Experimental and Numerical Analysis of Piled Raft Foundation with Different Length of Piles Under Static Loads

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ABSTRACT:

In order to understand the effect of (**length of pile / diameter of pile**) ratio on the load carrying capacity and settlement reduction behavior of piled raft resting on loose sand, laboratory model tests were conducted on small-scale models. The parameters studied were the effect of pile length and the number of piles. The load settlement behavior obtained from the tests has been validated by using **3-D** finite element in **ABAQUS** program, was adopted to understand the load carrying response of piled raft and settlement reduction. The results of experimental work show that the increase in (**L_p/d_p**) ratio led to increase in load carrying capacity by piled raft from (19.75 to 29.35%), (14.18 to 28.87%) and (0 to 16.49%) , the maximum load carried by piles decrease from (9.1 to 22.72%), (15.79 to 47.37%) and (44 to 81.05%) and the response of settlement piled raft decrease from (16.67 to 23.33%), (9.09 to 39.39%) and (30%) with increase the number of piles from 4 to (6 and 9) and (**length of pile / diameter of pile**) ratio increase to (14.14 and 21.2), respectively. The numerical and model test results are found to be in a good agreement.

KEYWORDS: Piled Raft; Different Length of Piles; Experimental and Numerical Static Work.

دراسة عملية وتحليلية للاسس الحصيرية المدعمة بالركائز مختلفة الاطوال تحت الاحمال الساكنة

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الخلاصة

من اجل فهم تأثير نسبة (**طول الركيزة/ قطر الركيزة**) على مقدار التحمل والهطول للأساس حصيري مدعم بالركائز جالس على تربة رمليه مفككة تم بناء نموذج مختبري مصغر. العوامل التي تم دراستها هي تأثير طول الركيزة وزيادة عدد الركائز. النتائج التي تم الحصول عليها مختبريا سوف يتم تأكد منها ومقارنتها عدديا باستخدام العناصر المحددة المتاحة في برنامج (**ABAQUS**) لقد أظهرت النتائج أن زيادة في نسبة (**طول الركيزة/ قطر الركيزة**) يؤدي إلى زيادة في سعة تحمل الأساس الحصيري المدعم بالركائز من (19.75 الى 29.355)، (14.18 الى 28.87%) و (0 الى 16.49%)، نقصان في بمقدار سعة التحمل للركائز من (9.1 الى 22.72%)، (15.79 الى 47.37%) و (44 الى 81.05%) وان مقدار التقليل في الهطول الاساس الحصيري المدعم بالركائز بلغ (16.67 الى 23.33%)، (9.09 الى 39.39%) و (30%) مع زيادة عدد الركائز من (4) الى (6 و 9) وزيادة نسبة (**طول الركيزة/ قطر الركيزة**) من (21.2 الى 14.14) على التوالي . وان المقارنة النتائج العملية والعددية باستخدام العناصر المحددة أظهرت توافق جيد.

الكلمات الرئيسية:اساس حصيري مدعم بالركائز، ركائز مختلفة الاطوال، دراسة عملية وعددية تحت تأثير الاحمال الساكنة.

1. INTRODUCTION

One of the most important aspects of a civil engineering project is the foundation system. Designing the foundation system carefully and properly, will surely lead to a safe, efficient and economic project overall. In other words, foundation system design is one of the most critical and important step when a civil engineering project is considered. Until quite recently, there were some separately used systems like shallow foundations such as rafts and deep foundations such as piles. However, lately the foundation engineers tend to combine these two separate systems. By combining these two systems, the foundation engineer will provide the necessary values for the design obtain the required safety and also come out with a more economical solution. Several authors studied piled raft foundation in experimental and analytical work by different materials such as concrete model **Katzenbach et al**. (1997) and aluminum model, **Giretti** (2009).

In this paper, in order to examine the effect of pile length on the behavior of piled raft in loose sand, experimental work and three-dimensional finite element analyses were carried out using **ABAQUS/CAE 6.10.1** program. The parameters studies:

1) 4-piles raft at (**L_p/d_p**=10.61, 14.14 and 21.2) where L_p and d_p are variable length and diameter of pile (dp=14.14mm), respectively.
2) 6-piles raft at (**L_p/d_p**=10.61, 14.14 and 21.2)
3) 9- piles raft at (**L_p/d_p**=10.61, 14.14 and 21.2).

2. EEXPERIMENTAL WORK:

A series of model loading tests were conducted inside a steel box of dimensions (600X600X700mm) depth, made of steel plate of 3mm thickness, stiffened with 3 lines of 25mm angle sections, provided with 280 *220mm hatch for sand refilling as shown in **Plate (1)**.

The internal faces of the box were covered with polyethylene sheets in order to reduce the slight friction which might be developed between the box surface and soil. Scaling laws were followed in the design of the model to eliminate the model stress error and boundary effects.

The square aluminum raft model was a 120mm in dimension and thickness (t_r=15mm). The square cross section aluminum model of piles employed in the tests (d_p=14.14mm) as shown in **Plate (2).**

2.1. Static Loading Measurment

A conventional compression machine with digital control system was used to apply the axial loading on footing model .The load on the footing was measured using proving ring of 3KN capacity. The settlement of pile raft model was measured by two dial gauges (0.001mm, division) fixed on the edges of the footing by two magnetic holders as shown in **Plate (3)**.

The static load of pile in group measured by strain gage was (50mm) gage length, (120Ω) resistance, (2.1) gage factor and it was bonded to the pile surface by using instance adhesive which was specially used for the strain gage type. Before bonding the strain gage, the pile surface was smoothed and cleaned by alcohol. The surface of pile was coated by epoxy resin to protect the strain gauges. Thus each model pile was tightly secured through openings in the raft using screws to create a fixed-head condition (see **Plate (4)**). The half Wheatstone bridge circuit was used for strain gages connection, **Dally et al**. (1965).

2.2. Soil Used

2.2.1 Sand Properties:

Poorly graded sand was used in the tests. The sand was placed in the test box at unit weight of approximately 15.3 kN/m^3 (relative density=30%). Some properties of sand are given in **Table (1)**.

2.2.2 Mechanical Behavior of Sand

The mechanical behavior of dry sand in loose state used at (Dr=30%, γ_d=15.3kN/m^3 and e=0.73) using triaxial test (UU test) and direct shear test are listed in **Table (1).**

2.3 Mechanical Properties of Aluminum Used

The aluminum specimen used to model raft and piles were tested in accordance to the **ASTM** (**B557–06**) specifications. Yield strength **(**fy), tensile strength (fu), elongation (e) and Poisson's ratio (v). The results mechanical properties of aluminum used under tensile test can be listed in **Table (2).**

3. NUMERICAL WORK

All the numerical calculations were carried out with the finite element program **ABAQUS/CAE.** The 3D-models are developed to soil depth, pile dimensions and soil properties from the test are adopted into the models. Each separate part of the model, such as piles and soil, is given its material properties.

Piles are assumed to have linear elastic behavior and the material behavior of the soil was simulated using the modified Drucker-Prager elasto plastic material model. In **ABAQUS/CAE** program a mesh of model type C3D8R an 8-node linear hexahedral element used and the total number of element (22392) as shown in **Plate (5).** The interactions between surfaces need to be assigned properties in order to determine the behavior of the interfaces. The relative motions between surfaces are set normally. Tangentially interaction has “rough” behavior which means that the relative velocity between the surfaces is zero i.e. no slip can occur. The interaction between the raft and the soil is assumed to be rough to represent the assumed full adhesion between the sand and the raft surface, but the interaction between pile surfaces and soil is assumed surface to surface contact (standard) tangentially behavior depend on interface angle.

4. RESULTS AND DISCUSION OF EXPERIMENTAL WORK

Figures (1 to 3) show the measured load-settlement curves for piled raft at (N=4, 6 and 9), s=3dp, tr=15mm and Dr =30% (where N is the number of piles, s: spacing between piles, tr: raft thickness and Dr: relative density of sand). In general the results show the increase L_p/d_p value led to increase in load carrying of piled raft and decrease in load carrying by piles in piled raft due to increase in the interaction load with increase L_p/d_p ratio.

Figure (4) shows the computed maximum load versus the ratio L_p/d_p. It is clear that the maximum load carried by piled raft increase from (19.75 to 29.35%), (14.18 to 28.87%) and (0 to 16.49%) and the maximum load carried by piles decrease from (9.1 to 22.72%), (15.79 to 47.37%) and (44 to 81.05%) with increase the number of piles from N= 4 to (N = 6 and 9) and L_p/d_p ratio increase to (14.14 and 21.2), respectively.

Figure (5) shows the computed maximum settlement versus the ratio L_p/d_p. The response of settlement piled raft decrease from (16.67 to 23.33%), (9.09 to 39.39%) and (30%) with increase the number of piles from N= 4 to (N = 6 and 9) and L_p/d_p ratio increase to (14.14 and 21.2), respectively.

5. COMPARSION OF EXPERIMENTAL AND NUMERICAL WORKS

The results obtained from the 3D-finite element analysis are presented and compared with the experimental results. **Figures (6 and 7)** show the comparison results of max. load and max settlement plotted with L_p/d_p ratio, respectively. It can be seen from the figures that the finite element results are close to the experimental test results are in the ranges of (1.1-1.16). **Figures (8 and 9)** show the three dimensional full and half contour mapping of miss stress at max load of 6-Piled Raft**.**

6. CONCLUSION

- In general the increase in L_p/d_p ratio led to increase in maximum load carrying by piled raft and decrease in maximum settlement.
- The increase in L_p/d_p ratio led to decrease in load carrying by pile (axial load) due to increase in the load carrying by shaft of pile (interaction load).
- The increase in L_p/d_p ratio for piled raft has the number of piles (N=4 and 6) is more effective than piled raft at (N=9).
- 3-D finite element by using **ABAQUS** program shows good results are compared with the experimental test results.

7. REFRENCES

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Plate (1): Container of Sand Used.

Plate (2): Square Aluminum Raft Model, Piles and the Screwed Opening to Fix Piles.

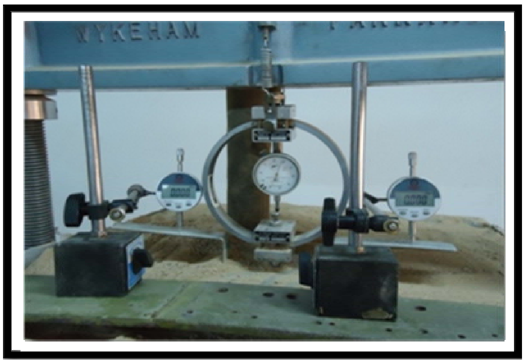

Plate (3): Instrumentation of Static Loading.

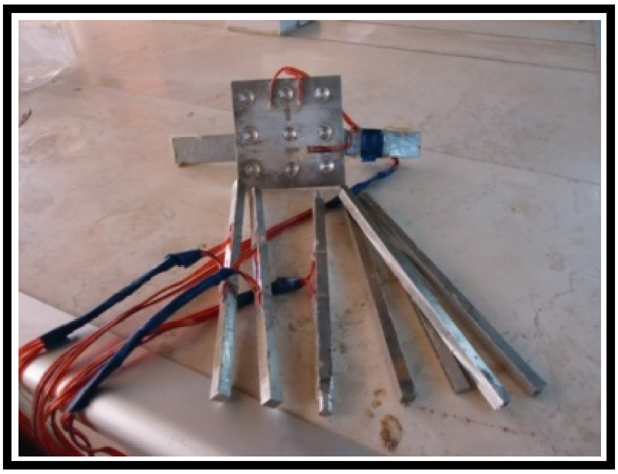

Plate (4): Aluminum Footing Model with Strain Gage.

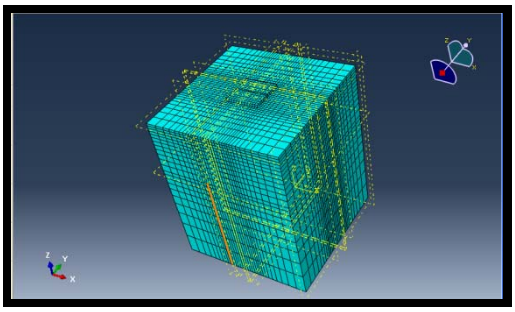

Plate (5): Meshing Model of Piled Raft.

Table (1): Properties for Sand Used.

Property		Values
Specific Gravity, Gs		2.65
Dry Unit Weight (γ_d) of Sand	Maximum unit weight, γ_{dmax}	17.9kN/m^3
	Minimum unit weight, γ_{dmin}	14.4 kN/m^3
Void Ratio(e) of Sand	Maximum void ratio (e_{max})	0.81
	Minimum void ratio (e_{min})	0.45
Dry Unit Weight Used (γ_d)	Loose state, γ_{dused}	15.3
Void Ratio Used (e)	Loose state (e_{used})	0.73
Friction Angle (ϕ^o)	Loose state	28.81°
Poissons Ratio (v)	Loose state	0.30
Modulus of Deformation (E_s, kN/m^2)	Loose state	10000

Table (2): Mechanical Properties of The Used Aluminum Alloy.

Property	Value
Modulus of Elasticity (GPa)	70
Minimum % of Elongation (e)	10
Assume Poisson's Ratio (v)	0.33

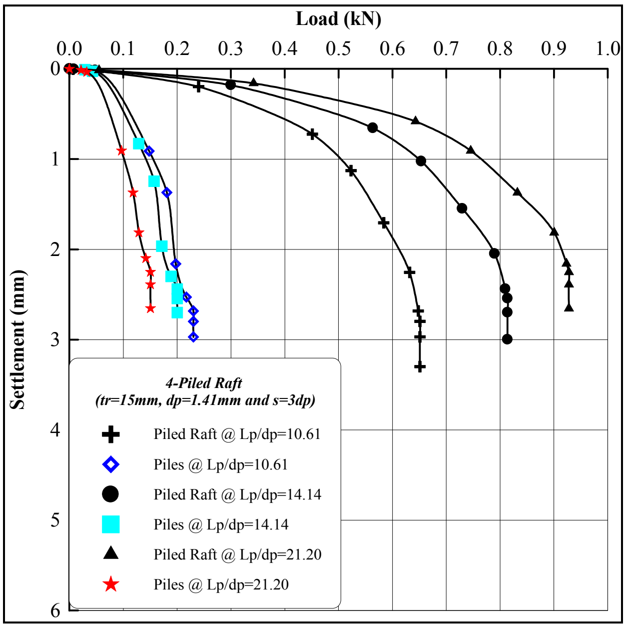

Figure (1): Load-Settlement curves for 4-Piled Raft.

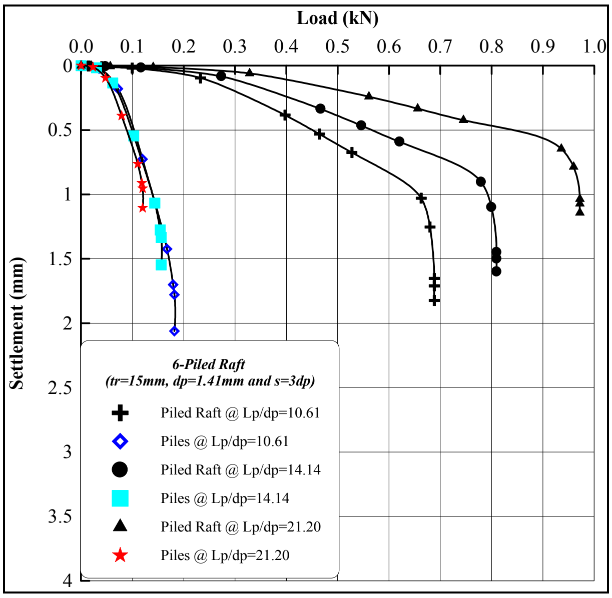

Figure (2): Load-Settlement curves for 6-Piled Raft.

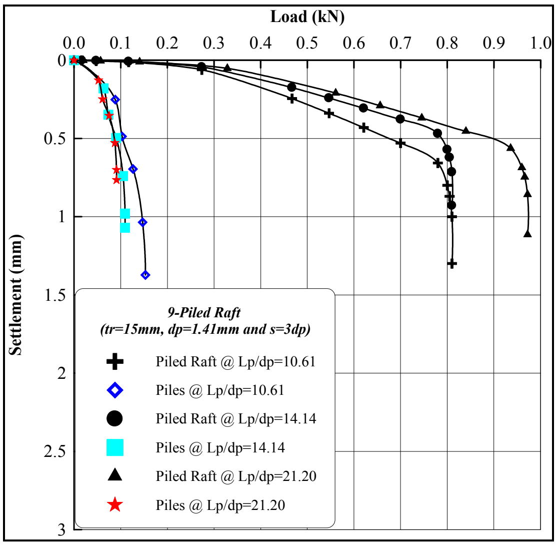

Figure (3): Load-Settlement curves.

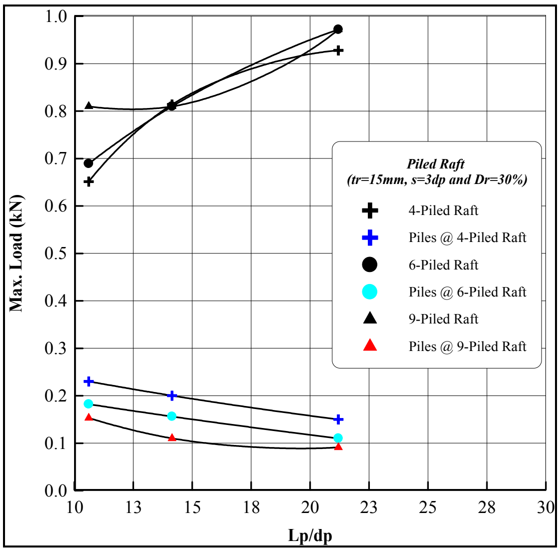

Figure (4): Max. Load- L_p/d_p Ratio Curves.

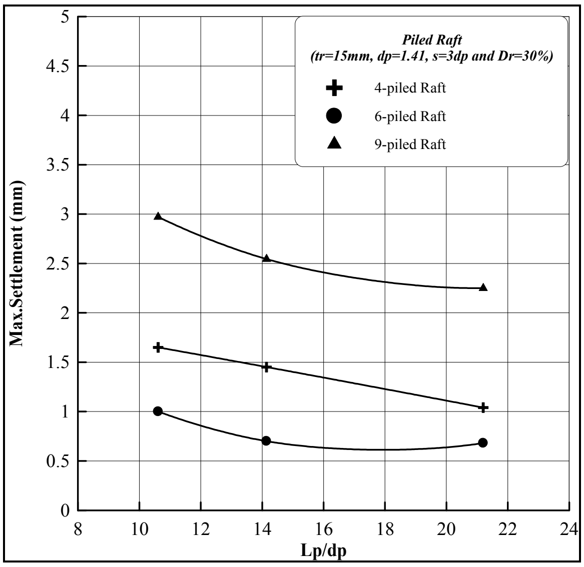

Figure (5): Max. Settlement L_p/d_p Ratio Curves

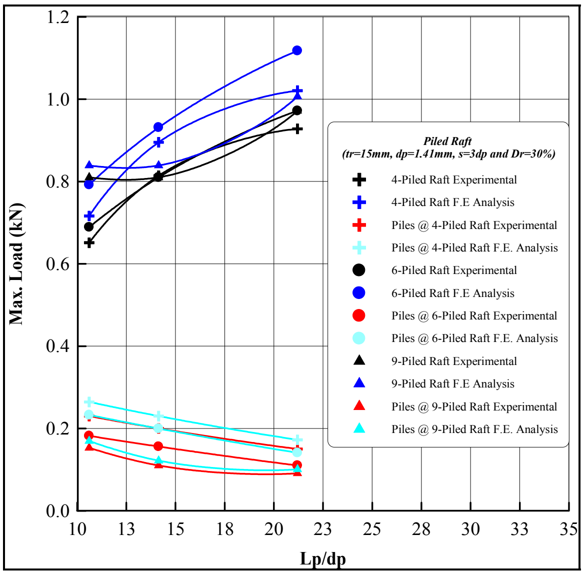

Figure (6): Comparison of Max. Load- L_p/d_p Ratio Curves.

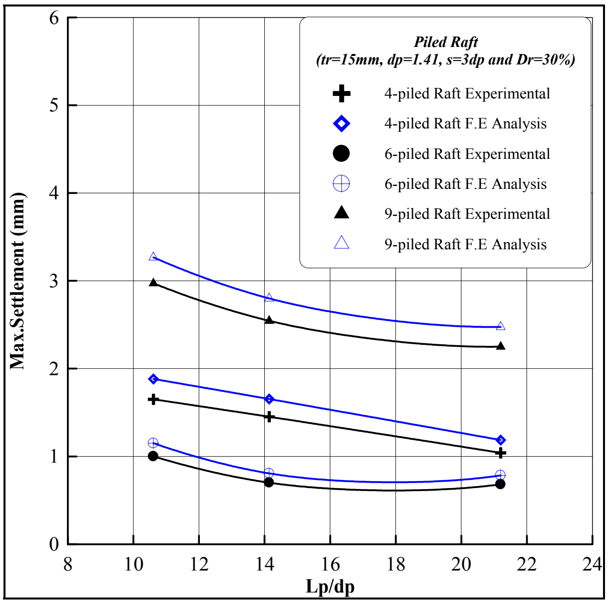

Figure (7): Comparison of Max. Settlement L_p/d_p Ratio Curves.

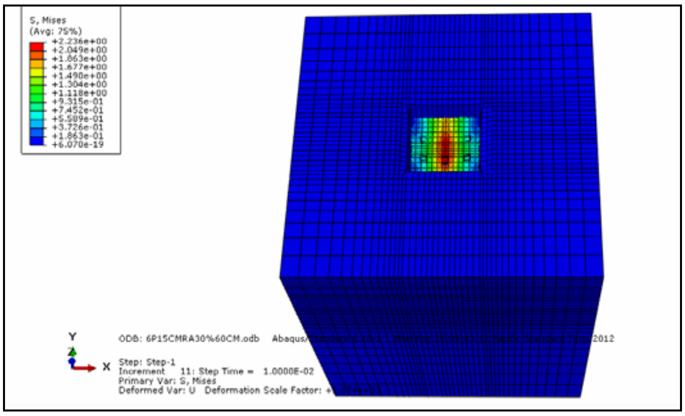

Figure (8): Three Dimensional Full Contours Mapping of Miss Stress

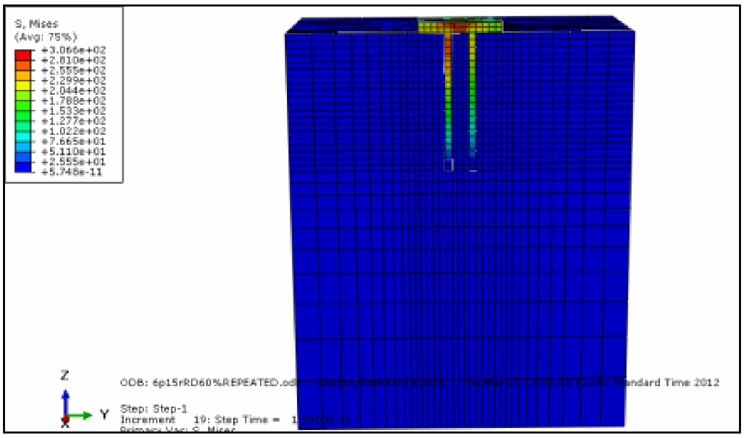

Figure (9): Three Dimensional Half

Contours Mapping of Miss Stress