ANALYSIS OF PILED-RAFT FOUNDATIONS FOR BURJ AL-AMIR IN A NAJAF CITY USING FINITE ELEMENT METHOD

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ABSTRACT

This study describes the process of analysis of a piled raft foundation for a high rise residential building (Burj al-Amir) on the Najaf Sea in Iraq. Piled raft foundation is a foundation used, in which the total load coming from the super structure is transferred to the soil by a load sharing mechanism between raft and pile. The present study attempts to do a three dimensional finite element analysis of piled raft foundation subjected to vertical load using PLAXIS program. Various tests are done to explore soil properties, also parametric study to find effect the piled raft dimensions include pile spacing, number of piles, pile diameters, pile lengths for pile groups, raft thickness and raft dimension ratio (L/B) on piled raft foundation behavior are considered.

It has been found that the maximum settlement of the piled rafts depends on the pile spacing and the number of piles..

The maximum bending moment in raft increases with increase raft thickness, decrease pile number and decrease in pile length. Maximum and differential settlement decreases with increase raft thickness and uniform increase in pile length.

In the scope of this study, the results of the parametric study are presented and design strategies for piled rafts are discussed.

KEYWORDS: **Raft foundation, Piles, Analysis of foundation, Finite Element Method.**

تحليل الاساس الحصيري المستند الى ركائز لبرج الامير في مدينة النجف باستخدام طريقة العناصر المحددة

سهاد عبد الستار حسن المحبوبي

كلية الهندسة في جامعة الكوفة

الخلاصة

هذه الدراسة توضح عملية تحليل اساس برج سكني عالي الارتفاع اقترح تسميته ببرج الأمير في منطقة بحر النجف في العراق. نوع الأساس المستخدم في التصميم هو الاساس الحصيري المستند الى ركائز (Piled Raft Foundation)، والذي ينتقل الحمل من خلاله الى للتربة عن طريق تقاسم الحمل بين الاساس

الحصيري والركيزة. هذه الدراسة اعتمدت طريقة التحليل باستخدام العناصر المحدودة الثلاثية الأبعاد لنوع الاساس المستخدم عند تعرضه للأحمال الرأسيه باستخدام برنامج PLAXIS. وقد تم اجراء مجموعه من الفحوصات المختبريه لإيجاد خصائص تربة الموقع، وأيضا تم اجراء تحليل نظري لإيجاد تأثير أبعاد ألأساس والذي يشمل تباعد الركائز وعددها وأقطارها وتأثير اطوالها، اضافة الى دراسة تأثير ابعاد الاساس الحصيري على سلوك الاساس المستخدم.
وقد وجد أن القيمه العظمى لعزم الانحناء بالأساس الحصيري المستخدم تزداد بزيادة سمكه ونقصان عدد الركائز، والنقصان في طول الركيزة كما وجد ان القيمة العظمى والتفاضلية للهبوط تقل بزيادة سمك الاساس الحصيري. والزيادة المنتظمة في طول الركيزة.

مفاتيح الدلالة: **اساس حصيرة، ركائز، تحليل الاساس، طريقة العناصر المحددة.**

LIST OF SYMBOLES

The major symbols used in the text are listed below:

Gs = Specific Gravity of Soil

γ_{max} = Maximum Unit Weights

γ_{min} = Minimum Unit Weights

γ_{dmax} = Maximum Dry Unit Weights

k = Coefficient of Permeability

e_o = Initial Void Ratio

C_c = Coefficient of Curvature

c = Cohesion

φ = Friction Angle

B = Width of Raft

L = Length of Raft

E_s = Young's Modulus of Soil

E_p = Young's Modulus of Pile

E_r = Young's Modulus of Raft

υ_s = Poisson's Ratio of Soil

υ_p = Poisson's Ratio of Pile

υ_r = Poisson's Ratio of Raft

q = The Intensity of Loading

n = Number of Pile

d_p = Pile Diameter

L_p = Pile Length

tr = Raft Thickness

S = Pile Spacing

L/B = Raft Dimension Ratio

1. INTRODUCTION

Piled foundation is an old method to improve the load capacity and reduce the settlements for a raft foundation in areas with insufficient soil. The main purpose of this method is to transfer the load by the piles to firm rock or stiffer soil, i.e. further down in the ground. In conventional design of piled foundation, all loads are designed to be transferred via the piles to the soil. Hence, neglecting the pressure, which could be, transferred from the raft directly to the soil by contact pressure. In the last decades geotechnical engineers have started to design piled foundation more optimized by allowing a part of the pressure to transfer directly from the raft to the ground. Such a foundation, where the raft and the piles interact to transfer the loads to the ground is called piled raft foundation or piled raft.

Piled raft foundations have a complex soil-structure interaction. In this research the method for analysis of piled raft foundation are three dimensional finite element method 3D Foundation Plaxis.

The objective of this research is to develop a numerical method for the analysis of piled rafts foundation.

2. REVIEW OF SIGNIFICANT RELATED WORKS

The finite element method is one of the most powerful tools for the analysis of piled rafts. It requires the dissertation of both the structural foundation system and the soil. An early example of the analysis of a piled raft (the Hyde Park Barracks) was given by Hooper (1973), in which an ax symmetric model with eight nodded isoperimetric elements was used. In the analysis, approximation of the equivalent stiffness of the pile group was made such that each concentric row of piles was modeled by a continuous annulus with an overall stiffness that was equivalent to the sum of the stiffness's of the individual piles. Chow and Teh (1991) presented a numerical method to examine the behavior of a rigid piled raft embedded in a non-homogeneous soil. Liu and Novak (1991) employed the finite element method to examine the behavior of a raft supported by a single pile at the centre. Wiesner (1991) presented a method for the analysis of a circular piled raft that was constructed in Cairns. The raft was treated as a thin elastic plate and modeled by rectangular plate bending finite elements. Clancy, P. and Randolph, M. F. (1993) designed approach for piled raft foundations for tall buildings. Smith and Wang (1998) proposed the use of iterative techniques with the finite element method to examine the behavior of a non-uniformly loaded piled raft. Prakoso and Kulhawy (2001) analyzed piled raft foundations by the use of linear elastic and non-linear plane strain finite element models which involved the analysis of a three dimensional piled raft as a two-dimensional strip piled raft. Fioravante and Jamiolkowski (2005) performed centrifuge tests on models of a rigid circular piled raft in over consolidated clay and found that the load distribution within a pile group under a rigid raft, in the working load range, is not uniform and is consistent with the prediction of a linear–elastic analysis.

3. RESULTS OF EXPERIMENTAL WORKS AND PARAMETRIC STUDY

3.1 Soil Tests

An experimental testing program was conducted to determine the behavior of piled raft foundation installed in sand. Sieve analysis for the sand soil carried out and a grain size distribution curve was obtained as shown in Fig.(1) the grain size distribution is analyzed according to ASTM (D422-2001). Physical properties, shear strength and compressibility parameters are shown in Table (1).

3.2 Parametric Study

This part deals with detail 3D analysis of piled raft foundations for building in Najaf Sea reign using the PLAXIS program, one-layer soil model is adopted.

The numerical work is carried out on 3D PLAXIS analysis which 3D mesh is created by connecting the corners of the 2D triangular elements to the 15-nodded wedge elements, so that the size of the elements in *y*-direction is about equal to the average element size defined for the 2D mesh, Fig.(2) shows the applied three dimensional finite element mesh and Fig.(3) shows piled raft foundation model.

Extensive parametric studies were carried out with the variables pile spacing, number of piles, pile diameters, pile lengths for pile groups and raft thickness, raft dimension ratio (L/B) (B, L: the width and length of raft). The plane strain models are also simulated for the case of the variation in raft dimension ratio (L/B), Fig.(4) shows piled raft foundation model configuration.

Details of piled rafts and pile groups in this parametric study are described below:

3.2.1 *Effect of Pile Spacing*

A 5x5 pile group is analyzed with variable pile spacing of 4d, 5d, 6d, 7d, and 8d. (d is the diameter of the pile which is equal to 1m) at (Width x Length) of the raft is (20×20, 25×25, 30×30, 35×35, 40×40**)** m respectively. The pile length is 20m. The raft is 3m thickness and the loading q is 10, 20 and 30 MN/m^2. Fig.(5) shows the maximum settlement (the maximum settlement of the raft is always found to be at the centre). with pile spacing. Fig.(6) provides differential settlement (differential settlement is the difference in settlement values of the center point and the 4 corner points) and Fig.(7) the maximum bending moment. The maximum settlement increased when the pile spacing increased from 4d to 8d at the same loading condition, this rate of increase in maximum settlement reached to 195 mm when q is 30 MN/m^2 and pile spacing is 8d. The differential settlement is 14 mm when q is 10 MN/m^2 but it reached to 74 mm at q is 30 MN/m^2. When the pile spacing is 8d the bending moments are 56, 113 and 189 MNm/m width at q is 10, 20 and 30 MN/m^2.

3.2.2 *Effect of Number of Piles*

A 5x5, 6x6 and 7x7 pile groups are analyzed with pile spacing varied from 8, 7 to 6d, the diameter of the piles d is 1m and the pile length is constant as 20m when the raft dimension are (40x40x3) m raft. The results are presented in Fig.(8) and Fig.(9). The increase in the number of piles doesn't have a lot of effect on maximum settlement when q is 10 MN/m^2 but the effects are more at q is 30 MN/m^2 and when the number of piles increased from 25 to 36 and 36 to 49.

3.2.3 *Effect of Pile Diameter*

To examine the pile diameter effects, (40x40x3) m raft is analyzed with 5x5 piles and 8m pile spacing. The pile diameter varied from 0.6, 0.8 to 1m. In Fig.(10), shows that the differential settlement increased clearly at q equal to 20 and 30 MN/m^2 and when the pile diameters are 0.8 and 1.0 m.

3.2.4 *Effect of Raft Dimension Ratio*

If the (L/B) ratio of the raft is changed (40×40, 40×60, 40×80) m (Width x Length), the result is discussed when the raft thickness is 3m with 5x5 piles, 8m pile spacing, the diameter of the piles d is 1m and the pile length is 20m. Fig.(11) shows the maximum settlement increased clearly with the (L/B) ratio when the q value are 20 and 30 MN/m^2, also the bending moment decrease with increased in L/B ratio in Fig.(12).

3.2.5 *Effect of Raft Thickness*

A (40x40) m raft is analyzed with the raft thickness varied from 1,2,3 to 4m, 5x5 pile group. The pile spacing is 8m, the diameter of the piles is 1m and the pile length is 20m. In Fig.(13) the maximum settlement decrease slowly when raft thickness increased. In Fig.(14) the differential settlement values become more convergent when the value of raft thickness 4 m for all values of q.

3.2.6 *Effect of varying pile length*

Fig,(15),(16) and (17), shows the effect of varying the pile length (5,10,15,20) m, on the maximum settlement, the differential settlement and the maximum moment in the raft, As expected, the maximum settlement, differential settlement and maximum moment are decreased as pile length increased.

4. COMPARES THE COMPUTED RESULTS IN THIS RESEARCH WITH RESULTS OBTAINED FROM OTHER RESEARCH.

Variation of maximum positive bending moments, maximum settlement and differential settlement with raft thickness between computed results obtained from this research and the result computed from ELPLA program (M. Rabiei, 2005). In this parametric study the details of model properties are described in table (2), and are respectively illustrated on Figs. (18), (19) and (20). The values shown in the figures indicate that for both cases there is reasonably good agreement between the computed results in this research with the other results with difference not exceeding 5%.

5. CONCLUSIONS

In this research, three dimensional finite element method under plane strain condition was applied to investigate the piled-raft performance under one layer soil condition. The geotechnical parameters were obtained several in-situ tests. Based a series of case studies were conducted on piled raft foundation in sandy Najaf Sea soil condition. Although the examined piled raft conditions are limited, the following concluding remarks can be given:

1. The maximum settlement of the piled rafts depends on the pile spacing and the number of piles.

2. To reduce the maximum settlement of piled raft foundation, we need to increase the length of the piles but the differential settlement and the maximum bending moment in raft are not much effect by increasing the pile lengths.

3. The raft thickness has effect on the bending moments and differential settlement. The increase of raft thickness has much effect to decrease the differential settlement than its effect to decrease the maximum settlement.

4. The analysis indicates that thick rafts induce higher bending moments than thin rafts.

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Table (1): Physical properties, shear strength and compressibility parameters.

Property	Value	Type of test
Gs	**2.68**	**Specific Gravity of Soil**
γ_{max}	**15.7 kN/m3**	**Maximum Unit Weights**
γ_{min}	**13.8 kN/m3**	**Minimum Unit Weights**
γ_{dmax}	**17.9 kN/m3**	**Standard Compaction**
k	**1.75×10^{-4} cm/s**	**Coefficient of Permeability**
e_o	**0.61**	**One dimensional consolidation**
C_c	**0.51**	
c	**0**	**Direct Shear Tests**
φ	**39**	

Table (2): The model properties used in ELPLA program (M. Rabiei, 2005).

B = L	t_r	L_p	d_p
20 m	0.7 m	10 m	1 m

E_s	E_p=E_r	υ_s	$\upsilon_p = \upsilon_r$
20 Mpa	30000 Mpa	0.3	0.2

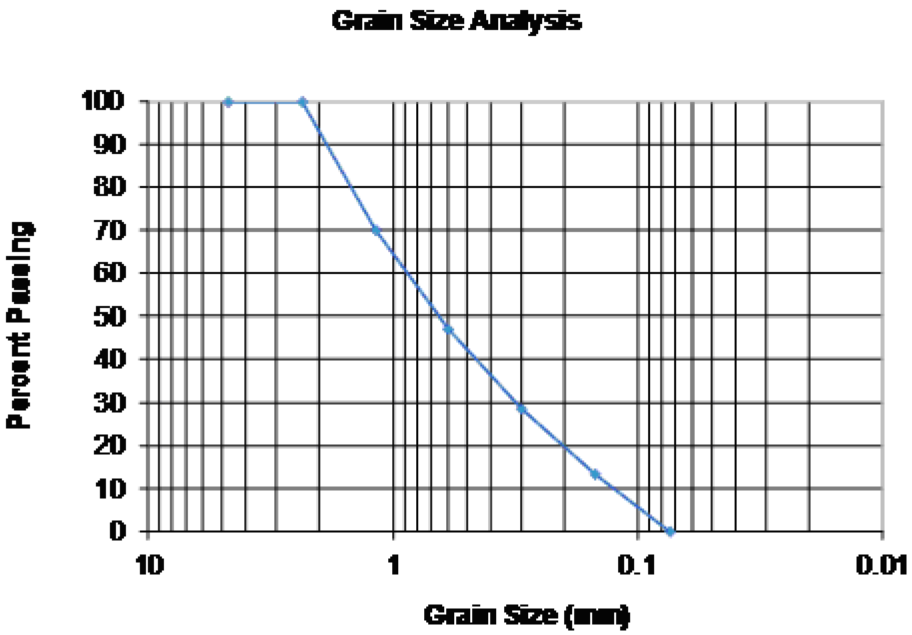

Figure (1): grain size distribution curve. ASTM (D422-2001).

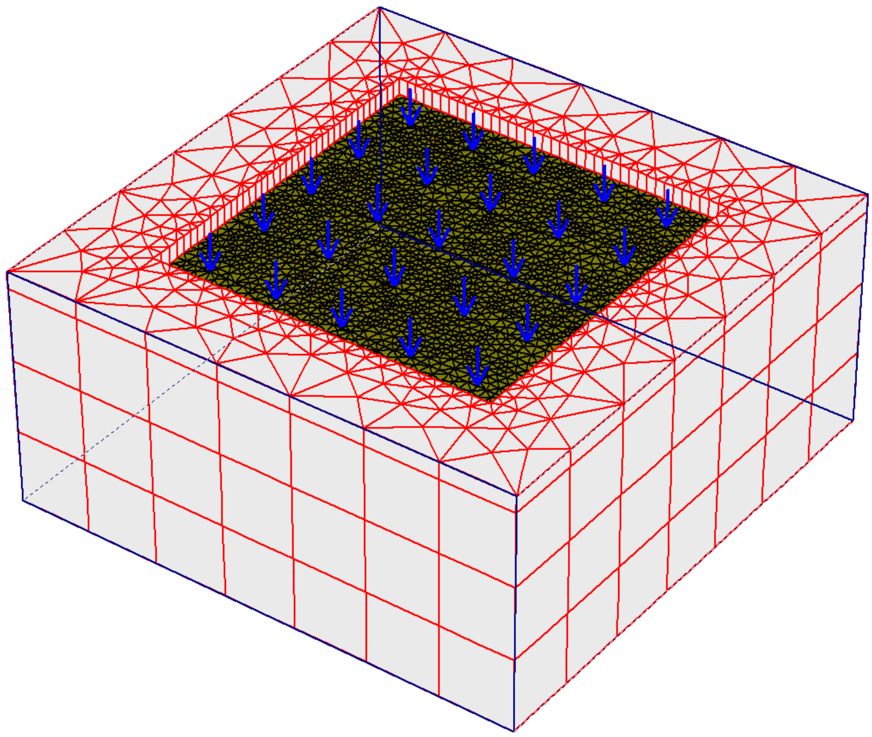

Figure (2): 3D FE-model to the building foundation.

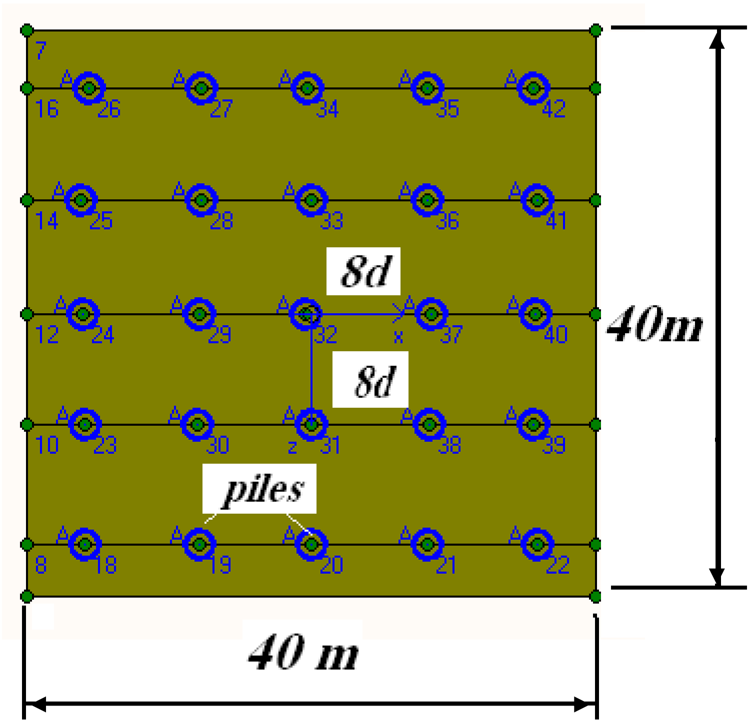

Figure (3): piled raft foundation model.

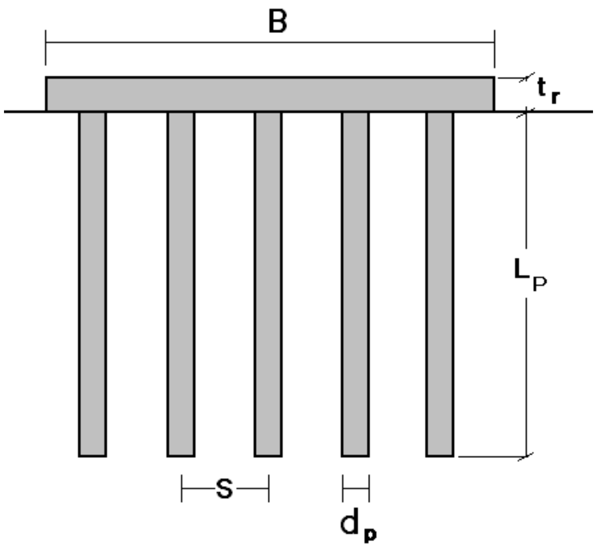

Figure (4): model configuration.

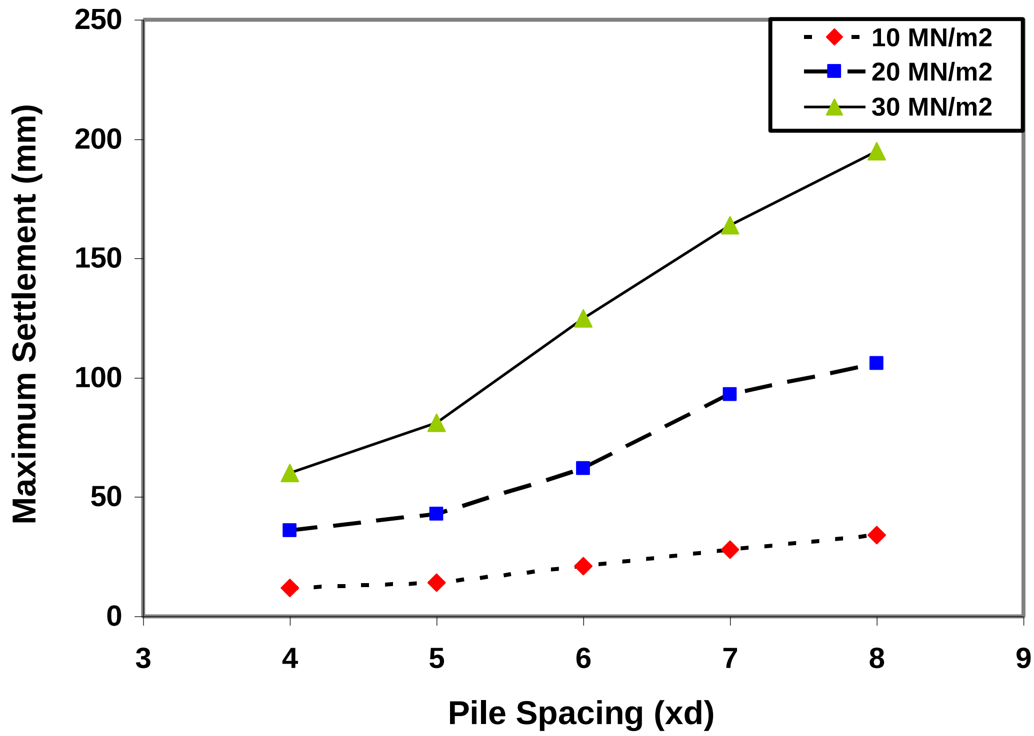

Figure (5): shows the relation between the maximum settlement at center of pile raft with pile spacing.

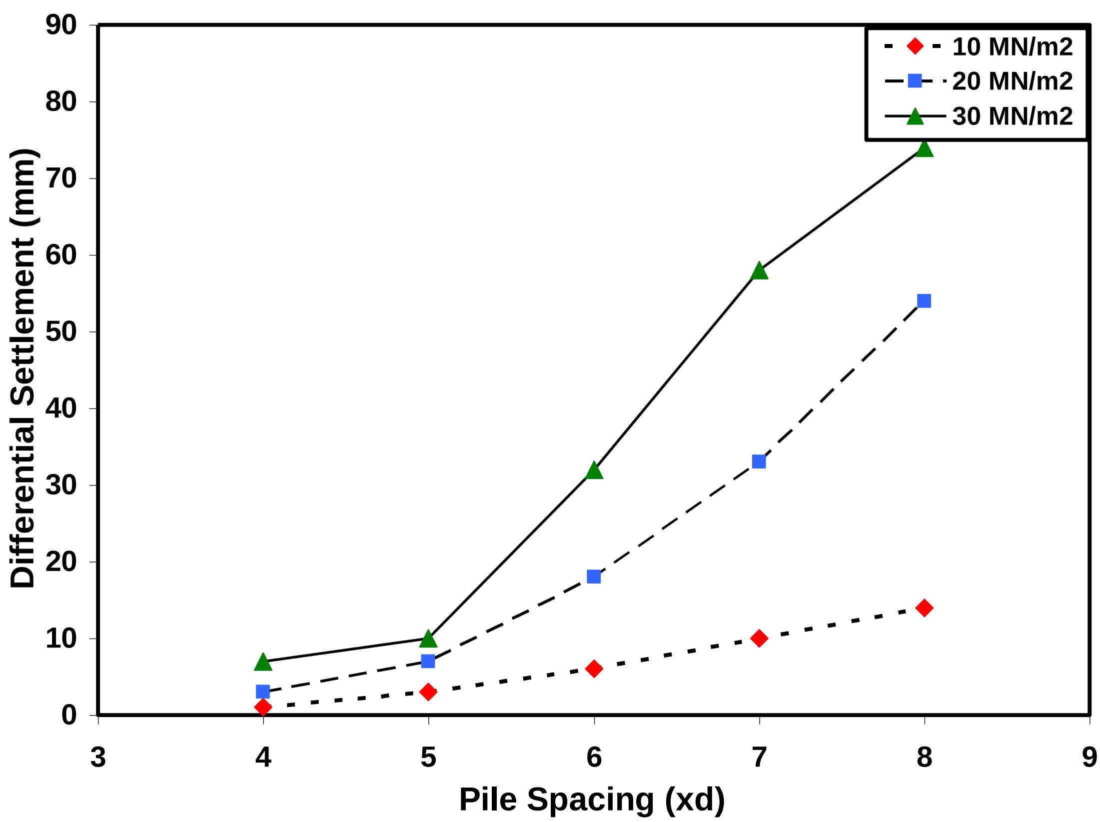

Figure (6): shows the relation between the differential settlement with pile spacing.

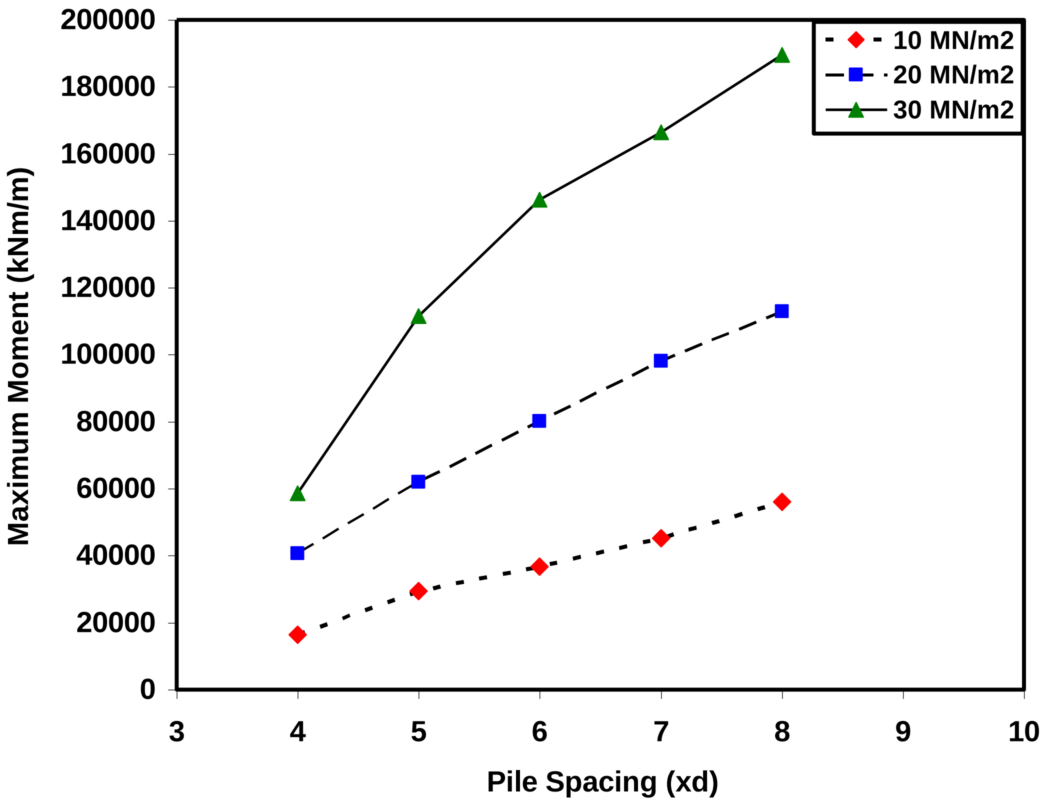

Figure (7): shows the relation between the maximum moment with pile spacing.

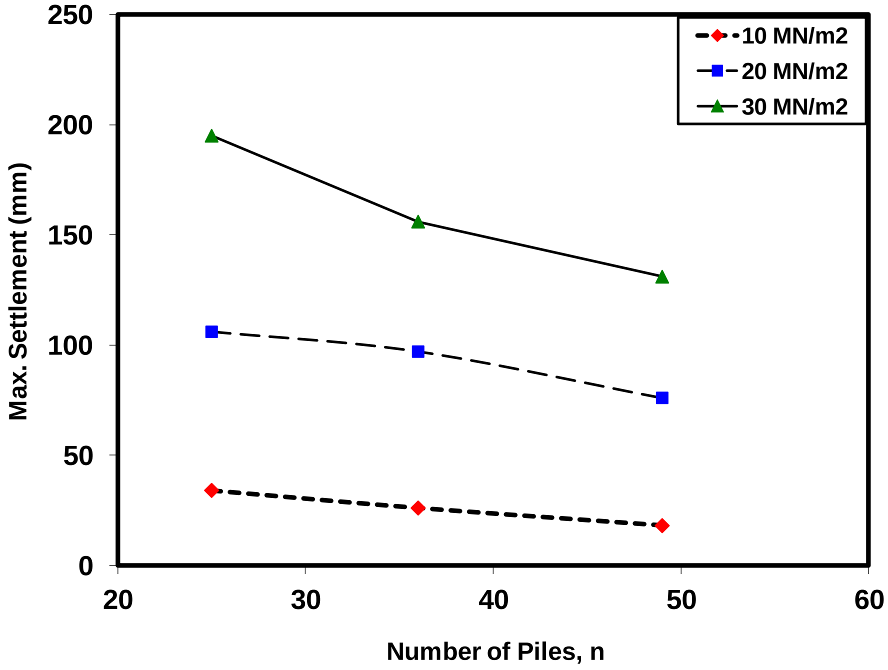

Figure (8): shows the relation between the maximum settlement at center of pile raft with no. of pile.

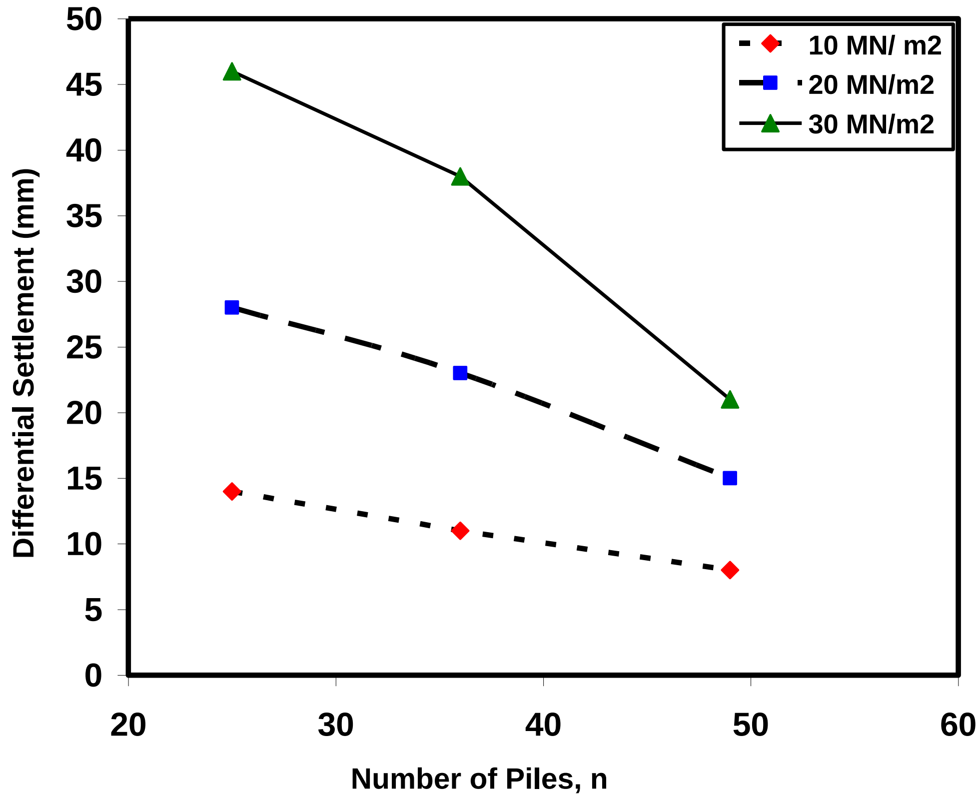

Figure (9): shows the relation between the differential settlement with no. of pile.

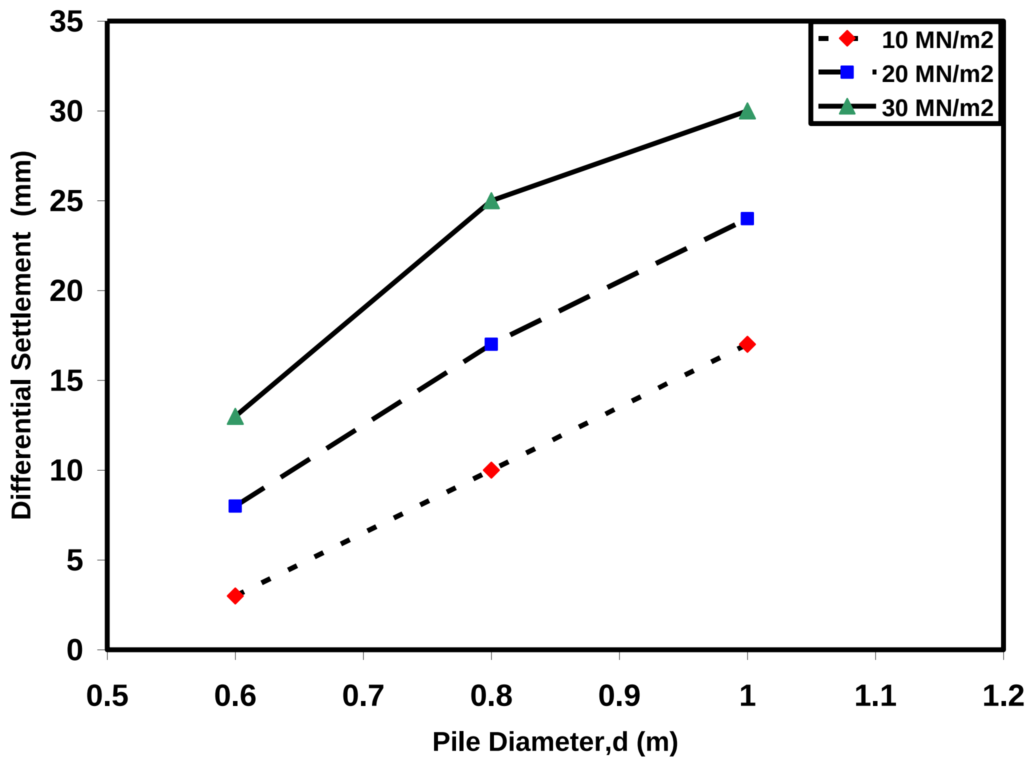

Figure (10): shows the relation between the differential settlement with pile diameter.

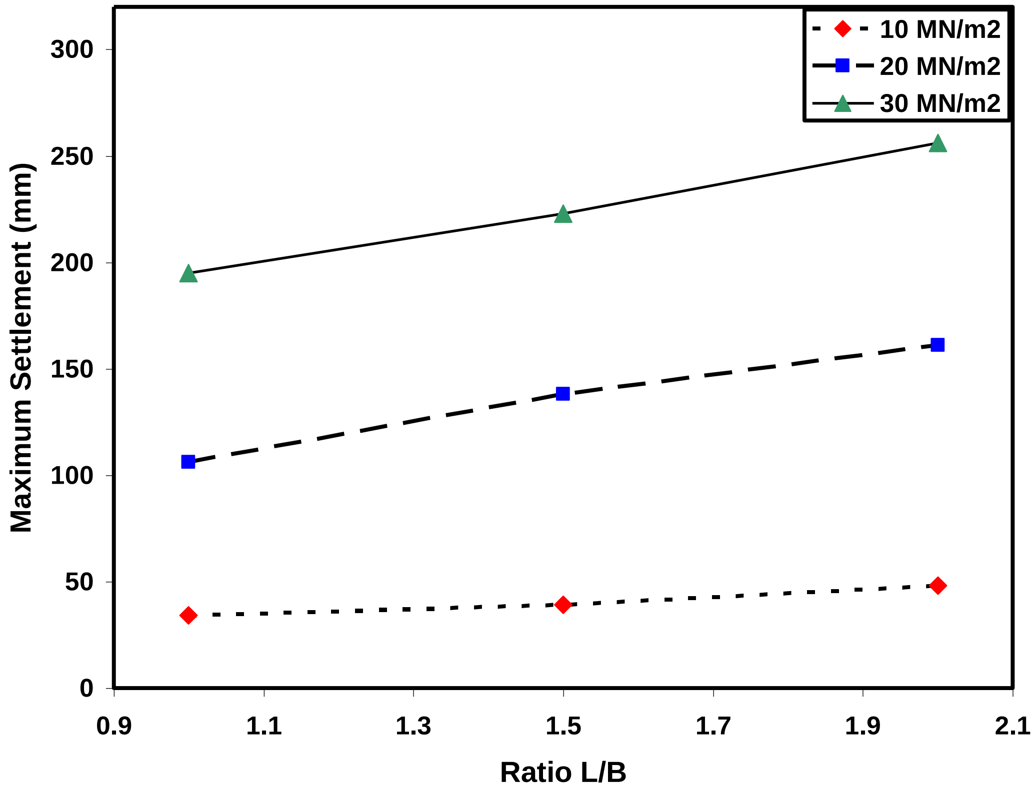

Figure (11): shows the relation between the maximum settlement at center of pile raft with raft dimension ratio.

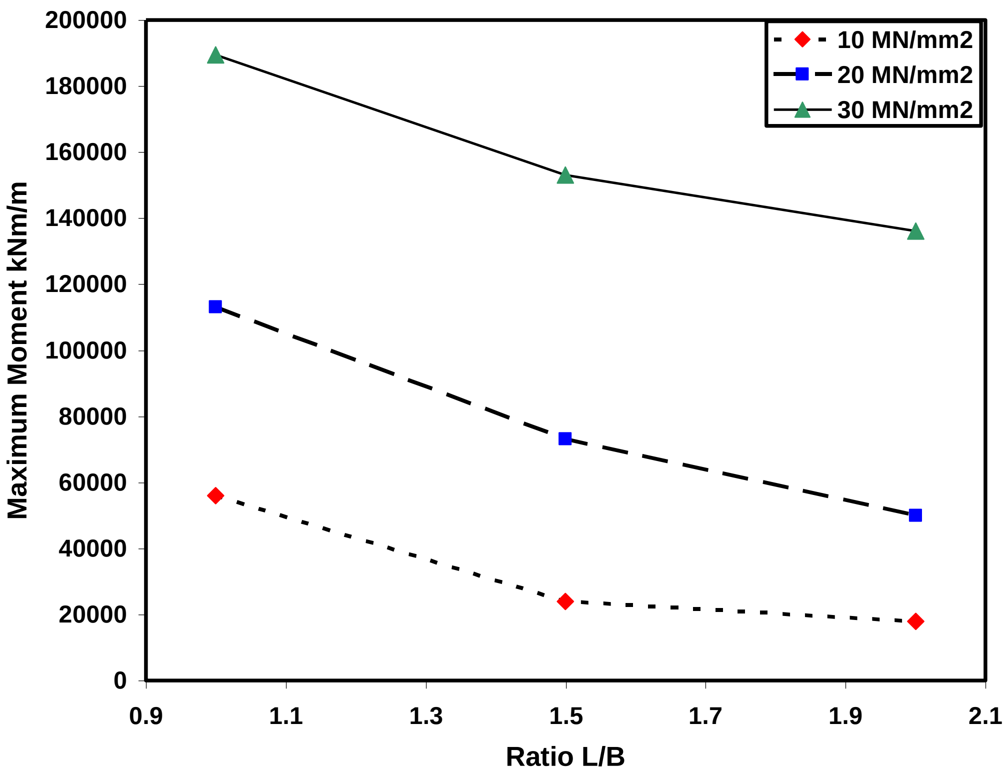

Figure (12): shows the relation between the maximum moment with raft dimension ratio.

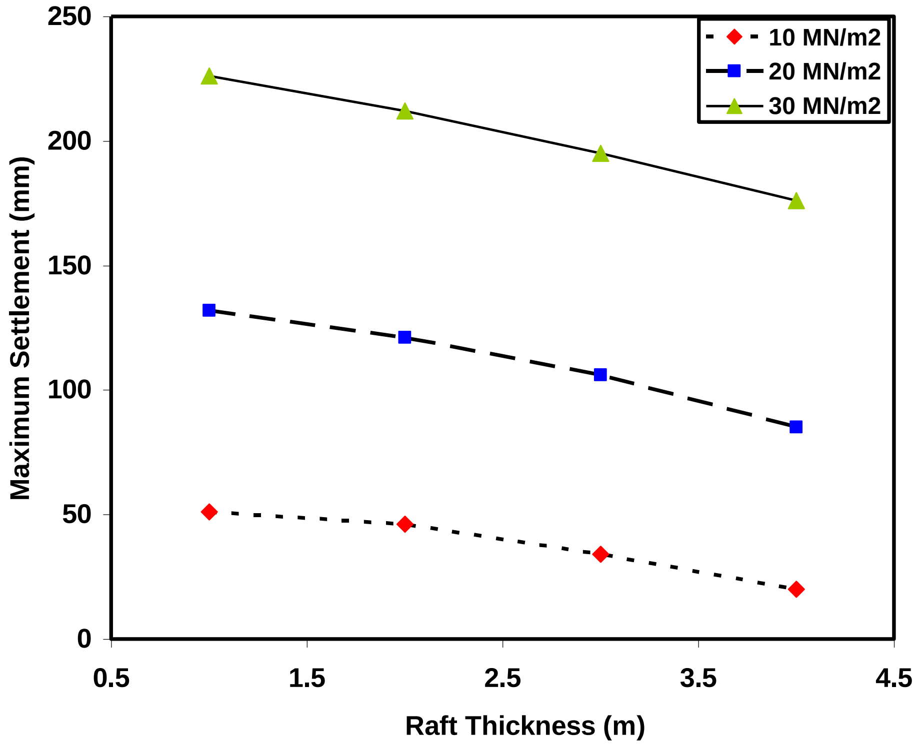

Figure (13): shows the relation between the maximum settlement at center of pile raft with raft thickness.

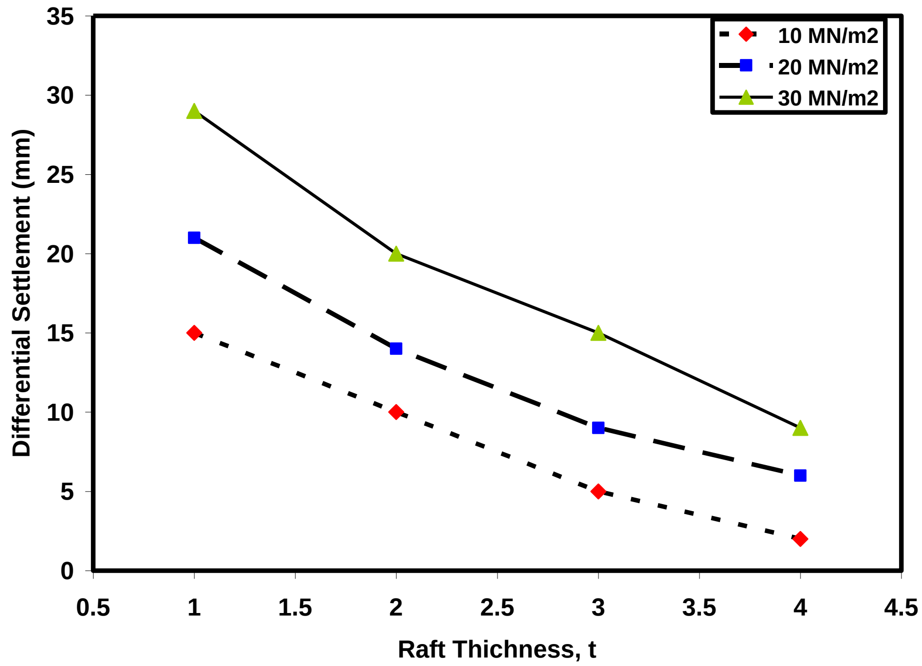

Figure (14): shows the relation between the differential settlement with raft thickness.

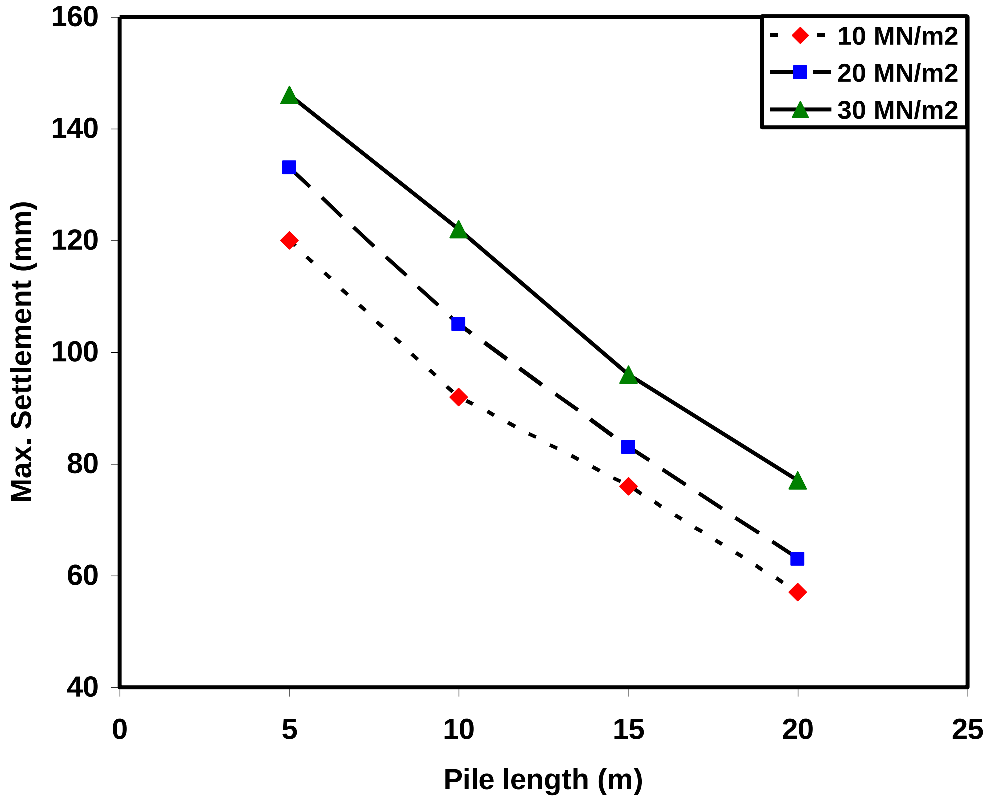

Figure (15): shows the relation between the maximum settlement at center of pile raft with pile length.

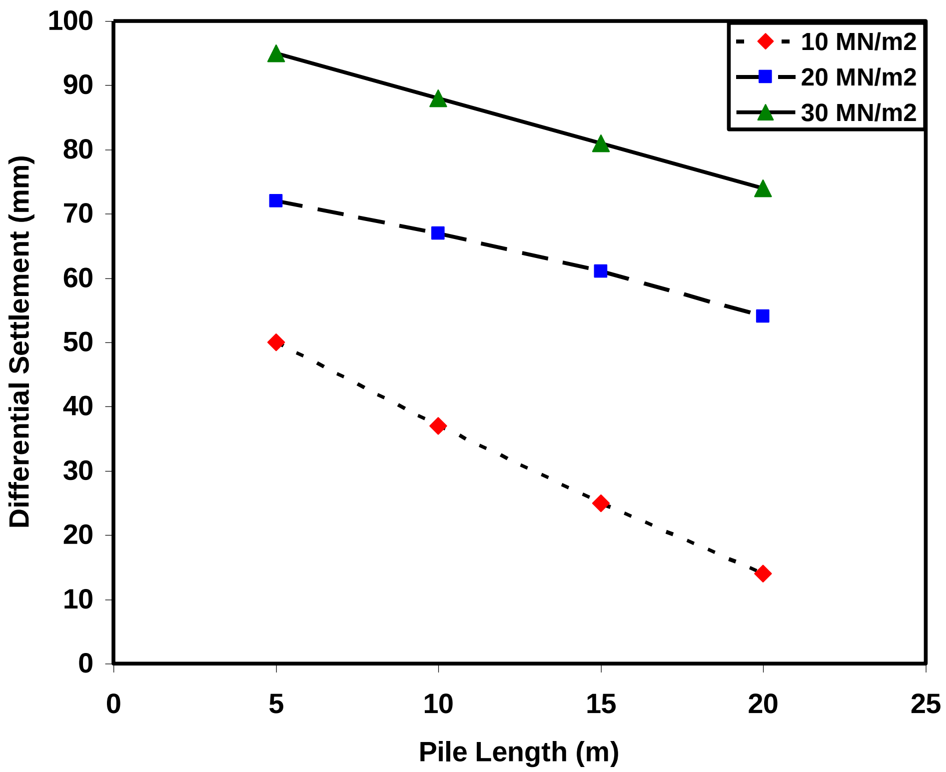

Figure (16): shows the relation between the differential settlement with pile length.

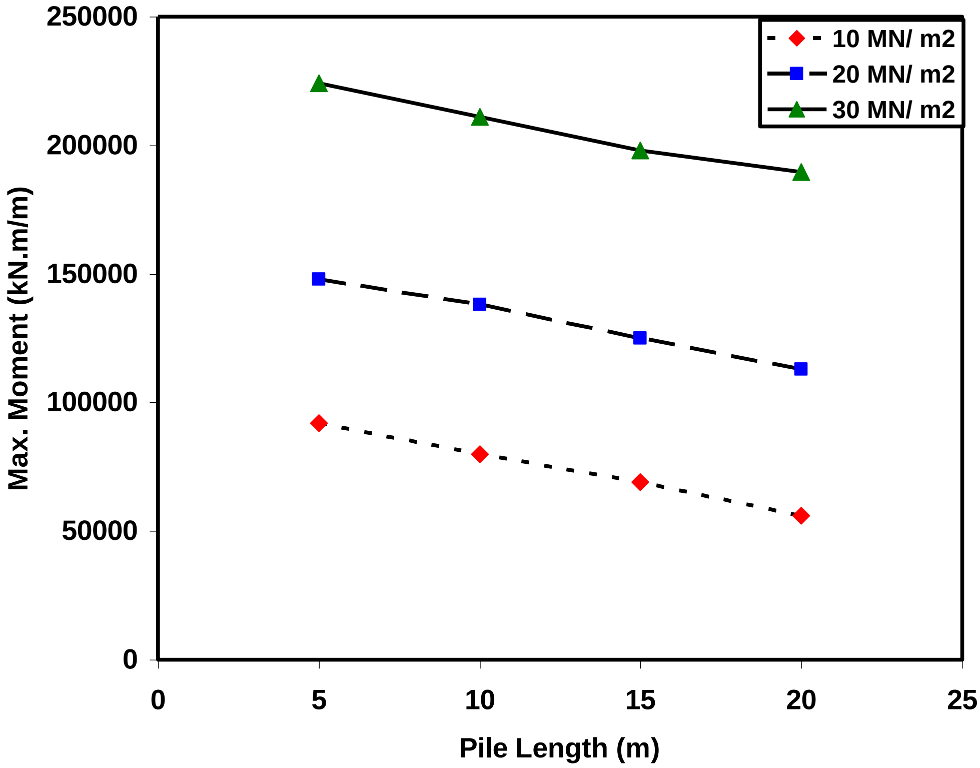

Figure (17): shows the relation between the maximum moment with pile length.

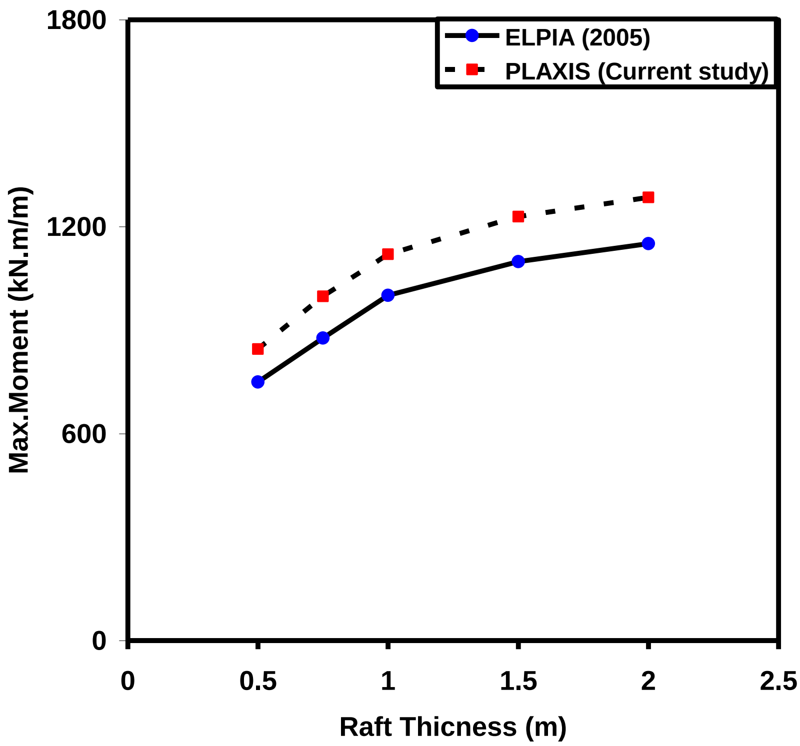

Figure (18): shows the effect of raft thickness on maximum moment.

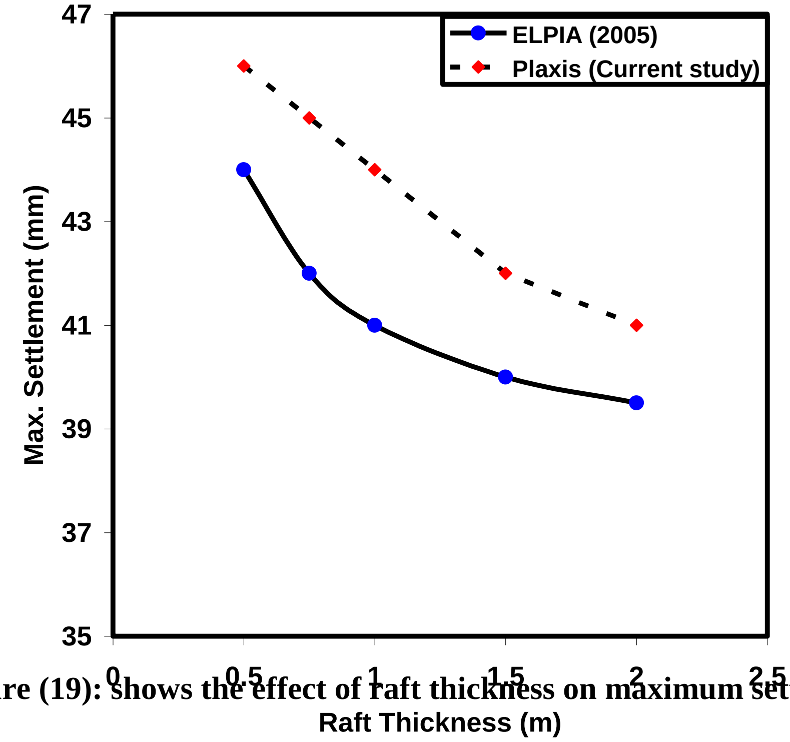

Figure (19): shows the effect of raft thickness on maximum settlement.

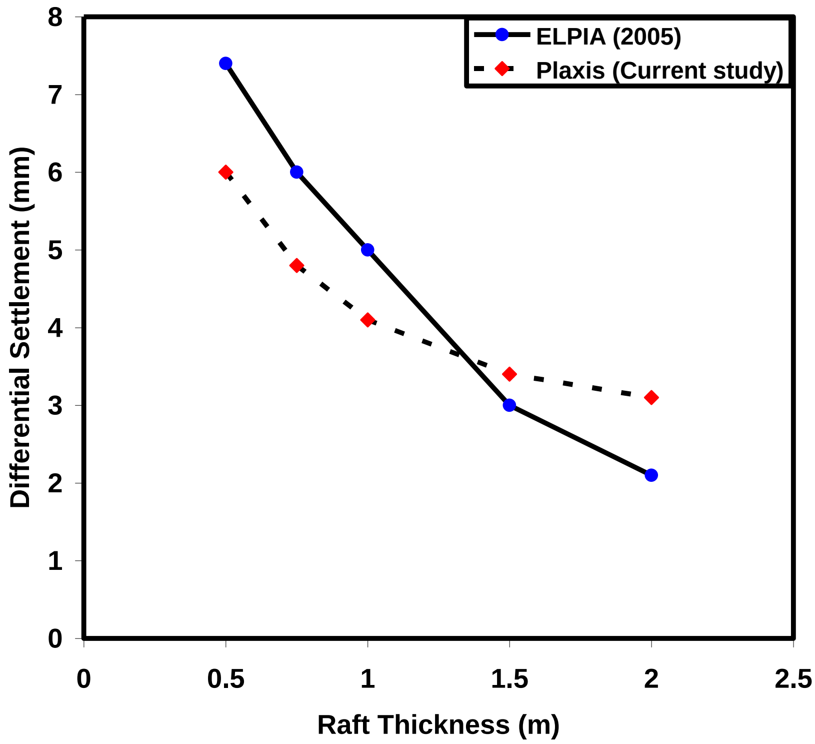

Figure (20): shows the effect of raft thickness on differential settlement.