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Design of the Piled Raft Foundations for Load Settlement Behavior using a Multiphase Model

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Abstract: The piled raft is a geotechnical composite construction consisting of three elements: piles, raft and soil. In the design of piled rafts, the load will be shared between the piles and the raft. Therefore, the piled raft foundation allows an increase in the load capacity and reduction of settlements in a very economic way as compared with the some traditional foundation concepts. With development of structures by using piled rafts as foundation system, an extensive research work has been performed considering different factors and conditions. This thesis presents combinations of numerical studies by (ABAQUS) to investigate the behavior of piled raft system in soils under different conditions. The settlement was measured at the center of the models of piled raft with (single, two, three, four) piles. A numerical modeling is used to verify the same problem of (mudhafar kareem hameedi. Thesis, experimental and theoretical for piled raft foundation in soft clay (2005)) model and analyze two models for the same previous configurations, the results show an agreement. The effect of number of piles, spacing between piles, Elastic of modulus and raft size on the load carrying capacity of the piled raft system and the load carrying capacity of the raft piles was studied, and the load-settlement presentation is included.

Keywords: ABAQUS, Piled Raft.

I. INTRODUCTION

Raft and pile groups are the two alternative foundation options to support structures with heavy column loads. Raft is normally designed as rigid in order to withstand high moment and differential settlement, which is a function of intensity of load and relative stiffness of raft and soil. In the case of pile groups more number of piles is provided than required to cater the column load and to practically eliminate the settlement, which makes the foundation to be very expensive. The concept of pile raft was conceived and introduced about three decades back to overcome the difficulties stated above as well as for the effective utilization of the pile group.

A. Piled Raft Foundations

A piled raft foundation (Fig.1), in the past few years, there has been on increasing recognition that that the use of piles to reduce raft settlement and differential settlement. The total load coming from the superstructure is partly carried by the raft through contact with soil and the remaining load is carried by piles through skin friction and base bearing. Such piled raft foundations on thick clay deposit have been found successful in places like coastal belt of Frankfurt, London, etc. In conventional piled foundation it is assumed that the raft does not carry any load even if raft is in contact with ground. Also in conventional piled foundation, as the contribution of raft is ignored, long piles are provided which extends up to the deep strata. On the other hand, if only raft has to carry the total load coming from the superstructure, very thick raft is needed which increase the cost of the foundation (Franke, 1991). Such raft foundation undergoes excessive settlement. So in such condition the piled raft foundation can be considered the best solution in which shorter piles and raft of lesser thickness can be provided (Yamashita et al, 1994)

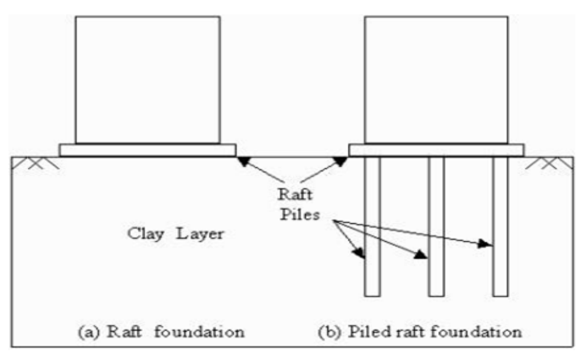


Fig.1. Piled raft foundation (Maharaj, 2003).

On the basis of the design requirements to be satisfied, Russo and Viggiani (1998) grouped piled rafts into two broad categories.

1. Small piled rafts: i.e., those in which the bearing capacity of the unpiled raft is insufficient, and thus the primary reason to add the piles is to achieve a suitable safety factor. The width of the raft B_r, belonging to this category, is generally small in comparison to the length L of the piles (B_r /L<1) and amounts to a few meters. The flexural stiffness of the raft is usually high and the differential settlement does not represent a problem.

2.Large piled rafts; i.e., those in which the bearing capacity is sufficient to carry the total load with a reasonable margin, so that the addition of piles is usually intended to reduce settlement. In general, the width B_r of the raft is relatively large in comparison with the length of the piles (B_r /L>1).

B. Aim of the Thesis

This research highlights on the percentage ratio of the bearing loads between the piles and the pile cap (Raft). The finite element method through ABAQUS program and experimental work is adopted to evaluate the effect of parameter on the load-settlement behavior of the piled raft foundation. This parameter is the scale factor effect on the load – settlement behavior of pile raft foundation.

C. Layout of the Study

This study is divided into seven chapters; the first one is introductory chapter. Chapter Two involves a summary of the analysis methods and gives a brief historical background of the previous studies concerning experimental and theoretical work on the problem of behavior of the piled raft foundation. Chapter Three is devoted to present the experimental setup used for modeling the pile, raft and piled raft system in the laboratory, properties of the model piled rafts and modeled clay soil. Chapter Four presents the computer package (ABAQUS) used for analyzing the raft, pile and piled raft foundation by using finite element method. The pile, raft, and the soil are presented as three-dimensional linear finite elements; the soil is modeled as elastic- perfectly plastic solid. Chapter Five includes presentation of results of experimental work and numerical model using (ABAQUS). Chapter Six includes conclusions and recommendation for further works.

II. REVIEW OF LITERATURE

A. Introduction

This chapter will review the available methods used for analysis of raft, pile group and combined piled raft foundation (CPRF).The footing can be considered first for minor structures as a raft. The pile foundation is normally used when constructing a heavy building on a low bearing. The use of a composite foundation becomes a very popular in recent years. This composite foundation (which is called a piled raft foundation) consists of a spread foundation, usually a raft foundation, and a comparatively few number of piles (Figure 2). In the case of a piled raft foundation, the load bearing mechanism is fairly complex because the load is transmitted to the ground through the raft and piles. In foundation design, rafts, pile groups and piled rafts are commonly used to support structures. Extensive research work had been carried out and published in the last decades and different analysis methods had been developed that can be classified into several categories: empirical, analytical, experimental work and numerical methods. In this chapter, a brief review of the techniques developed for the analysis of raft, pile group and piled raft foundations are presented.

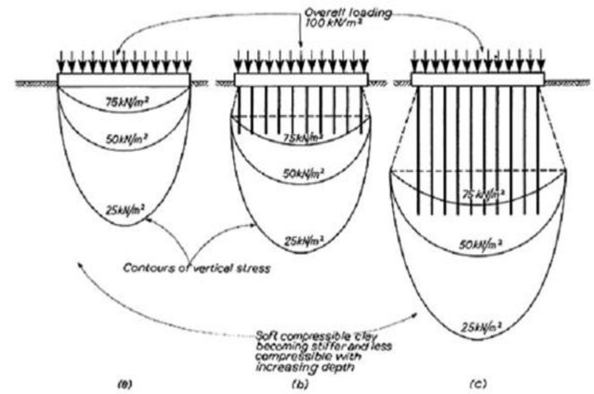


Fig.2. Piled raft foundation (Tomlinson, 2004).

B. Load – Settlement Behavior of Piled Raft Foundation

Figure (3) illustrates, conceptually, the load-settlement behavior of piled rafts designed according to various design philosophies as follows (Poulos et al, 2001).

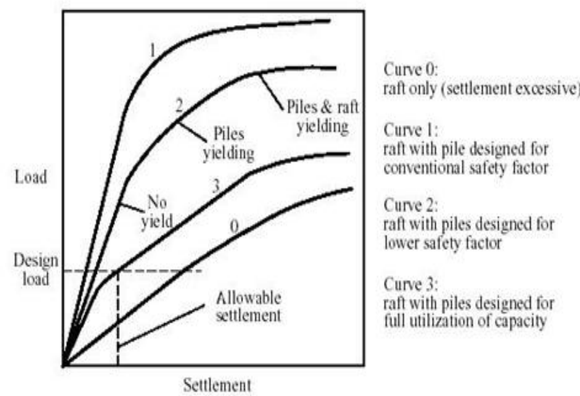


Fig3. Load settlement curves for piled rafts according to various design philosophies (Poulos et al. 2001).

Curve 0: shows the behavior of the raft alone, which in this case settles excessively at the load design.

Curve 1: represents the conventional design philosophy in which the behavior of the pile-raft system is governed by the pile group behavior, and which may be largely linear at the design load. In this case, the piles take the great majority of the load.

Curve 2: represents the case of creep piling where the piles operate at a lower factor of safety, but because there are fewer piles the raft carries more load than that in Curve 1.

Curve 3: illustrates the strategy of using the piles as settlement reducers, and utilizing the full capacity of the piles at the design load. Consequently, the load-settlement may be nonlinear at the design load, but nevertheless, the overall foundation system has an adequate margin of safety and the settlement criterion is satisfied. Therefore, the design depicted by Curve 3 is acceptable and is likely to be considerably more economical than the designs depicted by Curves 1 and 2.

C. Analysis Methods of Piled Raft Foundations

The methods used for the analysis of piled raft foundation are broadly classified into three classes (Poulos et al. 1997):

1. Simplified calculation methods.
2. Approximate computer-based methods.
3. More rigorous computer-based methods.

1. Simplified Analysis Method: **Poulos-Davis-Randolph (PDR) Method**

For assessing vertical bearing capacity of a piled raft foundation using simple approaches, the ultimate load capacity can generally be taken as the lesser of the following two values:

- The sum of the ultimate capacities of the raft plus all the piles
- The ultimate capacity of a block containing the piles and the raft, plus that of the portion of the raft outside the periphery of the piles.

For estimating the load-settlement behavior, an approach similar to that described by Poulos and Davis (1980) can be adopted. However, a useful extension to this method can be made by using the simple method of estimating the load sharing between the raft and the piles as outlined by Randolph (1994). The definition of the pile problem considered by Randolph is shown in Figure (4).

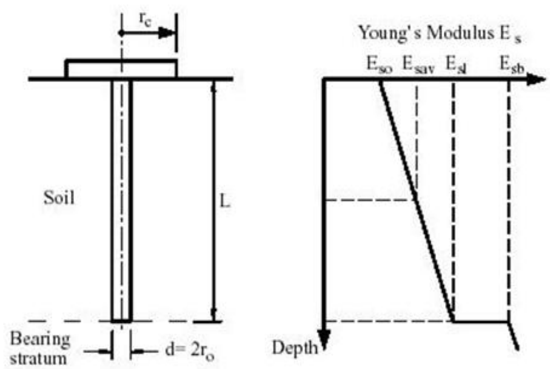


Fig4. Simplified representation of a pile-raft unit (Randolph, 1994). The above equations can be used to develop a tri-linear load-settlement.

Beyond point A in Figure (5), the stiffness of the foundation system belonged to the raft only (K_r) and this holds until the ultimate load capacity of the piled raft foundation system is reached at Point B. At this stage, the load-settlement relationship becomes horizontal. The load – settlement curves for a raft with various numbers of piles can be computed with the aid of a computer spreadsheet or a mathematical program such as MATHCAD. In this way, it is simple to compute the relationship between the number of piles and the average settlement of the foundation. Such calculations provide a rapid means of assessing whether the design philosophies for creep piling or full pile capacity utilization are likely to be feasible.

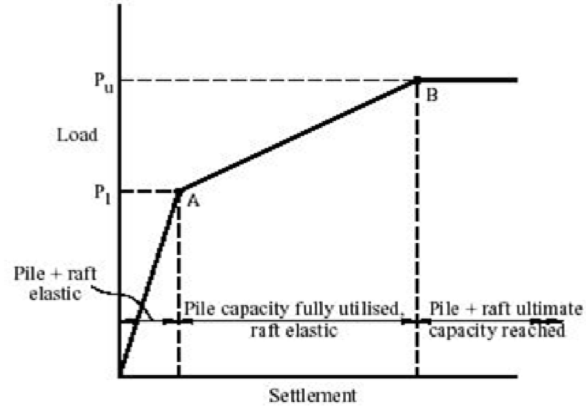


Fig5. Simplified load-settlement curve for the preliminary analysis (Poulos et al, 2001).

III. EXPERIMENTAL WORK

A. Introduction

Soil properties and raft piles of the experimental research implemented in this chapter are from mudhafar kareem hameedi. Thesis, experimental and theoretical for piled raft foundation in soft clay(2005),to study the load sharing mechanism between the raft and piles, as well as the load settlement behavior of the piled raft with different configurations. This chapter describes soil properties which used on (ABAQUS) for simulation

1. Set-up of the large scale model

The apparatus consists of compression machine steel container, loading frame, dial gauges, proving ring and accessories as follows:

Steel container: The large scale model is carried out in a tank manufactured of steel with dimensions of 70 cm × 70 cm and 50 cm depth, and the steel plate is 6mm in thickness as shown in Figure (6). The container is sufficiently rigid and exhibited no lateral deformation during the preparation of the soil bed and during the test. The internal sides of the tank are covered with polyethylene sheets in order to keep the water content of soil constant. The set–up of the small scale model consists of loading machine steel container with plastic sides which is manufactured by the researcher , l-loading frame with electric motor, digital indicator gauges, loading cell, monitor and accessories.

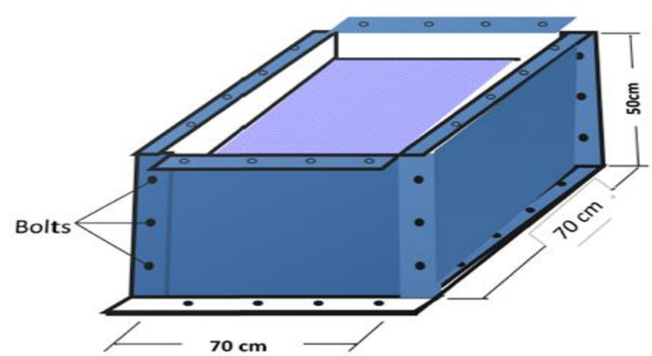


Fig6. Schematic of steel container Small scale model.

Plastic rigid container: The tests of the experimental small model are carried out in a container of steel frame with dimensions of 24 cm × 24cm and 24 cm depth, the plastic side of the container is 6 mm in thickness the container is sufficiently rigid and exhibited no lateral deformation during the preparation of the soil bed and during the test.

B. Models of Piled Raft

Pile casting was done by concrete mixture with mix ratio 1:1.5:2, the gravel gradation was (2-3.36) mm, w/c of 10% and the additive of (SP90) with 4% The model of piled raft foundation with different configurations have been done by making holes in a steel plate (raft) with diameters of 1.1 cm (for small scale model) and 2.6 cm (for large scale model) . Then, these holes were filled with epoxy for connection with piles. The model of the piles is concrete and with constant diameter and length.

Table 1: Properties the Pile and Raft

• Raft(steel plate)	
▪ Elasticity*	$2*10^8$ (KPa)
▪ Poisson's ratio*	0.33
• *Pile(concrete pile)*	
▪ *Elasticity***	*$2.9*10^5$ (KPa)*
▪ *Poisson's ratio**	*0.15*

TABLE II: Physical Properties of the Used Soil

Property	Value
Liquid limit (LL), %	42
Plastic limit (PL), %	21
Plasticity index (PI) , %	21
Specific gravity (G_S)	2.71
% Passing sieve No. 200	90
Sand content %	10
Silt content %	42
Clay content < 0.005 mm, %	48
Maximum dry unit weight kN/m^3	18.6
Optimum water content, %	18

The embedment length ratio L/DP = 16 the spacing(s) between piles is kept constant about 3 diameter of pile for large scale model, the length of model pile 40 cm and 2.5 cm diameter. The model of raft used is steel plate of size 15 cm×15 cm and thickness 1.2 cm, the ratio L/BR=2.66 where BR is the width of the raft and L is the length of embedment pile. For small scale model, the length of pile 16 cm and 1cm diameter the model of raft used is steel plate of size 6 cm×6cm and thickness 0.6 cm the ratio L/BR = 2.66 and ratio L/DP = 16 the spacing(s) between piles is kept constant 3 diameter of Pile. Table (1) shows the material parameters of the raft and pile.

C. Setup of the test of model

At the end of curing period, the following steps are followed in driving the pile to the specific depth in the soil bed for both models:

1. The top of the soil bed is leveled,
2. The pile model is driven by a hammer of 4 kg weight to a depth of 40 cm for large scale model to get L/DP ratio of (16). For small scale model, a hammer of 2 kg is used to drive the model of pile to a depth 16 cm to get L/DP ratio of (16),
3. Untrained shear strength and water contact are measured directly at three positions top, middle and bottom of the soil bed, and
4. The same procedure is used in piled raft with (single, two, three, four) piles
5. The models of the experimental work with different configurations of piles are shown in Figure (7).

Lr = 15cm length of raft
Br = 15 cm width of raft
tr = 1.2 cm thicknesses of raft
L=40 cm length of pile
Dp = 2.5 cm diameter of pile
S =7.5 cm spacing between piles

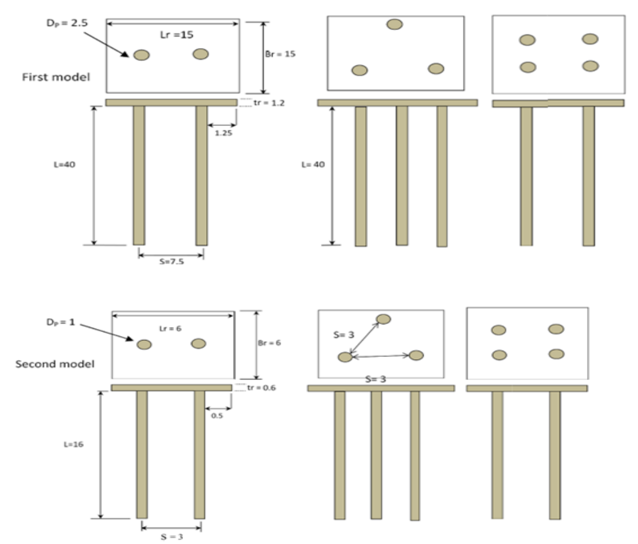


Fig7. Models of Piled raft for experimental work.

IV. FINITE ELEMENT METHOD AND PROGRAM

A. Introduction

The finite element method is one of the most popular numerical methods used for obtaining an approximate solution for complex problems in various fields of engineering. At the beginning, the method is developed as an extension of a matrix method for the analysis of structural engineering problems. However, later it has also been recognized as the most powerful method for analyzing problems in other fields of engineering, such as fluid mechanics, soil mechanics, rock mechanics, heat flow, etc. The generation of its application coupled with the availability of high-speed electronic digital computer has put the finite element method in a wide range of use.

B. Formulation of Finite Element Method

In the finite element method, a continuum is divided into a number of elements. Each element consists of a number of nodes, and each node has a number of degrees of freedom that correspond to discrete values of the unknowns in the boundary value problem to be solved. In the present case, the degrees of freedom correspond to the displacement components.

C. Overview of ABAQUS

ABAQUS is a suite of finite element analysis modules. The heart of ABAQUS is the analysis modules such as ABAQUS/Standard and ABAQUS/Explicit, which are complementary and integrated analysis tools.

- ABAQUS/Standard is a general-purpose, finite element module.
- ABAQUS/Explicit is an explicit dynamics finite element module.
- ABAQUS/CAE incorporates the analysis modules into a Complete ABAQUS
- Environment for modeling, managing, and monitoring ABAQUS analysis and visualizing results.

The finite element program we use in the FEA room is ABAQUS/CAE, which is an intuitive and consistent user interface throughout the system. Fig (8) shows the main user interface when entering ABAQUS/CAE.

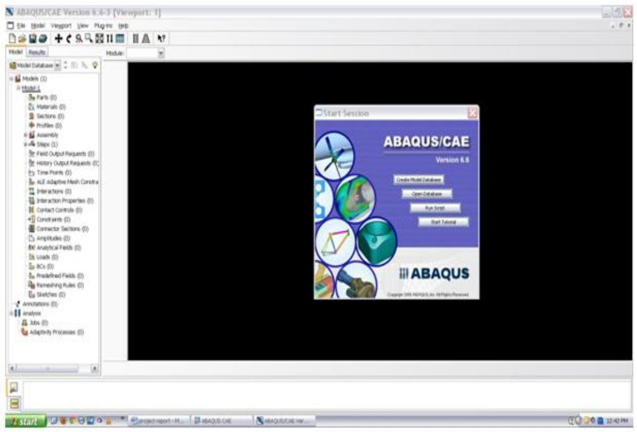


Fig8. ABAQUS/CAE Main User Interface.

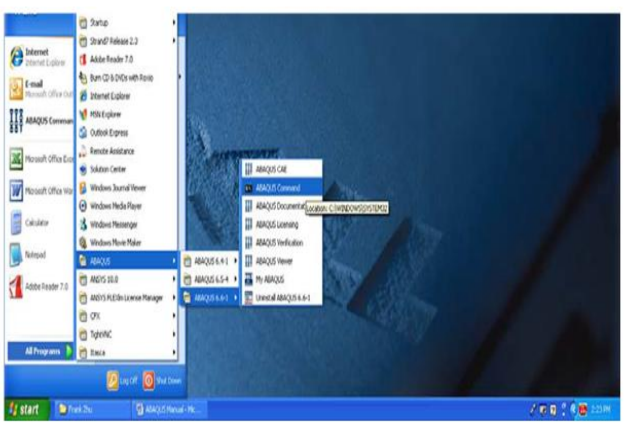


Fig 9. To enter ABAQUS CAE Main User Interface.

D. Launch and Exit ABAQUS

1. Steps to Launch ABAQUS

1. Click Start - All programs – ABAQUS - ABAQUS 6.6.3 - ABAQUS Command in Windows System.
2. An ABAQUS Command window appears in DOS environment see fig (9).
3. Use general commands in DOS system to move to your directory on the hard disk. For example, if you have created a file in catalogue C:\Temp named ABAQUS WORK and you want all your ABAQUS results be saved in this file, you can type command CD C:\Temp\ABAQUS WORK.
4. Run command ABAQUS CAE to enter ABAQUS/CAE user interface.

E. Create a Model

1. Defining the Model Geometry

1. Start ABAQUS/CAE, and enter the Part module by clicking Part – Create.

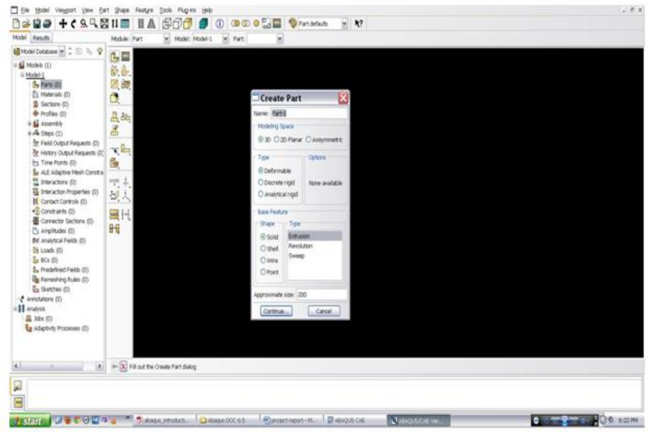


Fig10. To create part in ABAQUS CAE.

2. Choose the appropriate option for drawing a 2D model (fig 10).

2. Defining the Material Properties

In the Module selection, select and click Property to define the material and section properties (from fig 11 to 12).

Create Material: To define an elastic-plastic material

1. Click the button Create Material. The Edit Material dialog box turns up.
2. Enter the material name and choose the appropriate option for entering the properties of the material.
3. One or more materials can be added by choosing the appropriate name.

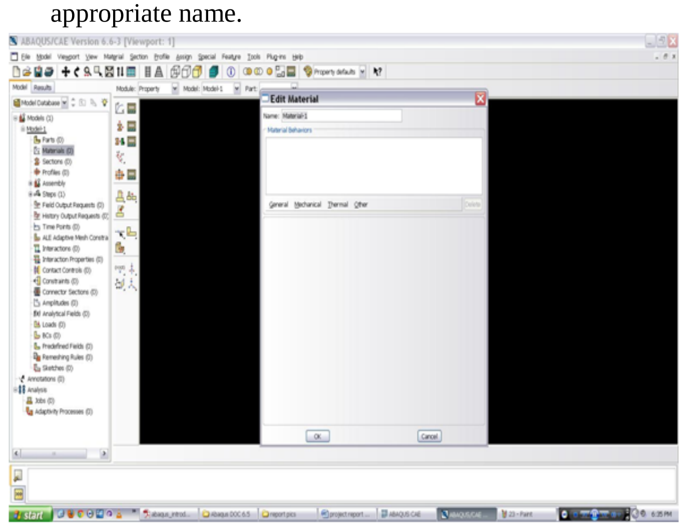


Fig11. To create material in ABAQUS CAE.

You should note that ABAQUS is numerical and hence it does not have default units. You need therefore to be consistent in using units when defining geometry, loads and material properties. In this example, we used mm as the unit of dimension in defining the geometry and presume the unit of load to be N, then the unit of stress and Young's modulus should be MPa.

3. Section Properties

Enter the section properties by selecting the appropriate option in category and type of material being used and press continue. Select the material created in material properties and continue. In section assignments, assign the material and section properties selected by selecting the material in the part created.

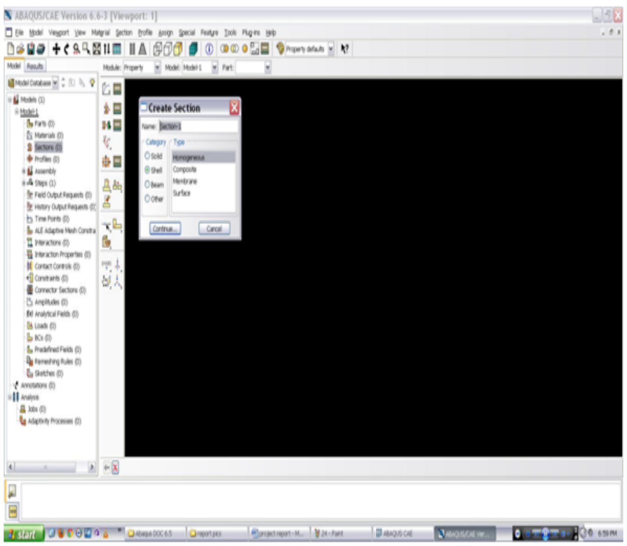


Fig12. To create section properties in ABAQUS CAE.

F. _ modeling

This study deals with the static structural analysis, which is use to determine deformation. For solving any problem by using ABAQUS program the processes consist of many steps (fig 13 to 18):

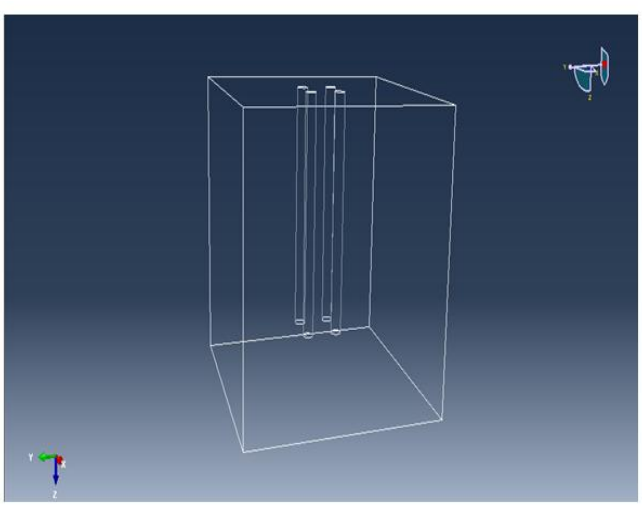


Fig13. Geometric shape of the solid model (soil).

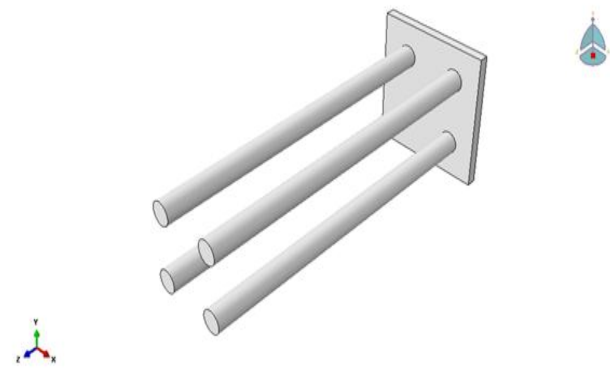


Fig14.Ggeometric shape of the solid model (pile raft).

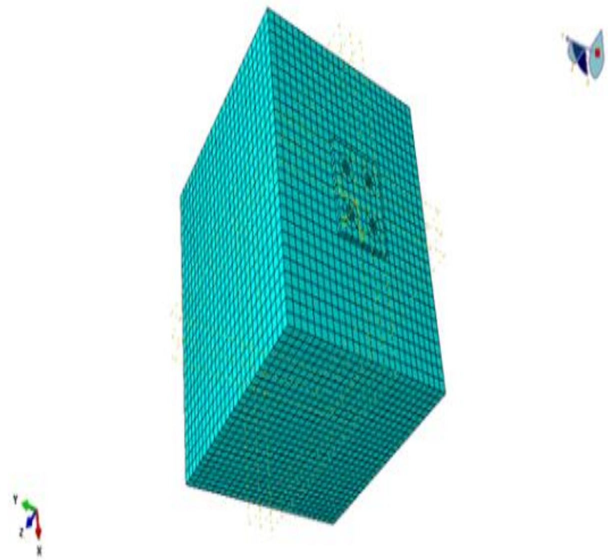


Fig 15: The finite element mesh for solid model.

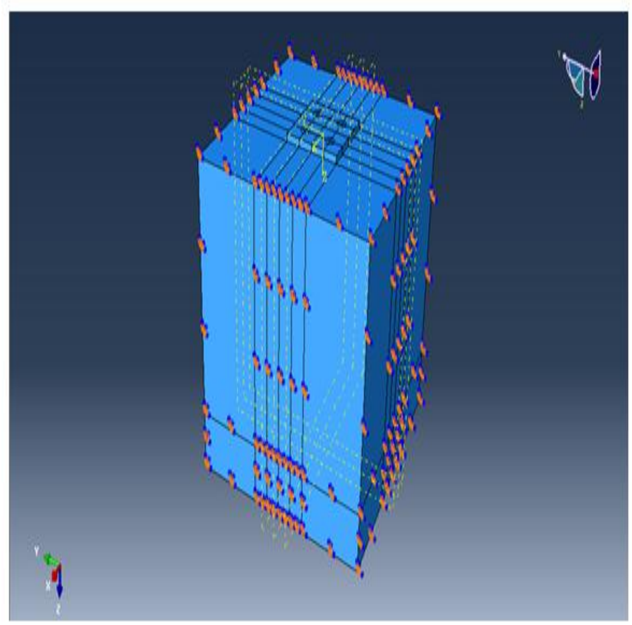


Fig 16: The application of boundary condition for solid model.

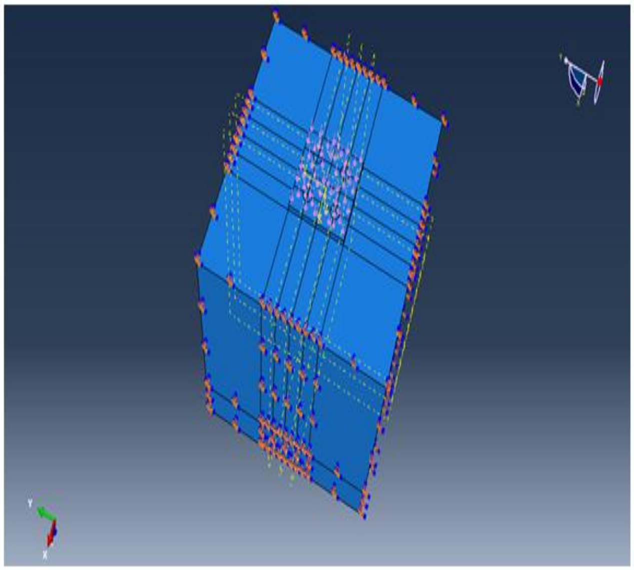


Fig17. The application of load for solid model.

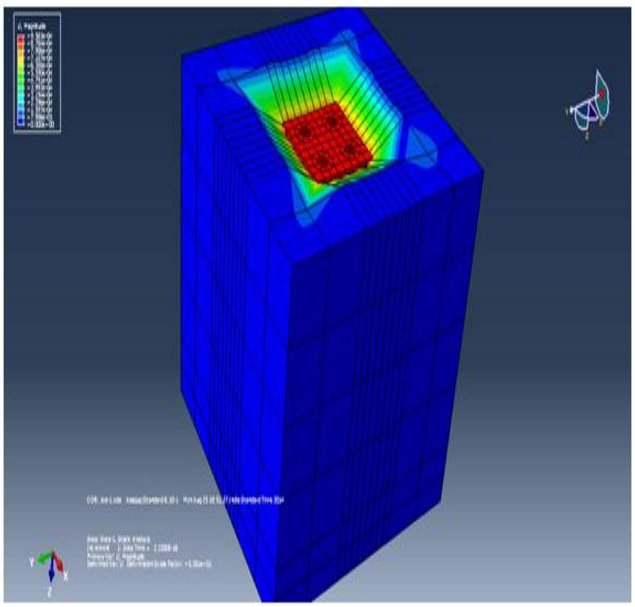


Fig18. Show the deformation in solid model Results and Discussion.

V. RESULTS AND DISCUSSION

In this chapter, the results of piled raft foundation analysis obtained from studying the effect of various parameters on the load- settlement behavior are presented. The analysis was performed using experimental work and the finite element analysis software (ABAQUS) The parameters chosen, for studying the effect on the load settlement behavior, are Elastic modulus, number of piles, and space between the piles

A. Selection of Failure Criterion and Type of Shear Failure

Several criteria have been proposed to define the failure load of the piles. Some of these criteria are described by Fellenius (2006) as follows: Terzaghi (1947) proposal, in which failure was defined as the load corresponding to displacement of 10% of the model footing width (or pile diameter), this criterion is used for both experimental models for the present work. De Beer (1967) proposal (as reported by Winterkorn and Fang, 1975). The bearing capacity is taken at break point of two interesting straight lines of different slopes after plotting the load-settlement relationship in log-log plot. This break point represents failure. Tangent proposal, in which definition of failure based on the intersection of the two tangents of load-settlement curve while the second is tangent to the lower flatter portion of the curve, this criterion is used for both numerical models for the present work. Both Terzaghi (1947) and Tangent proposals which have been used for failure criteria in the present work Three principal modes of shear failure may be defined in soil as:

1. General shear failure

This type of failure occurs when failure surface develops into one or both sides of the footing and extending from the edge of the footing to the ground surface. It is accompanied by sever tilling leading to a final collapse to one side, as shown in Figure (19).

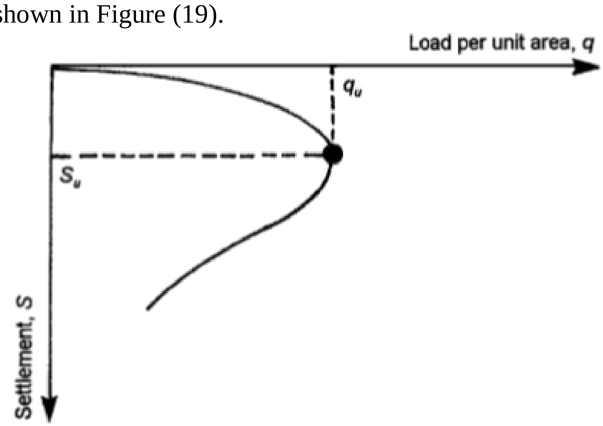


Fig19. General shear failure (Das.1999).

2. Local shear failure

In this case, the failure surfaces start at the edge of footing, but ends within the soil mass. Instead of meeting the surface, it accompanied by very little tilting, as shown the Figure (20).

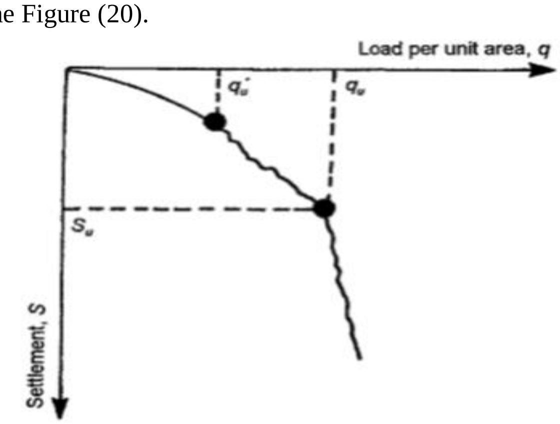


Fig20. Local shear failure (Das.1999).

It is accompanied by a vertical movement before any noticeable development of shear planes occurs, as shown Figure (21).

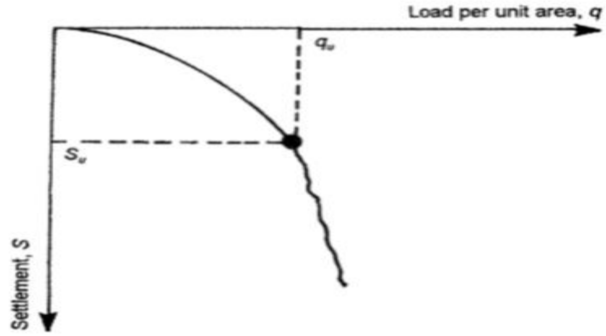
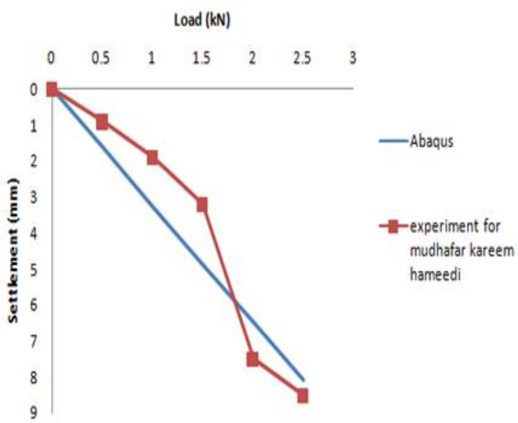


Fig.21: Punching shear failure (Das.1999).

B. The Results of the Experimental work and Numerical work

These results of experiment were for mudhafar kareem hameedi. Thesis, experimental and theoretical for piled raft foundation in soft clay (2005), the models of the work (raft size 6×6cm and 15×15cm) with different configurations of piles, this part of thesis make compare between (ABAQUS) and that experiment results

- Piled raft (single pile)
- Piled raft (two piles)
- Piled raft (three piles)
- Piled raft (four piles)



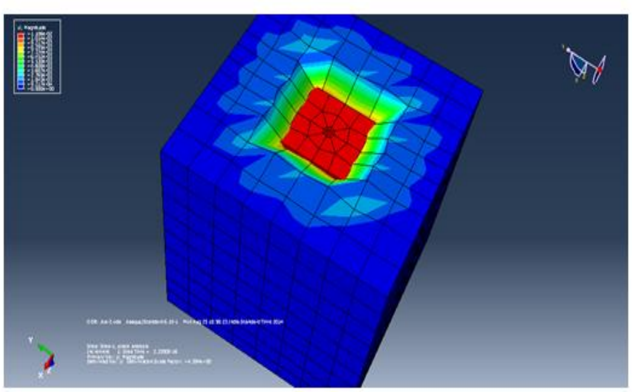
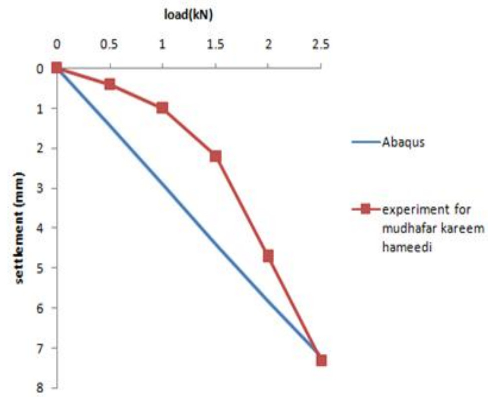


Fig22. Load–settlement curve for piled raft (single pile), for the first model.

The settlement versus vertical load is plotted for first and second models. Figures (22) to (26) show the load-settlement behavior of piled rafts of the first model. The raft size is (15×15cm) and thickness 1.2 cm as well as the load piled raft with (single, two, three, four) piles. The pile diameter (Dp) is (2.5 cm) and length (L) (40cm) with ratio of L/DP = 16.



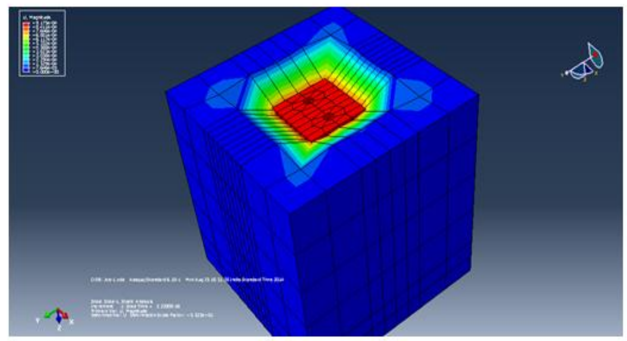
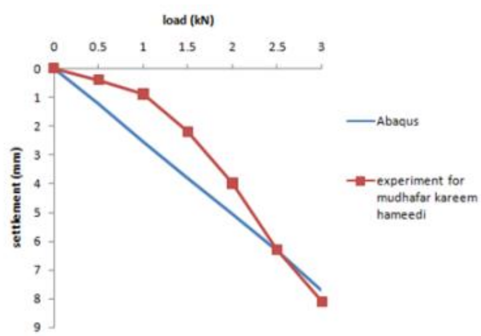


Fig23. Load – settlement curve for piled raft (two piles) of the first model.



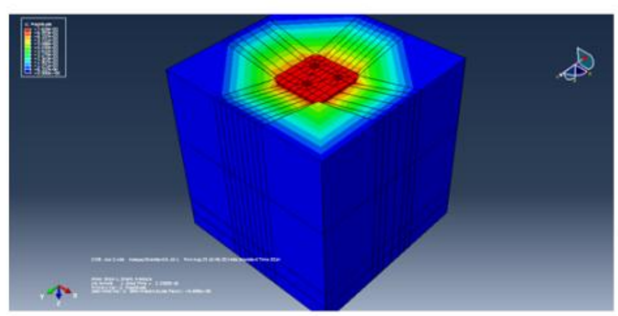


Fig24. Load – settlement curve for piled raft (three piles) of the first model.

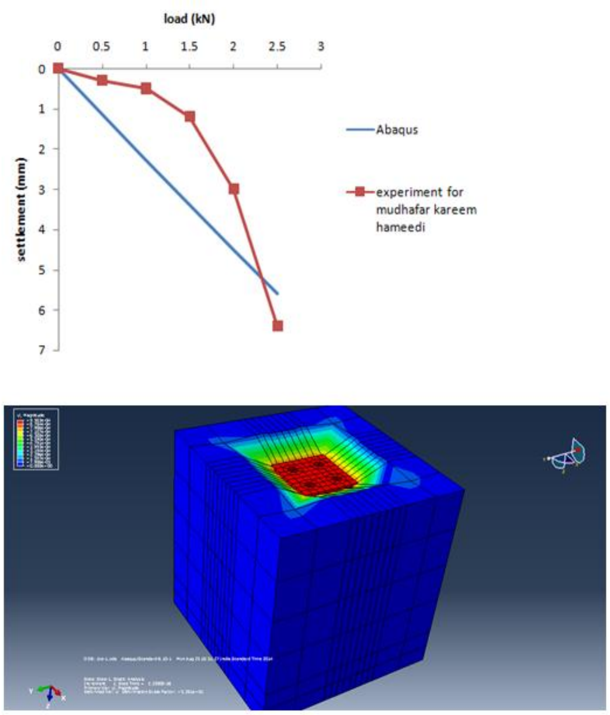


Fig25. Load – settlement curve for piled raft (four piles) of the first model.

Figures (27) to (31) show the load- settlement behavior of piled rafts of the second model. The raft size is (6×6cm) and thickness 0.6 cm as well as the load is carried on these configurations of the first model. The pile diameter is (1cm) and length (16cm) with ratio L/Dp = 16.

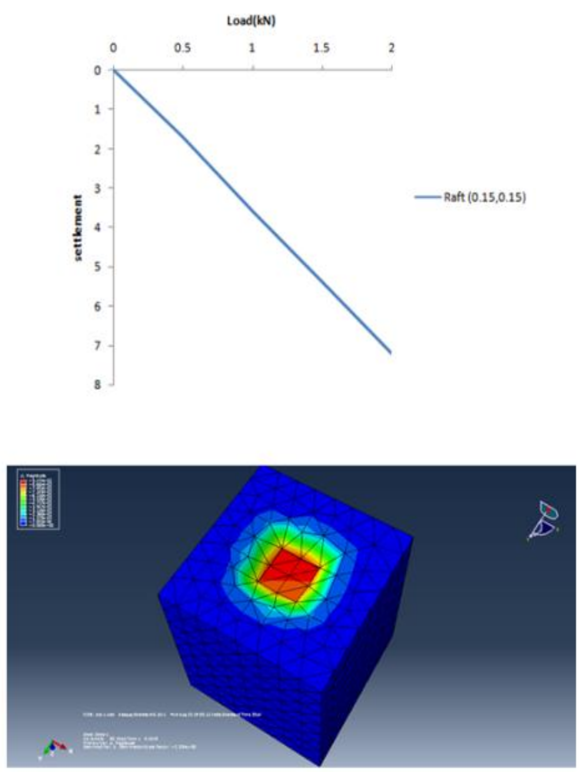


Fig26.Load – settlement curve for raft of the first model.

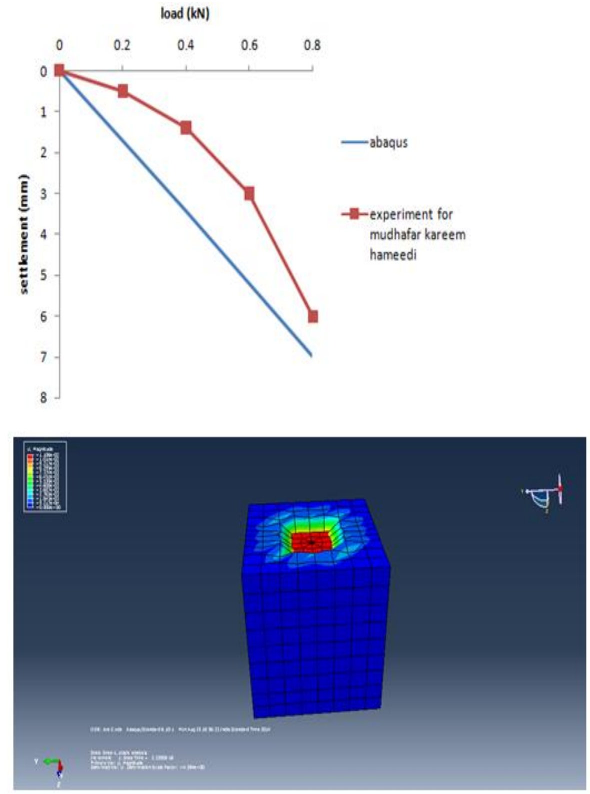


Fig27.Load – settlement curve for piled raft(single pile), of the second model.

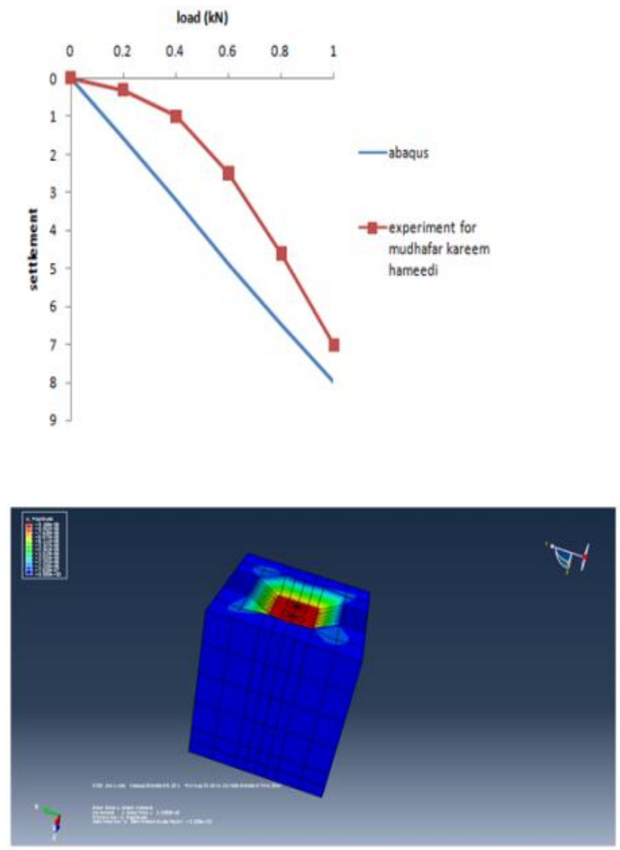


Fig28. Load – settlement curve for piled raft (two piles) of the second model.

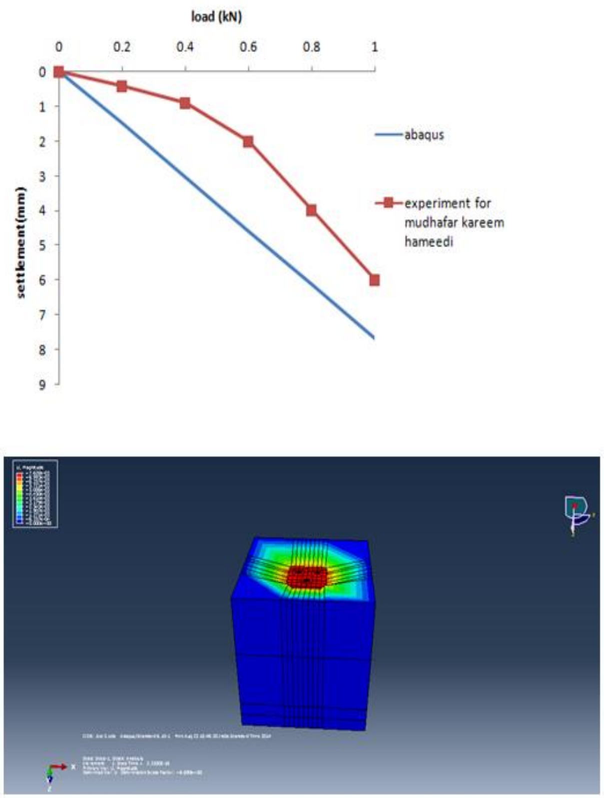


Fig29. Load – settlement curve for piled raft (three piles) of the second model.

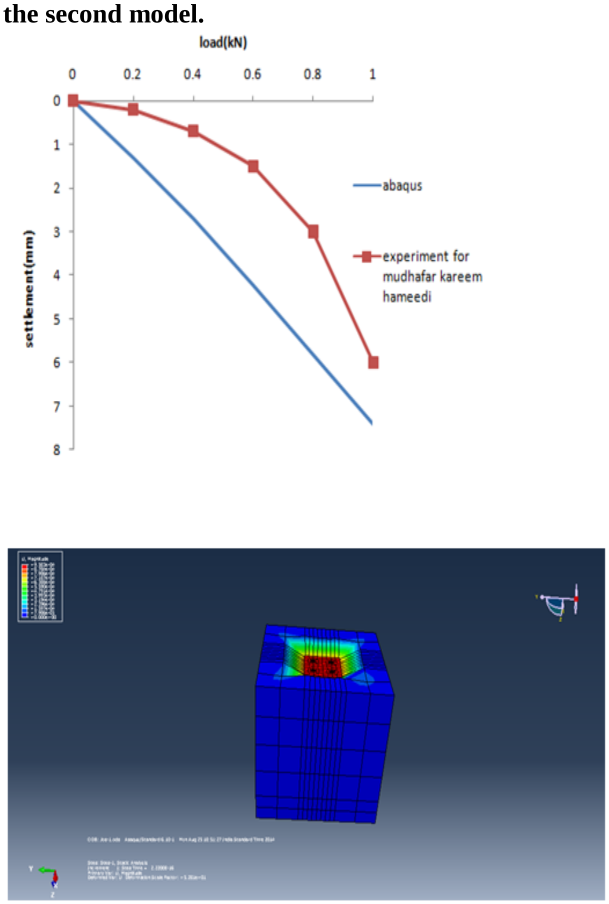


Fig30. Load – settlement curve for piled raft (four piles) of the second model.

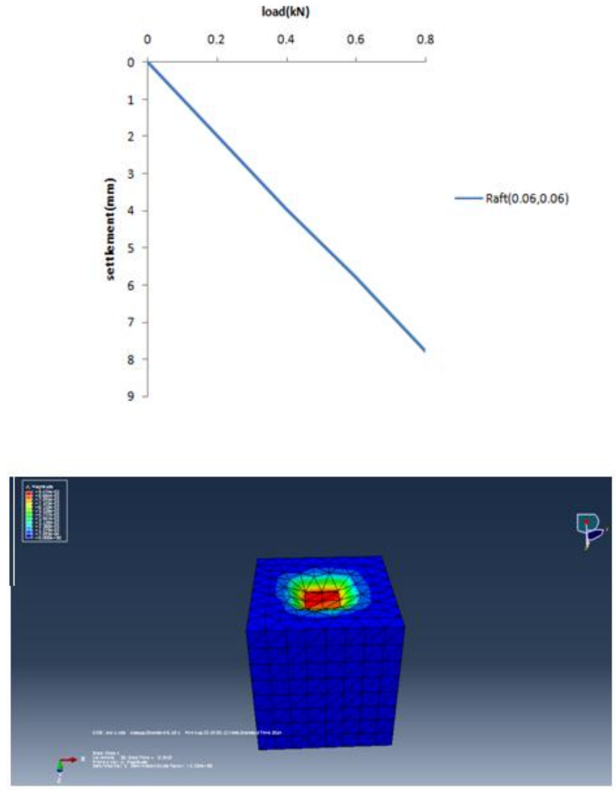


Fig31. Load – settlement curve for raft of the second model.

VI. CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

The main objective of this thesis is to study the distribution of the load under piled raft foundation considering the effect of piled raft geometry, length and diameter of piles, and other factors. This chapter summarizes the main conclusions and recommendations drawn through the experimental and numerical modeling of piled raft foundation. The experimental modeling yielded the following conclusions:

1.The percentage of the load carried by raft to the total applied load of the first model of piled raft with (single, two, three, four,) are 95%, 74% , 72% , 65% , respectively.

2.The percentage of the load carried by raft to the total applied load of the second model of piled raft with (single, two, three, four) are 81%, 69% , 62% , 61% , respectively.

3. The settlement improvement ratio of both models for experimental work in piled raft (four piles) is about 77%.

From a comparison between two models of the experimental work, it is found that the effect of scale factor on carrying load of piled raft increases when increasing number of piles. The numerical modeling of the piled raft problem which considered the load effect using the finite element method through the (ABAQUS) program reveals the following conclusions:

1.The percentage of the load carried by the raft to the total applied load, groups of the first model which are piled raft with (single, two, three, four), raft are carrying about 91%,82%, 55%, 40%, of the total vertical load, respectively.

2. The groups of the second model of piled raft with (single, two, three, four), raft are carrying about 85%, 70%, 60%, 48% of the total vertical load, respectively.

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Areas of Interest:

1.Pile Foundations under static and cyclic loading
2.Machine foundations
3.Ground improvement techniques and Environmental Geotechnology.

Dr E. Saibaba Reddy the Rector of the University. He obtained B.Tech. (Civil Engg) from JNTU Hyderabad and M.E. (Hons) from University of Roorkee, and PhD. from University of Nottingham (U.K). He did two Post Doctoral Research Programmes one from Saint Maries University, Halifax, Canada and the other from University of Birmingham, (U.K). He held various administrative posts and developed the university with his projects and developmental activities. Notable among his awards are the American Society for Testing Materials Award for the year 1998 for outstanding research paper, Shamshare Prakash Research Award 2000 from University of Roorkee now IIT, Roorkee, Commonwealth Scholarship for Ph.D. and Commonwealth Fellowship for post¬doctoral research. He was Chairman/Member of a number of Expert Committees formulated by the A.P. Government to examine the causes of failures and to suggest solution to the problems. He was the Convener EAMCET 2007 and EAMCET 2008 and Convener PRITACET 2008. He also served as Expert Committee Member of AICTE for scrutinizing project reports.