Response of Piles Group Subjected To Eccentric Lateral Load

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Abstract

This paper presents a series of pile group model tests subjected to eccentric lateral loads in sand. The objectives of the research are to investigate: the response of the pile groups subjected to eccentric lateral loads; the way in which the applied eccentric lateral load is transferred in the pile groups; the effect of L/D ratio, the position of load application, the effect of applied vertical load; and the direction of applied load on the response of pile group. The results of model tests revealed that, the pile group capacity to resist eccentric lateral loads increases when increasing the percentage of allowable vertical load, number of piles and L/D ratio. The direction of the eccentric lateral load with respect to pile group cap has great effect on the lateral load capacity of pile group. Also, the change in direction of eccentric lateral load the lateral load resistance of pile group will be changed according to piles pattern

Key words: : **Lateral loads, piles, pile group, L/D ratio**

1-Introduction

The design and analysis of pile group foundations present a complex problem to the geotechnical engineer because of many factors that affect foundation behavior. Such factors include mode of loading, soil properties, pile geometry, and method of construction. The mode and magnitude of loads transferred from the superstructure will influence on the selection of pile foundation to resist the imposed loads. For some structures such as offshore platform, tall building, bridge bents, and electric transmission towers that are subjected to lateral load of considerable magnitude from wind and wave action, ship impacts, high speed vehicles, and other recourses of loading, significant torsional force can be transferred to the foundation piles by virtue of eccentric lateral loading [1], [5.[

Pile foundations are often subjected to significant amount of lateral loads besides vertical loads. Grouped piles are usually used as foundations for offshore platforms, bridge bents and tall buildings, because of eccentric lateral loading on these structures from wind and wave action, ship impacts, or high-speed vehicles, the grouped piles may be subject to significant torsional loads.These torsional loads transferred to the foundation of the structure in the form of horizontal loads and moments. In practice piles are used in groups and are connected by a cap at the pile heads. The spacing between the piles, arrangement of piles, their batter, and direction of load has an important role in the assessment of load deformation behavior of pile groups under torsional loads, [2[

Sajjad et al. [3] investigated group interaction effects on laterally loaded pile groups in sand. They examined two pile groups 1×3 and 3×1, as shown in Figure (1). The concrete pile used has diameter 0.4 m and length 8 m, the spacing between piles changes from 3D to 1

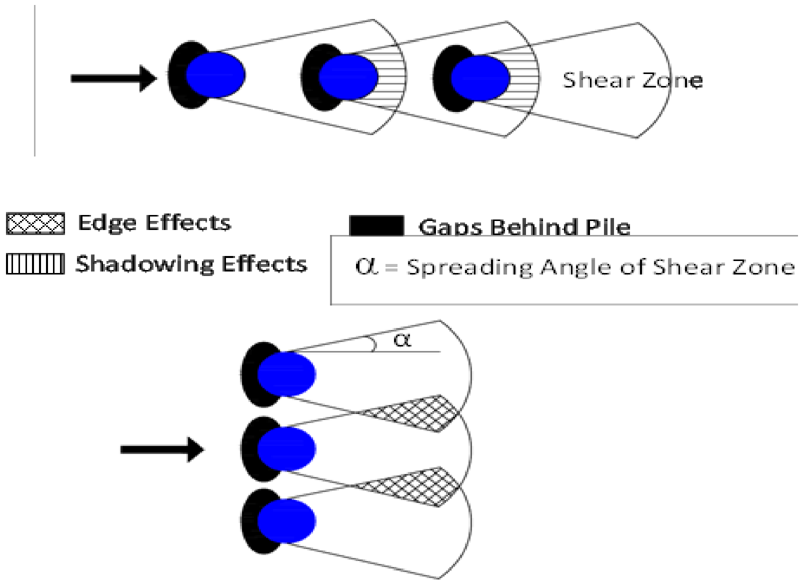


Figure (1) Schematic Diagram for Two pile Groups subjected to Lateral Load

(Sajjad et al. [3])

The researchers found that the difference in response of a pile group subjected to lateral load due to the edge effect can be even more than 50% of shadowing effect influence.

It can be concluded from previous studies on pile group subjected to lateral load that all researchers have examined the behavior of pile group under lateral load except some researchers who examined the single pile under torsion load and

Kong and Zhang [4] studied the behavior of pile group subjected to torsion, They tested three models of pile groups, 1×2, 2×2, and 3×3 pile group with spacing 3D, L/D ratio19 and different densities.

The current research study will focus on investigating the effects of factors that are not studied in the previous studies. These factors can be listed as follows:

- The effect of L/D ratio,

□□ The effect of number of piles,

□□ The effect of testing loaded and un loaded pile groups (applied vertical allowable load,(

□□ The effect of configuration or geometry of pile group; and

□□ The effect of direction and position of torsion load.

The effects of previous factors were investigated through extensive experimental program.

.2 Experimental Programs

2.1 Physical Soil Properties

It is important to note here that all standard tests were conducted according to ASTM standards.

The soil tested in this research was Karbala sand. The grain size distribution curve of the sand can be shown in figure (2).

The details of the physical soil properties are listed in table (1).

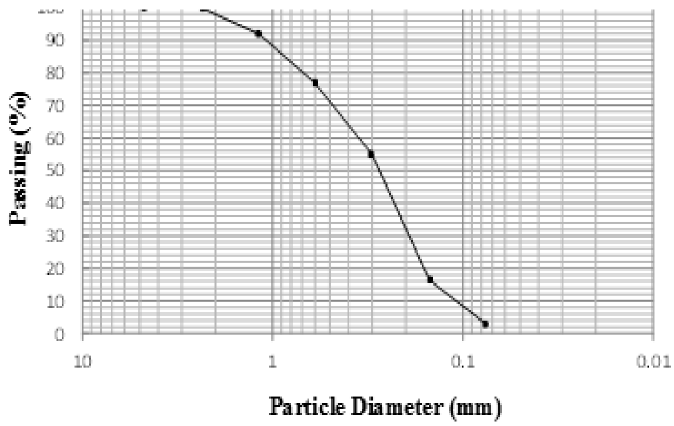


Figure (2) Grain Size Distribution for Sand

Table (1) Soil Properties

Index Properties	Values
Specific Gravity	2.61
Maximum dry unit weight (kN/m^3)	17.64
Minimum dry unit weight (kN/m^3)	14.53
Maximum void ratio	0.80
Minimum void ratio	0.47
Dry unit weight at testing (KN/m^3)	16.5
Angle of internal fraction	43°
Soil classification (USCS)	SP

2.2 Description of Laterally Loaded Pile Group Setup Model

To carry out the model of pile group subjected to eccentric lateral load, a new setup was manufactured. The setup consists of the following parts:

1- Steel Container,
2- Hydraulic System,
3- Steel Loading Frame,
4- Raining Frame; and
5- Load Cell and Digital Indicator.

2.2.1 Steel Container

Steel container made from five separate parts, one for the base and the others for the four sides. The internal dimensions of the container are (80×80×80) cm. The thickness of the container sides is (4mm) while the thickness of the base is (6mm). The front side of the container has a gate (60cm) in length, (60cm) in width and (4mm) in thickness located at the center of it. This gate was used to empty the steel container from soil. The inner surface of the container was divided to (8) layers, the thickness of each layer was (10) cm. The right side of container has glass plate to enable the observation of the soil behavior throughout the loading stages. The upper edges of right and left side of container have holes that are used for support of horizontal jack. See Plates (1) and (2)

Plate (1) Front Side of Container

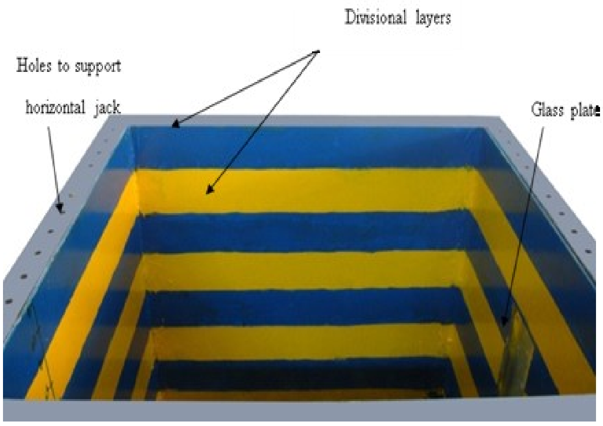


Plate (2) Inside of Container

2.2.2 Hydraulic System

The hydraulic system consists of hydraulic pump, vertical and horizontal jacks. The vertical jack is used to insert the models of pile groups in the soil while the horizontal jack is used to apply the torque on the models. The hydraulic system works by electric control. See Plates (3), (4) and (5).

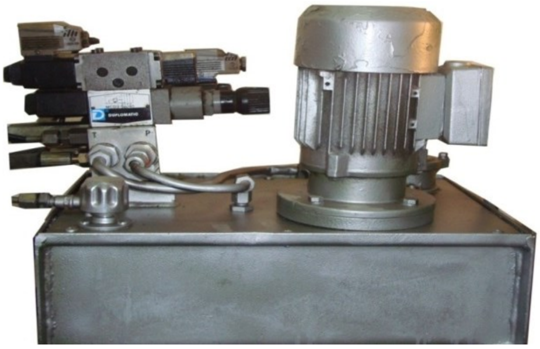


Plate (3) Hydraulic Pump

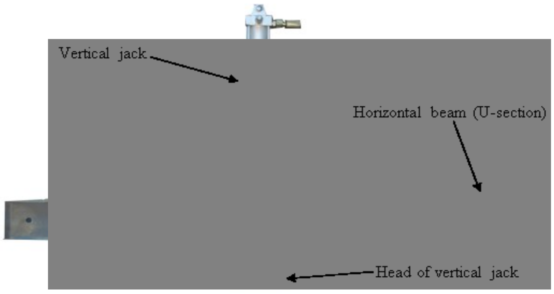


Plate (4) Vertical Jack

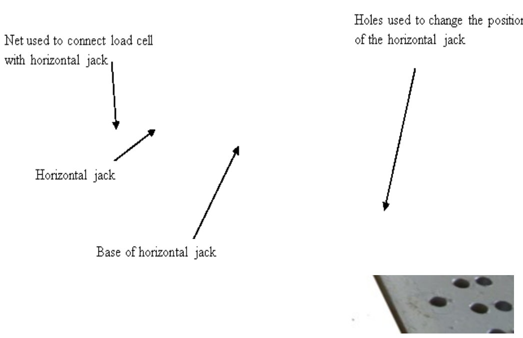


Plate (5) Horizontal Jack

2.2.3 Steel Loading Frame

Steel loading frame was manufactured to support the piston that is used for subjecting vertical load and insert the pile group in the soil. Steel loading frame consists of two beams in horizontal direction have (U-section) to allow the piston to move horizontally along the beam and two column in vertical direction have (square-section), at the sides of columns found holes that are used to help in controlling vertically the distance between the piston and the container surface. See Plate (6).

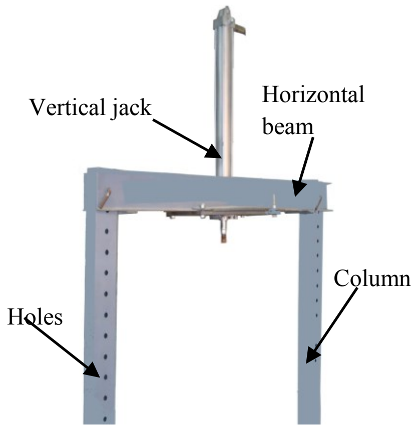


Plate (6) Steel Loading Frame

2.2.4 Load Cell and Digital Indicator

A compression/tension load cell (SEWHA, Korea) model S-beam type (SS300) is used to measure the load. It is made of stainless steel L-S300, with a maximum capacity of 1 ton. A digital weighing indicator is used for displaying the load amount (SEWHA, Korea) model SI 4010, with an input sensitivity of 50 gm, as shown in plate (7).

Plate (7) Load Cell and Digital Indicator

2.2.5 Technical Properties of the Manufactured Model

- The model consists of a hydraulic system to exert the static loads in vertical and horizontal direction in any position,
- Steel frame and axial loading system can be moved horizontally and vertically respectively to enable the model tests to be performed within any point throughout the container,
- Raining frame consists of a movable cone with perpendicular directions; and
- The model contains a glass plate to enable the observation of the soil behavior throughout the loading stages.

2.3 Sand Preparation

Sand samples for small scale tests can be prepared by tamping, vibration, or raining. Generally, raining is expected to provide relatively homogenous specimens with the desired relative density. Sand raining is achieved either by automatic spreaders or by manual single hose rainers. The adopted technique in this work was the single hose raining method.

2.4 Model of Pile Groups

The models of pile groups used in this research study can be classified in two groups. The first group consists of 3 circular piles connected with Aluminum pile cap of (11.5×11.5×3 cm) while the second group consists of 5 circular piles connected with pile cap of the same dimensions of that used in the first group. The pile is modeled as Aluminum closed end tube and fixed head with (15 mm) outer diameter and (2mm) thickness. Two pile lengths were used (30, and 45 cm), plate (8). The spacing between piles is 3d, Figure (3) shows pile groups pattern.

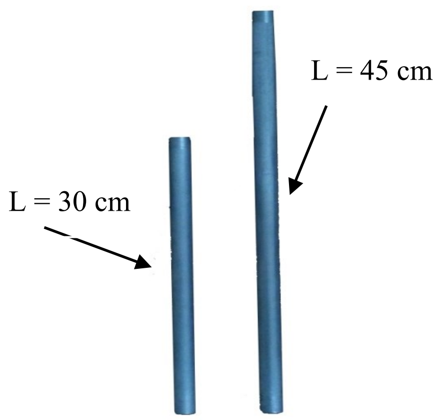


Plate (8) Piles of Different Lengths

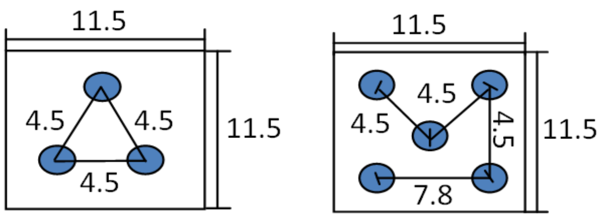


Figure (3) Pile Groups Pattern (All Dimensions in cm)

2.5 Model Tests of Pile Groups Subjected to Eccentric Lateral Load

The steps followed for performing test on model pile group subjected to eccentric lateral load are summarized as follows:

A. Soil Preparation:

a) Prepare the soil by raining technique at the chosen density and the corresponding relative density (RD = 69% for dense state),

b) Level the sand surface at final depth when the raining is completed, the level of sand layers is checked by leveling tool.

B. Pile Group Installation*:*

a) Fix the pile group in the head of vertical hydraulic jack,

b) The group are instilled in sand by pre jacking method,

C. Testing preparation:

a) Support the allowable vertical load (if any) on the pile group,

b) Fit the dial gages in the horizontal direction at the corner, at the middle of the pile cap while at the vertical direction in the right and left side of the pile cap

c) Fit the load cell with the horizontal jack and connect it with the digital indicator,

d) Fix the horizontal jack in the upper edge of the right side of the container to be ready to subject the eccentric lateral load on the pile cap, see plates (9) and (10).

D. Testing

a) Now apply the eccentric lateral load and record the readings of all the dial gages used and calculate the rotation angle,

$$\text{Rotation (Degree)} = \tan^{-1}\left(\frac{Rco - Rce}{D}\right)$$

b) At the end of the test, remove all the dial gages, load cell, horizontal jack, allowable vertical load, pile group, and open the gate for removing the sand to prepare the model for another test. Repeat all the above steps in the next test.

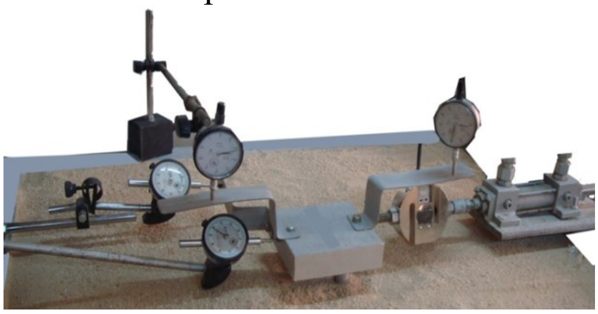


Plate (9) Pile Group Subjected to Eccentric Lateral Load without Allowable Vertical Load

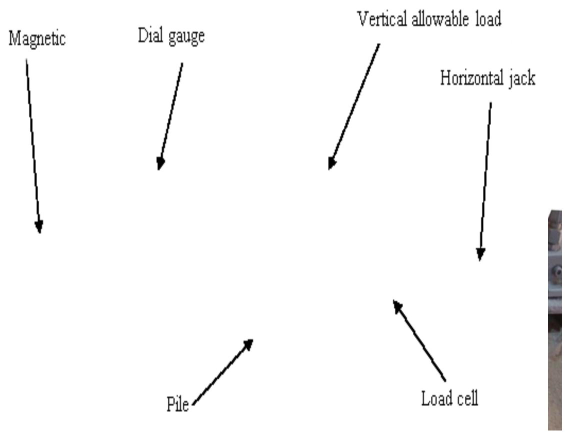


Plate (10) Pile Group Subjected to Eccentric Lateral Load with Allowable Vertical Load

3- Results and Discussions

Grouped piles are usually used as foundations for offshore platforms, bridge bents and tall buildings, because of eccentric lateral loading on these structures, the grouped piles may be subject to significant torsional loads. These torsional loads transferred to the foundation of the structure in the form of horizontal loads and moments. The arrangement of piles and direction of load has an important role in the assessment of load deformation behavior of pile groups under torsional loads. The results obtained from testing program on pile group model (PG3: Pile group which consists of 3 piles subjected to torsion load, PG5: Pile group which consists of 5 piles subjected to torsion load, DD PG3: Pile group which consists of 3 piles subjected to the torsion load in different directions, DD PG5: Pile group which consists of 5 piles subjected to the torsion load in different directions) can be summarized as follows:

3.1 Effect of Direction of Eccentric Lateral load on Torsional Resistance of Pile Groups

The pile group configuration and the torsion load direction with respect to pile group geometry have significant effect on the torsional resistance of the group. This effect was studied in different ratios of L/D, (20 and 30) and investigated for loaded and unloaded pile group (100% of allowable vertical load, 0% of allowable vertical load) respectively. It is important to note that the allowable vertical loads were estimated from the vertical loading tests that carried out on the pile groups in laboratory. Table (2) shows the results of the vertical loading tests.

Table (2) Results of Vertical Loading Tests

Pile Grup	UltimateVertical Load (N)		AllowableVertical Load (N)	
	L/D = 20	L/D = 30	L/D = 20	L/D = 30
PG3	330	470	110	156
PG5	685	870	228	290

Figure (4) shows the effect of direction of torsional load on the torsional resistance of (PG3 and DD PG3). It is obvious that, the torsional capacity of pile group PG3 is less than that of pile group DD PG3. This behavior may be attributed to the mobilized lateral load and torsional resistance, i.e., complicated pile-soil-pile interactions in the pile group take place. The overlapping in shear zones observed in pile group PG3 refers that two shadowing effects and one edge effect had occurred, while in pile group DD PG3 the overlapping in shear zones shows that one shadowing effect and two edge effects had been occurred shown in Figure (5). According to previous study on interaction of pile-soil-pile (Sajjad et al. [3]) found that the difference in response of a pile group subjected to lateral load due to the edge effect can be even more than 50% of shadowing effect influence, that's mean the shadowing effect leads to decrease in torsional resistance greater than edge effect, Therefore, the torsional resistance in pile group DD PG3 is more than that for pile group PG3.

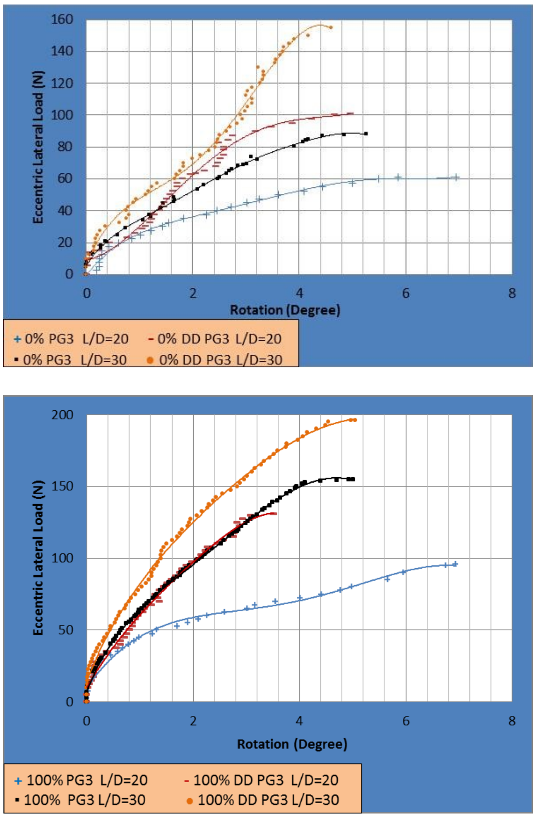


Figure (4) Effect of Direction of Eccentric Lateral Load on Variation of Eccentric Lateral Load with Rotation of Pile Groups PG3 and DD PG3 at Different Percentage of Allowable Vertical Load (0%, 100%) and L/D Ratios are 20 and 30

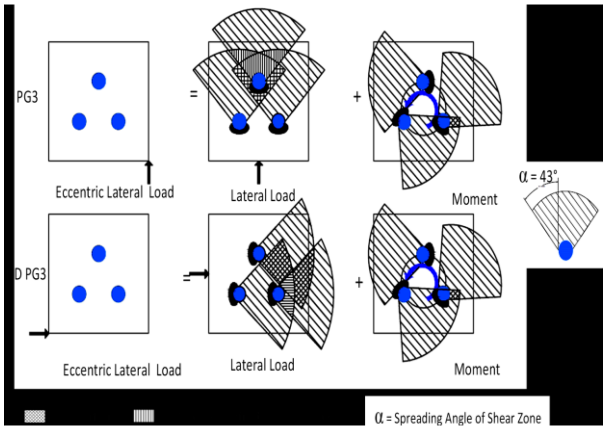


Figure (5) Loading and Movement Direction in Pile Groups PG3 and DD PG3 Subjected to Eccentric Lateral Load

Also, when comparing between pile groups PG5 and DD PG5, it is found that the torsional resistance of pile group DD PG5 is greater than that of pile group PG5, as shown in figures (6). This behavior may be attributed to the overlapping of shear zone in pile group PG5 (4 shadowing effects + 2 edge effects) which is seam greater than the over laping shown in pile group DD PG5 (2 shadowing effects + 6 edge effects). In addition the leading row in PG5 group shares loading less than that shared by leading row in pile group DD PG5, since the distance between two piles in leading row for pile group DD PG5 is greater than that in pile group PG5, as shown in Figure (8).

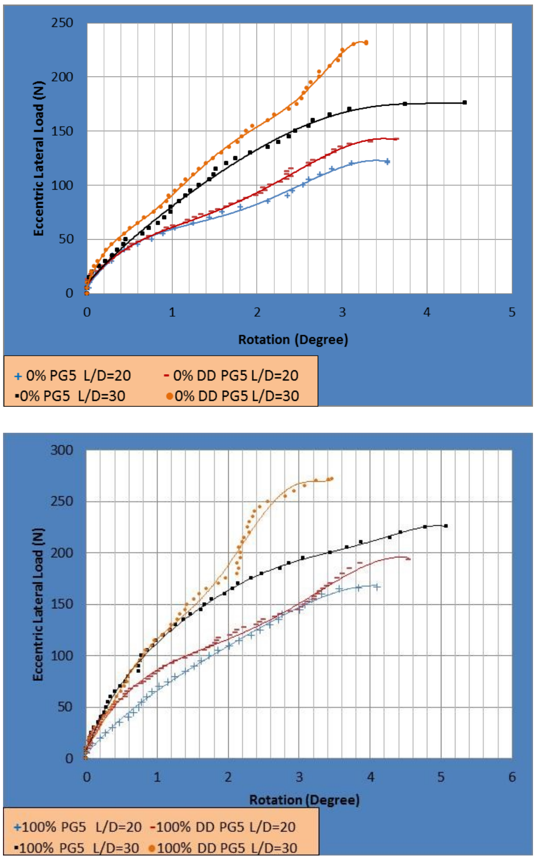


Figure (6) Effect of Direction of Eccentric Lateral Load on Variation of Eccentric Lateral Load with Rotation of Pile Groups PG5 and DD PG5 at Different Percentage of Allowable Vertical Load (0%,100%) and L/D Ratios are 20 and 30

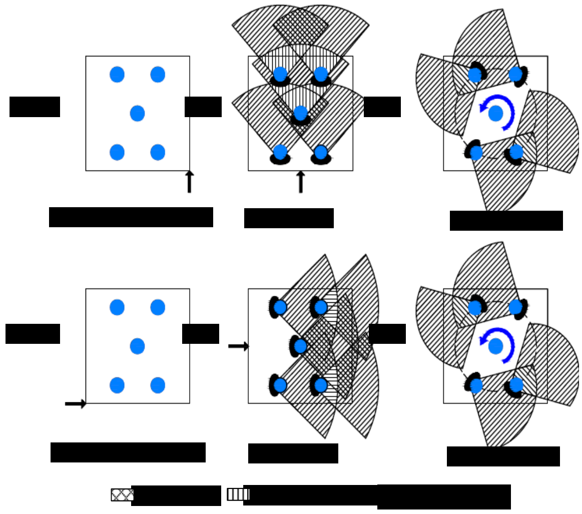


Figure (7) Loading and Movement Direction in Pile Groups PG5 and DD PG5 Subjected to Eccentric Lateral Load

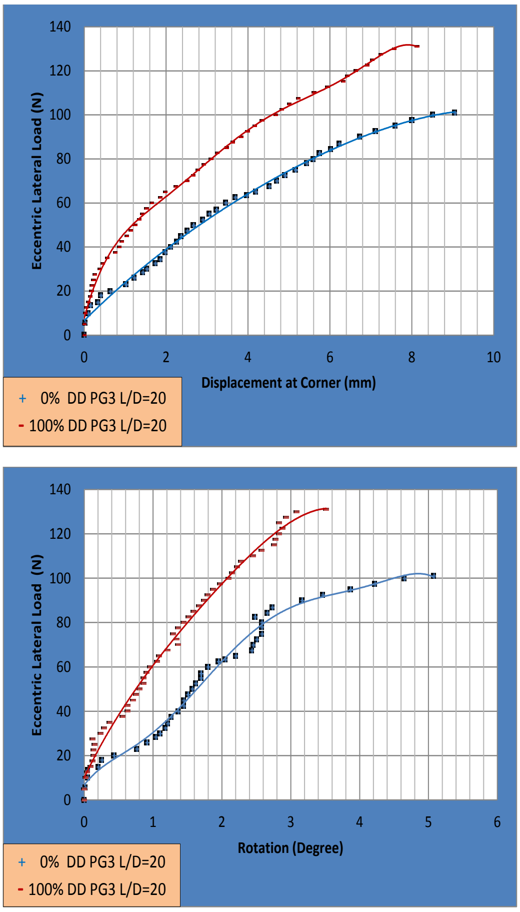


Figure (8) Effect of Percentages of Allowable Vertical Load on Variation of Eccentric Lateral Load with Displacement at Corner and Rotation of Pile Group DD PG3 when L/D Ratio (20)

3.2 Effect of Allowable vertical load on Torsional Resistance of Pile Groups

From the results obtained it is found that the allowable vertical load has a noticeable effect on the torsional resistance of pile group. The larger the allowable vertical load, the greater the torsional resistance at constant L/D ratio. This behavior can be observed in figure (8) and figure (9) for pile group DDPG3 and figure (10) and figure (11) for pile group DDPG5.

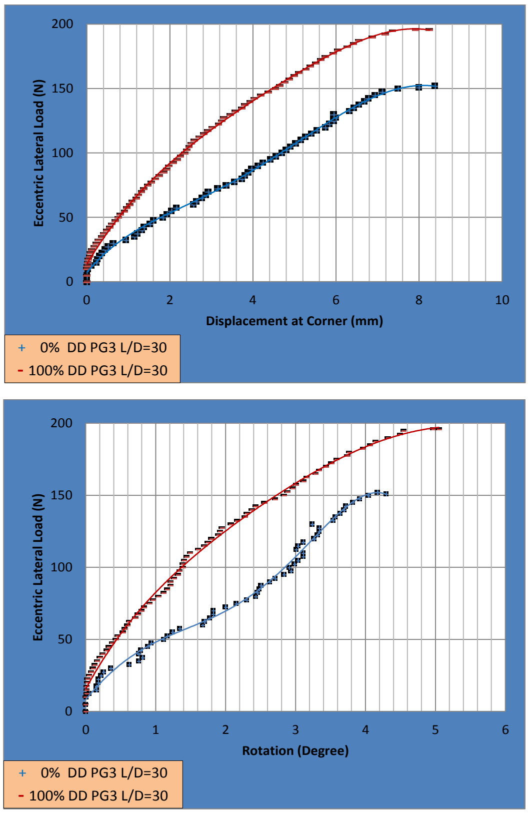
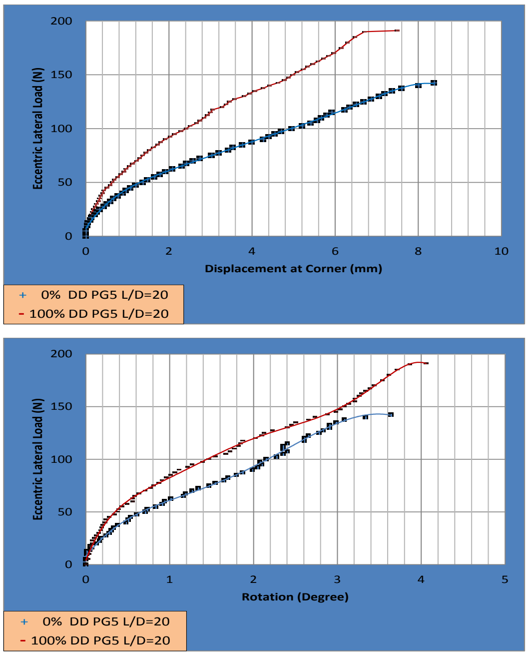


Figure (9) Effect of Percentages of Allowable Vertical Load on Variation of Eccentric Lateral Load with Displacement at Corner and Rotation of Pile Group DD PG3 when L/D Ratio (30)



Figure(10) Effect of Percentages of Allowable Vertical Load on Variation of Eccentric Lateral Load with Displacement at Corner and Rotation of Pile Group DD PG5 when L/D Ratio (20)

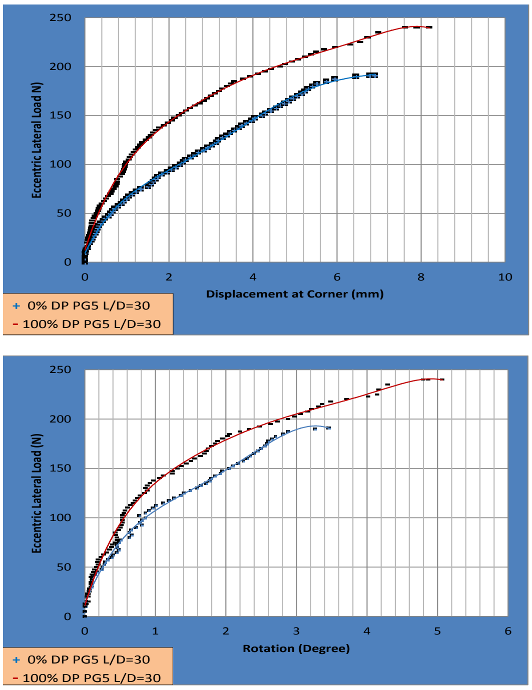


Figure (11) Effect of Percentages of Allowable Vertical Load on Variation of Eccentric Lateral Load with Displacement at Corner and Rotation of Pile Group DD PG5 when L/D Ratio (30)

4- Conclusions

Based on the analysis of model pile group tests subjected to torsion load (Eccentric lateral load), the following conclusions were obtained:

1. The torsional capacity of pile group increases about 42% when increasing the percentage of allowable vertical load from (0% to 100%) for pile group PG3 and 53% for pile group PG5. Also, the increase in number of piles and L/D ratio leads to increase the torsional capacity of pile group.

2. For all tests the maximum twist angle at failure is 3º for pile group PG3 when L/D ratio is (20) and the percentages of allowable vertical load are 0% and 100%,.
3. The direction of the torsion load has great effect on the torsional capacity of pile group. When change the direction of torsion load the torsional capacity of pile group will be changed. This change in torsional capacity of pile group depends on its pattern,

5- References

[1] Kong, L. G., (2006): "Behavior of Pile Group Subjected to Torsion", PhD Dissertation, The Hong Kong University of Science and Technology, Hong Kong.

[2] Karsan R. and Verma A. K., (2011): "Lateral Load Carrying Capacity of Batter Pile Group", PhD Dissertation, Gujarat Technological University, Ahmadabad.

[3] Sajjad, F., Mahdi T., Liam F., and Carlos E. V., (2012) "Evaluation of P-Multiplier Method for Performance-Based Design of Pile Group", II International Conference on Performance-Based Design in Earthquake Geotechnical Engineering, Taormina, Italy, pp. 1105.

[4] Kong, LG, and Zhang, L. M., (2007): "Centrifuge Modeling of Torsionally Loaded Pile Groups", Journal of Geotechnical and Geoenvironmental Engineering, ASCE, Vol. 133, No. 11, pp. 1374-1384.

[5] Muralidhar, and Kalavathi G N., (2015): " Behavior of Piles under Lateral Loading Soil Structure Interaction", Journal of Mechanical and Civil Engineering JMCE, Volume 12, Issue 2, PP 68-74

6- Notations

D Distance between corner and center of pile cap

DDPG3 Pile group which consists of 3 piles subjected to the torsion load in different directions

DDPG5 Pile group which consists of 5 piles subjected to the torsion load in different directions

PG3 Pile group which consists of 3 piles subjected to torsion load

PG5 Pile group which consists of 5 piles subjected to torsion load

Rce Dial reading at center of pile cap

Rco Dial reading at corner of pile cap

استجابة مجموعة الركائز المعرضة لاحمال جانبية لامركزية

بشرى سهيل البوسودة
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الخلاصة

يعرض هذا البحث سلسلة من فحوص لموديل مجموعة ركائز معرضه الى احمال افقية لا مركزية في تربة رملية.
يهدف هذا البحث الى دراسة استجابة مجموعة الركائز المعرضة الى احمال افقية لا مركزية, طريقة انتقال الحمل الافقي اللامركزي المسلط في مجموعة الركائز, تأثير الحمل المسلط العمودي, اتجاه الحمل المسلط الافقي اللامركزي على استجابة مجموعة الركائز.
النتائج لفحوص الموديلات بينت ان قابلية مجموعة الركائز لمقاومة الاحمال الافقية اللامركزية تزداد عند زيادة كل من نسبة الحمل العمودي المسموح وعدد الركائز ونسبة الطول الى العرض للركائز.
اتجاه الحمل الافقي اللامركزي نسبة الى قبعة مجموعة الركائز له تأثير واضح على ماومة مجموعة الركائز للاحمال الافقية اللامركزية ووفقاً لترتيب الركائز.

<u>كلمات رئيسية:</u>

الأحمال الأفقية ،الركائز،مجموعة الركائز، نسبة الطول الى القطر

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