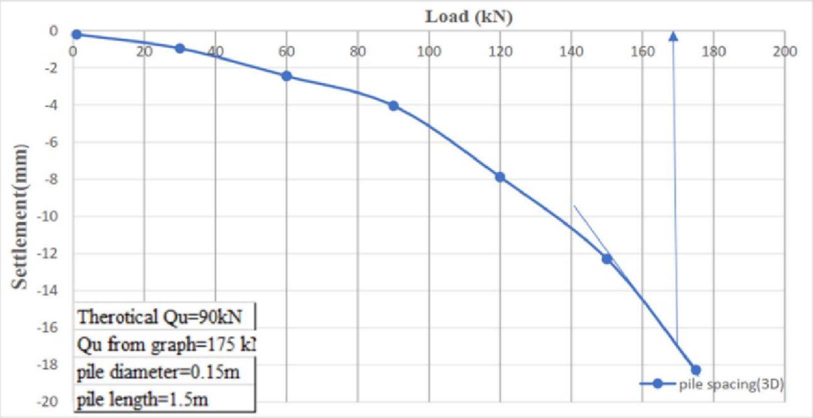

Fig (25) Determination of ultimate load by Butler & Hoy tangent method (1963), (Egyptian Code, 2001), for four piles (Sp=3D)

Figure (26) shows the distribution of load at pile from redistributed of load from soil measured from strain gauges for four piles where (LP=1.5m, D=0.15m, Sp=3D)

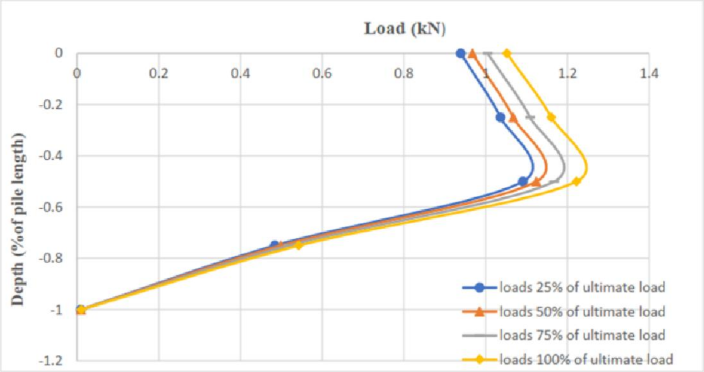

Fig (26) Distribution of load at pile from redistributed of load from soil measured from straingauges for four piles (Sp=3D)

Figure (27) shows the relation among the load borne by soil (load cell value) and after the load has been redistributed to pile, for four piles where (LP=1.5m, D=0.15m, Sp=3D)

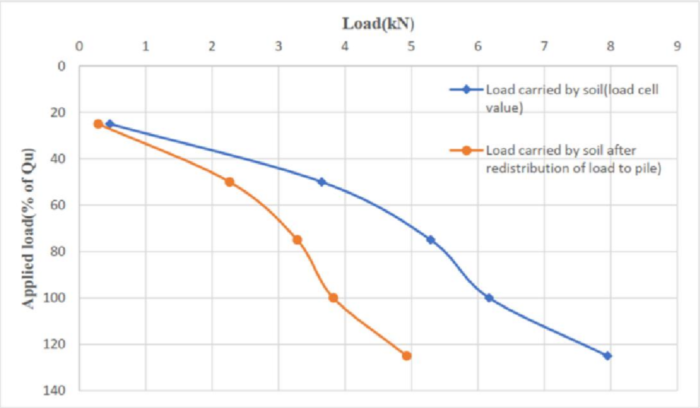

Fig (27) Relation among the load borne by soil (load cell value) and after the load has been redistributed to pile, for four piles (Sp=3D)

Figure (28) shows the determination of the ultimate capacity by Tangent and Butler for four piles where (LP=1.5m, D=0.15m, Sp=4D)

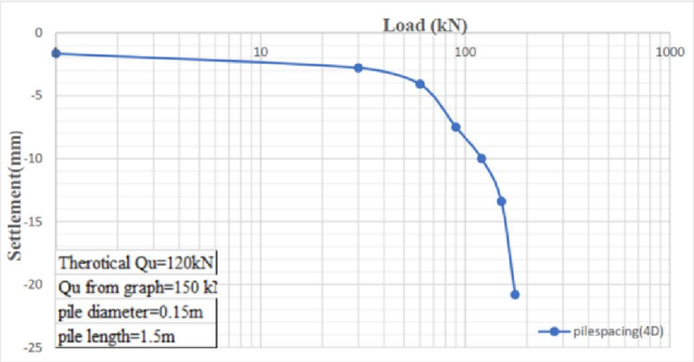

Fig (28) Determination of the ultimate load by tangent method (a), (U.S. Army Corps Engineers, 1991) for four piles (Sp=4D)

Figure (29) shows the distribution of load at pile from redistributed of load from soil measured from strain gauges for four piles where (LP=1.5m, D=0.15m, Sp=4D)

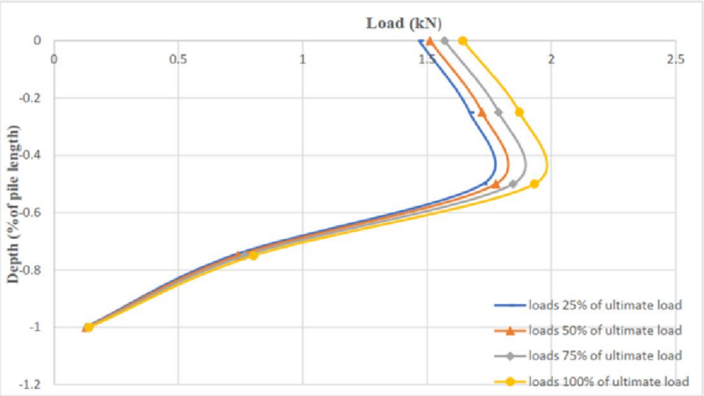

Fig (29) Distribution of load at pile from redistributed of load from soil measured from strain gauges for four piles (Sp=4D)

Figure (30) shows the relation among the load borne by soil (load cell value) and after the load has been redistributed to pile, for four piles where (LP=1.5m, D=0.15m, Sp=4D)

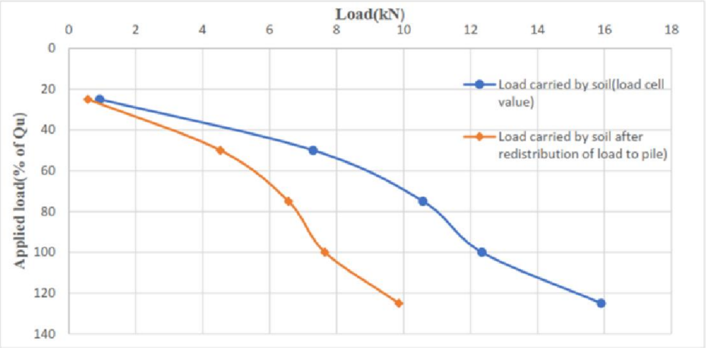

Fig (30) Relation among the load borne by soil (load cell value) and after the load has been redistributed to pile, for four piles (Sp=4D)

Figure (31) shows the relationship between pile spacing where Sp= (3D, 4D, 5D and 6D) and load on soil from load cell for four piles (LP=1.5 m, D=0.15m)

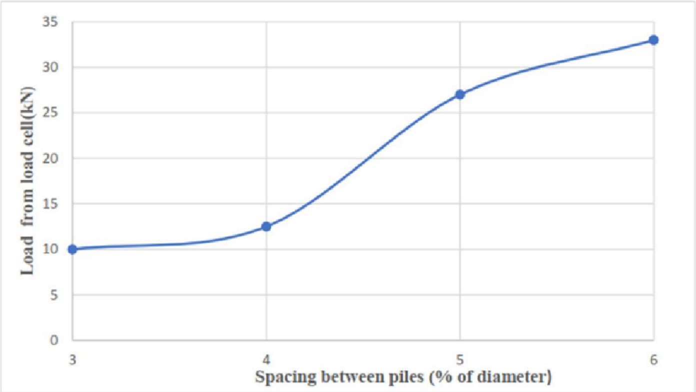

Fig (31) The Relation between spacing between piles and load from load cell for four piles (LP=1.5m, D=0.15m)

Figure (32) shows the comparison between pile spacing where Sp= (3D, 4D, 5D and 6D) and percentage of load on soil from load cell for four piles (LP=1.5 m, D=0.15m). From this figure it can be shown that the load on soil increase with increasing the spacing between piles.

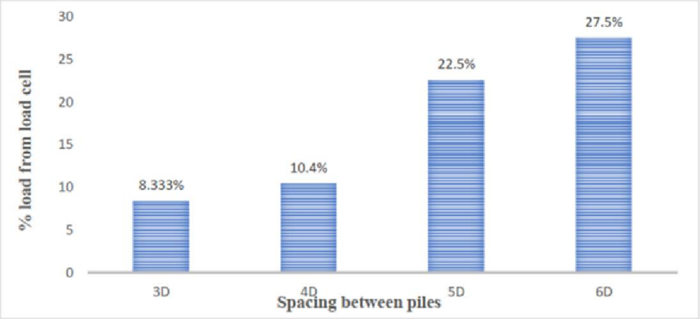

Fig (32) Comparison between spacing between piles and percentage of the load soil carried from load cell for four piles (LP=1.5m, D=0.15m)

Figure (33) shows the comparison between pile spacing where Sp= (3D, 4D, 5D and 6D) and percentage of load on soil from load cell and percentage of load redistributed on pile and load retained on soil for four piles (LP=1.5 m, D=0.15m). From this figure it can be shown that from (35% to 48%) from the load carried by soil redistributed to pile and soil carried from (5.5% to 14% from the total load applied to pile.

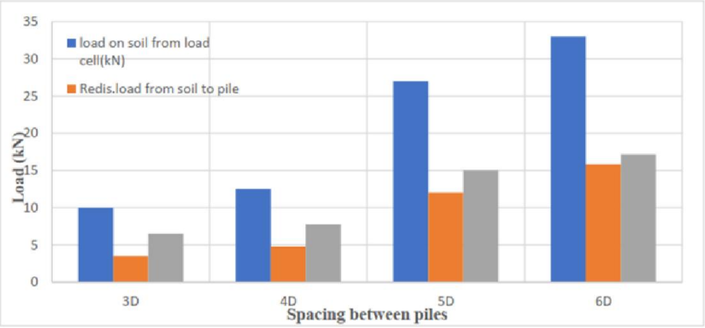

Fig (33) Comparison between spacing between piles and the load on soil before and after redistribution of load for four piles (LP=1.5m, D=0.15m)

Figure (34) shows the relationship between settlement and load at various pile spacing where Sp= (3D, 4D, 5D and 6D) for four piles (LP=1.5 m, D=0.15m). From this figure it can be shown that the settlement increase with increasing the pile spacing.

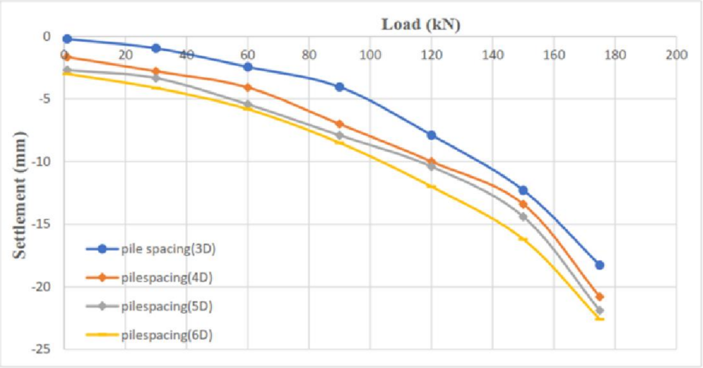

Fig (34) The Relation between load and settlement at various pile spacing for four piles (LP=1.5m, D=0.15m)

Figure (35) shows the comparison between ultimate load for different spacing between piles for four piles (LP=1.5m, D=0.15m). From this figure it can be shown that the ultimate load of four piles decrease with increasing the spacing between piles

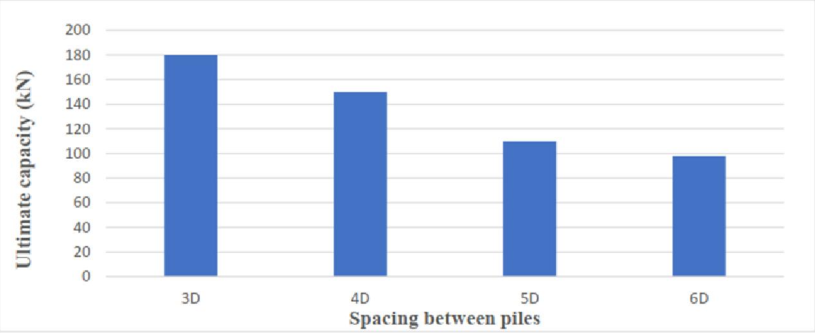

Fig (35) Comparison between ultimate load for different spacing between piles for four piles (LP=1.5m, D=0.15m)

Figure (36) shows the distribution of load at pile from redistributed of load from soil measured from strain gauges at different spacing where (Sp=3D, 4D, 5D and 6D) for four piles (LP=1.5m, D=0.15m).

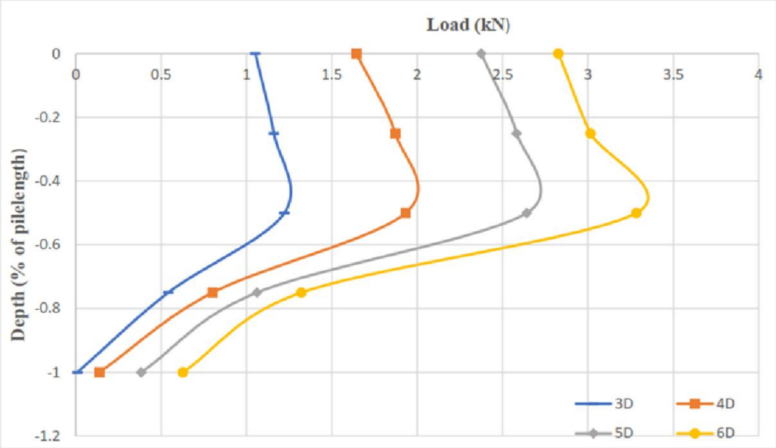

Fig (36) Distribution of load at pile from redistributed of load from soil measured from strain gauges at different spacing for four piles (LP=1.5m, D=0.15m)

Figure (37) shows the comparison between percentage of load borne by pile Pre and post load redistribution for four piles at various spacing where (Sp=3D, 4D, 5D and 6D), (LP=1.5m, D=0.15m).

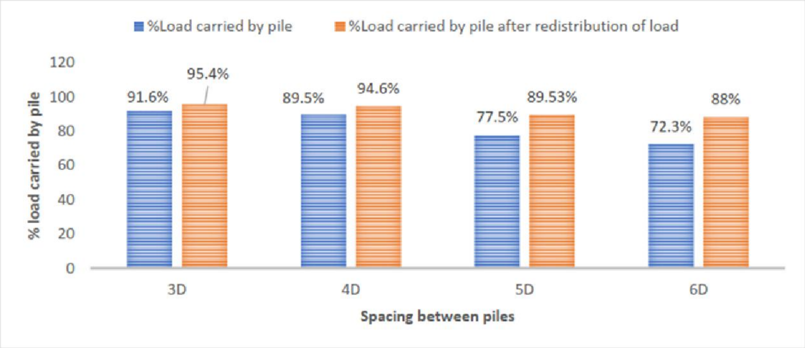

Fig (37) The Relation between spacing between piles and load carried by pile for four piles (LP=1.5m, D=0.15m)

Figure (38) shows the comparison between percentage of load borne by soil before and after redistribution of load for four piles at various spacing where (Sp=3D, 4D, 5D and 6D), (LP=1.5m, D=0.15m).

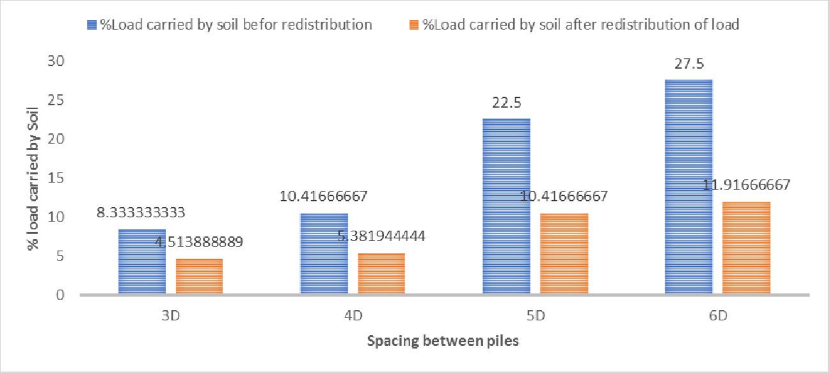

Fig (38) The Relation between spacing between piles and load carried by soil for four piles (LP=1.5m, D=0.15m)

Figure (39) shows the comparison between percentage of load borne by pile and soil Pre and post load redistribution for four piles at various spacing where (Sp=3D, 4D, 5D and 6D), (LP=1.5m, D=0.15m).

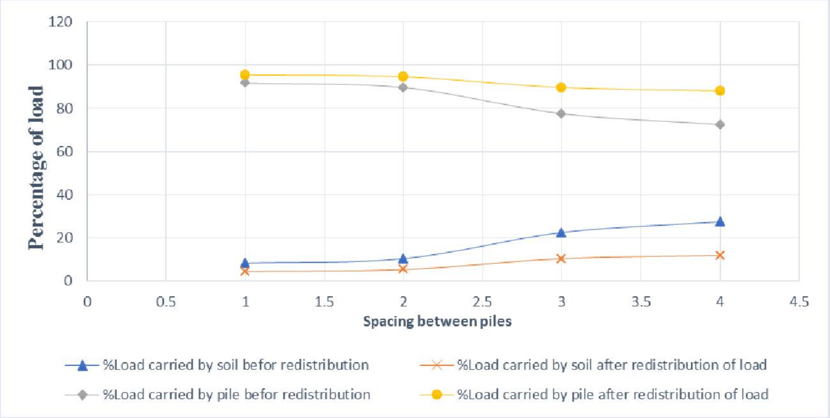

Fig (39) The Relation between spacing between piles and load carried by pile and soil for four piles (LP=1.5m, D=0.15m)

4. Analysis of finite element

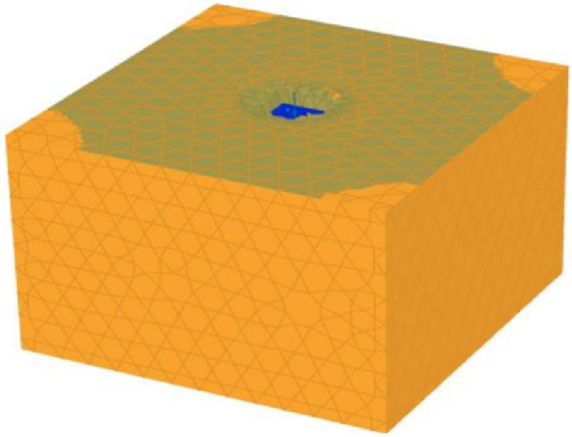

Fig (40) Deformed mesh of four piles (LP=1.5m, D=0.15m and Sp=3D)

A theoretical analysis has been done for experimental program. A finite element model was developed to simulate the four piles with various spacing where (Sp=3D, 4D, 5D and 6D) and vertically loaded on its top. The pile is designed on linearly elastic elements with a Young's modulus Ep= 20x106 kN/m2 and Poisson's ratio vp= 0.1 Figure (40) shows the deformed mesh for four piles (Lp=1.5m, Sp=3D, D=0.15m)

Figures from (41) to (45) show the vertical displacement (settlement) as shading and contour for four piles (LP=1.5m and D=0.15m) at various spacing where (Sp=3D, 4D, 5D and 6D). From these figures it can be shown that the settlement increase with increasing spacing between piles.

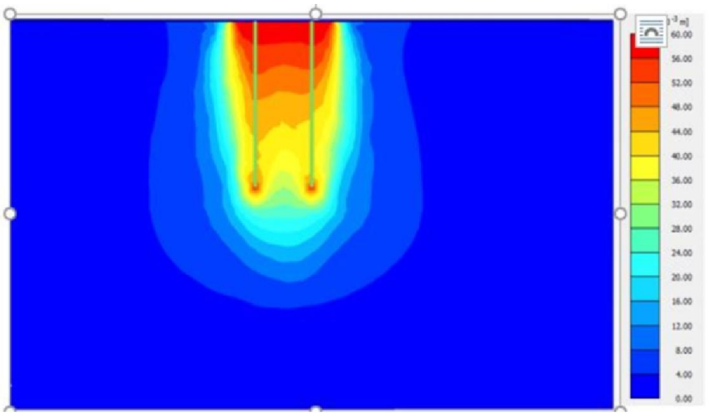

Fig (41) Vertical displacement (Settlement) as shading for four piles (LP=1.5m, D=0.15m and Sp=3D)

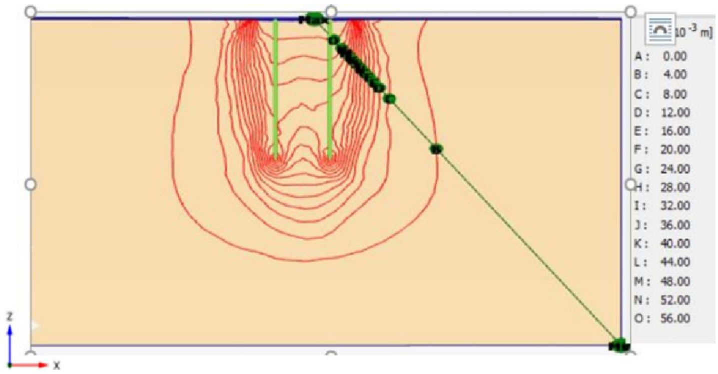

Fig (42) Vertical displacement (Settlement) as contour for four piles (LP=1.5m, D=0.15m and Sp=3D)

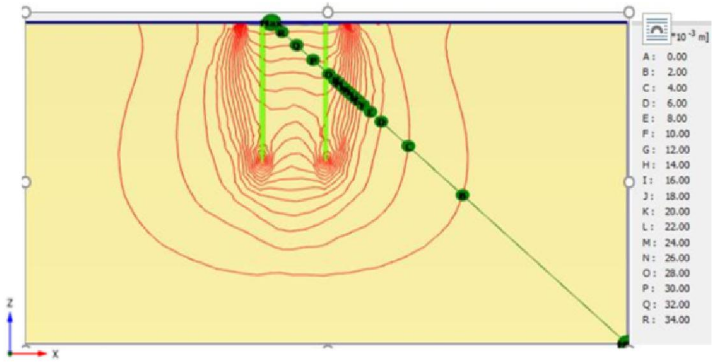

Fig (43) Vertical displacement (Settlement) as contour for four piles (LP=1.5m, D=0.15m and Sp=4D)

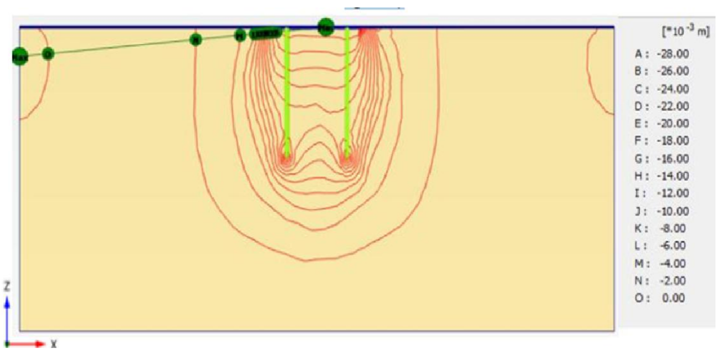

Fig (44) Vertical displacement (Settlement) as contour for four piles (LP=1.5m, D=0.15m and Sp=5D)

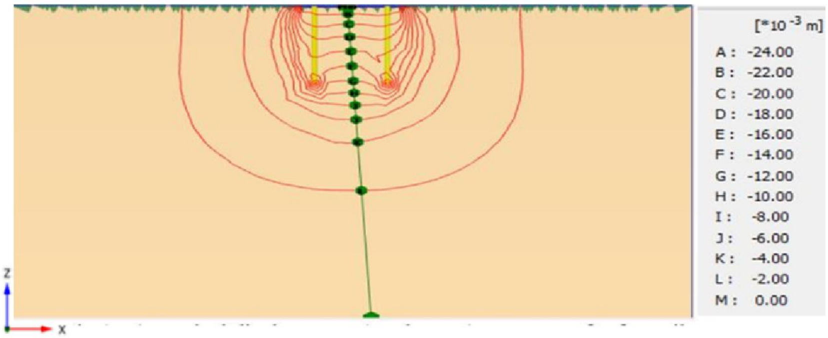

Fig (45) Vertical displacement (Settlement) as contour for four piles (LP=1.5m, D=0.15m and Sp=6D)

Figure (46) shows the Relation between pile spacing and load carried by soil theoretically and experimentally for four piles (LP=1.5m and D=0.15m).

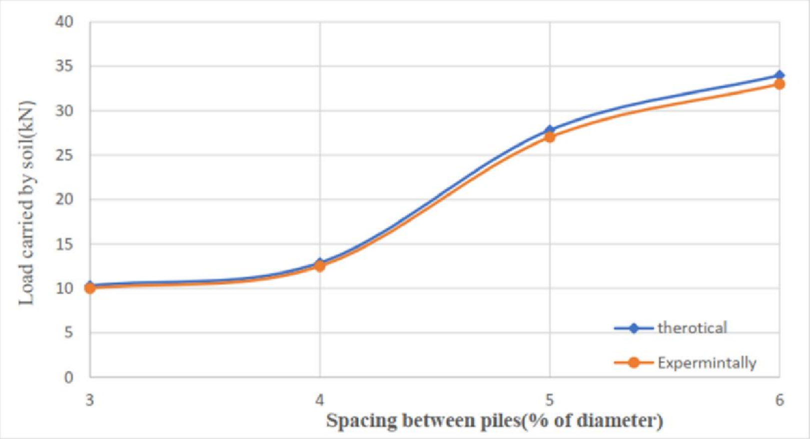

Fig (46) The Relation between spacing between piles and load carried by soil theoretically and experimentally for four piles (LP=1.5m, D=0.15m)

Figure (47) shows the comparison between load carried by soil theoretically and experimentally before redistributed of load to pile for four piles (LP=1.5m, D=0.15m).

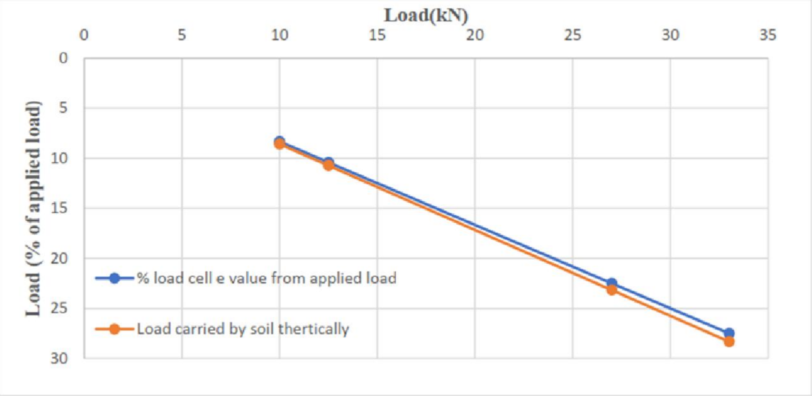

Fig (47) The comparison between load carried by soil theoretically and experimentally before and after redistributed of load to pile for four piles (Lp=1.5m, D=0.15m)

Figure (48) shows the comparison among load borne by soil theoretically and experimentally after redistributed of load to pile for four piles (LP=1.5m, D=0.15m).

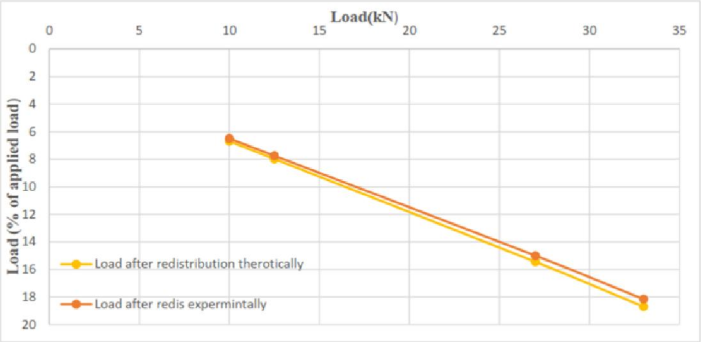

Fig (48) The comparison among load borne by soil theoretically and experimentally after redistributed of load to pile for four piles (Lp=1.5m, D=0.15m)

Figure (49) shows the comparison between spacing between piles and percentage of the load borne by soil from load cell and theoretically for four piles (LP=1.5m, D=0.15m) at various pile spacing where (Sp=3D, 4D, 5D and 6D).

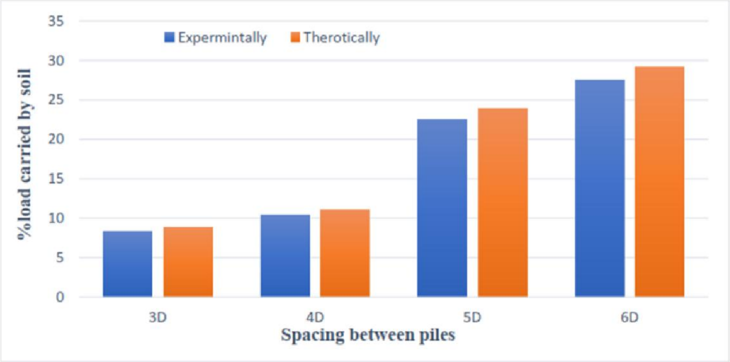

Fig (49) Comparison between spacing between piles and percentage of the load borne by soil from load cell and theoretically for four piles (LP=1.5m, D=0.15m)

From these results the following observations are noted: the settlement increase with increasing spacing between piles, the load carried by soil increase with increasing pile spacing. And that gives equal agreement with the loading tests obtained.

5-Conclusions

From the current research, the followings are concluded:

1) Increasing pile spacing increase the load carried by soil by ratio from (8.3% to 27.5%).

2) The ratio from (35% to 48%) of the load carried by soil redistributed to pile.

3) The Soil carried (5.5% to 14%) from the total load applied to pile after redistributed of load from soil.

4) The ultimate load of four piles decrease with increasing the spacing between piles.

5) The settlement increase with increasing the pile spacing.

6) Reasonable agreement was reached between the analysis of finite elements and the results of the experimental tests.

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9/15/2020