Original Article

The effect of internal forces variations on the behavior of piled raft system in a plastic cluster

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ABSTRACT

In designing foundations, in case of heavy structural loads, the most comprehensive option is to use a combination of two systems of raft and pile group, which are called "piled Raft foundation". As the behavior of the set is of the type of extensive interaction behavior between soil, piles and foundations, their analysis is complex, so far, several methods have been suggested for the analysis of bearing capacity and distribution of forces between the components of these systems. These methods include manual and computer methods. In most of these methods, the bearing capacity of the Raft, which has a significant portion, is generally ignored. Also, determining the parameters used in these methods, such as the hardness of the piled raft or the pile group, is practically associated with many problems or is sometimes impossible. In this study, after introducing the methods presented by the researchers, a method for analyzing the internal forces and the distribution of forces between the Raft and the pile group according to the settlement analysis and interaction performance as an equivalent block, has been proposed. In the following, the behavior of the piled raft system will be studied, and the internal forces will be examined and analyzed in detail, in order to obtain a safer and more efficient design.

Keywords: variations in internal forces, piled Raft, Finite element method.

Introduction

In general, construction projects consist of two parts: superstructure and substructure. The substructure is often in contact with the soil, and contributes in the process of direct transfer of the superstructure load into the soil or bed. The role of the foundation as a transitional part in the structure is to endure relatively large tensions in the superstructure components such as columns, foundations or walls, for the soil, which has a relatively low strength and load-bearing capacity compared to the superstructure components (The bearing capacity or so-called normal strength of soils is about 0.5 to 5 kg/cm^2). Foundation engineering is the art of applying sciences in the field of structures, genotechnics and engineering judgments associated to the analysis, design and implementation of foundations that eventually obtain the optimal foundation system by observing the technical, executive, sustainability and economic principles.

Bearing capacity or strength of soil and rock depends on the properties of the materials under the foundation as well as the geometry of the foundation.

Structure subsidence occurs due to variations in form and volume of substrate soil or infrastructure under the constant total tension. The above variations in form occur as a result of the elastic and plastic volume of the grains, the change in the volume of the soil mass as a result of the water and air outflow from the pores, and the general shear displacement of the particles or soil mass.

Settlement is mainly related to the sensitivity of the structure to displacements and vertical deformations of the bed, which is controlled by considering the applied loads, soil hardness properties and foundation geometry in the plan. Then, the structural designing is done based on the internal forces and tensions resulted from external forces in the foundation system,

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which includes the selection of materials, determining the thickness of the foundation and, if necessary, the way of reinforcing it. In case of the existence of inclined, horizontal and anchor loads on the foundation, stability control or external design, including slip control, overturning and tensile reaction under the foundation is required. Lastly, the evaluation of the designed system is operational and economical [1].

Constructing foundation in projects includes the implementation of surface foundations, improvement of bed soil along with the implementation of surface foundations, semi-deep foundations and finally deep foundations.

Surface foundations are one of the most common foundations, especially for construction projects and walls, and their installation depth is often less than their width. After excavation, digging and removing clay loams, these foundations are implemented while passing through the freezing zone and unsuitable surface layers, and in some cases with more excavation for the constructing some floors in the basement, and the analysis and structural design include paddle foundations, strip foundations (with continuous and linear loading) and supporting beams (with concentrated and intermittent loading) on the ground.

In estimating the pile settlement, it is noteworthy that the smallest displacement of the pile (about 1 to 2 mm) is sufficient to mobilize the total bearing capacity of the wall, but the capacity of the pile floor reaches to its final limit with larger displacements. Basically, single piles are less used in engineering projects and piles are generally used in groups. In the pile group, the usual method of determining the settlement is to use the equivalent Raft [1].

There are several ways of behavior- settlement of a Raft with a pile group. The "equivalent Raft" method is one of the most popular methods first introduced by Tomlinson [2]. In this method, it is assumed that the load enters the foundation surface somewhere deep and at a wider level, it enters an equivalent Raft foundation in order the effect of load transfer by the piles to the substrates to be observed.

In this regard, Poulos & Davis suggested a manual method to obtain the overall load-settlement curve until the moment of failure. A method based on the elastic solution of the problem is used to calculate the initial stiffness of the Raft and pile and the Raft alone. In this method, linear behavior - three parts for the load curve - Raft and pile settlement is achieved. Figure 1-3 indicates this three-part curve, and its three parts are famous. Of course, only fully flexible or completely rigid radii are included in this method [3, 4]. Randloph suggests a simple approximate method for approximate equations for calculating the stiffness of a Raft and pile system [5, 6]:

In case of larger and heavier projects on less resistant lands or in case of significant load difference in adjacent walls and columns, the entire infrastructure area is allocated to the foundation construction in order to achieve a uniform reaction and to minimize non-uniform settlements, to deal with local complications and case weaknesses in the bed soil, if the use of paddle or strip foundations is not possible, and all loads of walls and columns can be borne by an integrated dolly system. This system is called the spread footing or the so-called Raft general in French, and usually two reinforcing tables are applied at the bottom and top of the foundation in both longitudinal and transverse directions.

Spread footings generally include dolly under the effect of a set of vertical forces. The main difference between the different modeling modes is due to how the compressive behavior of the contact between the soil and the spread footing is considered.

One of the biggest problems that engineers have been facing in analyzing and designing structures has been finding scientific methods for analyzing and designing spread footings. Based on each of the different modes of analysis, different results are obtained for designing. Based on this issue, it is always necessary to strike a balance between theoretical aspects in solving the problem of spread footings and practical cases.

The use of finite element method to solve three-dimensional foundation behavior on the continuous environment is among the latest methods of spread footings analysis, on which broad studies are being conducted nowadays. In this case, modeling of three-dimensional elements is used to model the foundation and soil behavior. Though, in finite element modeling, the behavior of spread footings, the effect of adhesion and internal friction on the results of the behavior of foundations should always be considered. Considering the effect of this parameter on the modeling of soil and foundation interaction behavior leads to the fact that the deformation results obtained from the analysis in this way are not consistent with reality in practice.

In the growing trend of analysis of spread footings by three-dimensional modeling method, by releasing the horizontal displacement at the junction of the foundation with the soil, only vertical displacement is permissible to the model. Another approach that has been considered in this modeling is to determine different properties for elements located at lower ground levels compared to the upper levels [7].

To analyze the reinforced soil system by finite element method, we need to make use of software that in addition to having proper yield criteria to model the complex behavior of the soil, includes different and diverse elements for modeling.

Plaxis software is a computer program based on finite element numerical method that is designed with a definite purpose to analyze soil and rock problems.

The key purpose of developing this software is to create a suitable tool for practical and applied analysis of geotechnical problems by geotechnical engineers who are not necessarily experts in numerical methods. The result of the study done by Plaxis company is the creation of a powerful and potent software that can be used by many geotechnical engineers around the world. Based on the contents of the current study, the effect of variations in internal forces on the behavior of the piled raft system in the plastic environment has been investigated.

Materials and Methods

Step-by-step stages of calculating the pile group settlement

1. The soil profile are specified and be divided into a number of layers for conducting calculations, and the parameters of each layer are specified.
2. Calculations of pile bearing capacity and pile group and load distribution and resistance are performed to determine the location of the practical plate.
3. The pile group is replaced by an equivalent foundation at the neutral plate location, and the tensions below the foundation are calculated in a manner similar to the 1: 2 slope method (or other common methods such as Bosinski and Westergaard). Tensions are the initial effective tensions and the secondary effective tensions resulted from the dead load on the pile group.
4. The settlement of each subsoil layer is very much determined by the Janbo tangent modulus method or conventional classical methods, and they show the sum of the total settlement values at the location of the neutral plate. The pile group settlement is equal to the sum of the above values as well as the pile compression value resulted from the dead load and elastic force.
5. Regarding the point that determining the location of the neutral plate is assuming the full activation of the pile floor resistance, it is necessary to control the amount of settlement below the pile floor level. If this value is less than 5% of the pile diameter, in the second stage, by assuming a smaller value for the repeated floor resistance, a newer (higher) location for the plate is obtained. Then the third to fifth stages are repeated.

Investigating the load behavior – spread footing settlement with the pile group:

If it is assumed that the load- the Raft and the pile settlement behavior is partial, then the secant stiffness of the pile (Kp) and Raft (Kr) sequences is calculated as follows:

(1)

$$K_p = K_{pi}(١ - R_{fp} P_p / P_{pu})$$

$$K_r = K_{ri}(١ - R_{fr} P_r / P_{ru}) \quad (2)$$

In this relation:

K_{pi}, the initial tangential stiffness of the pile group;

R_{fp}, partial coefficient for pile group;

P_p, load carried by piles;

P_{pu}, final load capacity of piles;

K_{ri}, Raft tangential initial stiffness;

R_{fr}, partial coefficient for Raft;

P_r, load carried by Raft;

P_{ru}, the ultimate bearing capacity of the Raft;

The load carried by the piles will be as follows:

$$P_p = \beta_p P \le P_{pu} \quad (3)$$

$$P_r = P - P_p \quad (4)$$

Where P is the total load on the foundation system.

The relationship between load and Raft and pile settlement is expressed as follows:

$$S = \frac{P}{X K_{pu}\left(١ - \frac{R_{fp}\beta_p P}{P_{pu}}\right)} \quad (5)$$

The relationship 0-5 are methods or tools for calculating load-settlement relationships (on average) in the Raft and pile system. As K_r and K_p change with the intensity of the work, the parameters X and β_p will also change. Therefore, a step-by-step analysis, ie a step-by-step analysis based on the application of step-by-step load to the final load, should be performed on these foundation systems, starting with K_{ri} and K_{pi} .This method can be used in manual calculations or calculations with the help of mathematical software such as MATHCAD or MATLAB [8].

-Immediate settlement and final settlement:

Due to the probable nonlinear behavior of the soil in its non-drained state, it is possible to use the method described above, does not always have the desired accuracy. As Poulos & Davis point out [3, 4], it is better to calculate the consolidation settlement from the difference between the final general elastic settlement and the consolidation settlement and add this value to the immediate settlement calculated from a nonlinear analysis. Therefore, the final S_{TF} General settlement will be equal to:

$$S_{TF} = \frac{P}{K_u} + P\left(\frac{١}{K'_e} - \frac{١}{K_{ue}}\right) \quad (6)$$

In this relationship:

P, is the load on the Raft and pile system

K_u, is the undrained hardness of foundation (from nonlinear analysis)

K_{ue}, is undrained hardness of foundation (from non-drained elastic analysis)

K'_e , is the drainage hardness of the foundation (from the analysis of elastic drainage).

Non-uniform settlements:

The process described above generally yields a moderate amount of load-bearing behavior of the Raft and pile system. Non-uniform settlements under a composite spread footing with a pile group are highly affected by the distribution of forces on the Raft, the arrangement of the piles, and the relative stiffness of the Raft. Randoloh suggests an approximate method for maximum non-uniform settlement under a spread footing under the effect of a uniform wide load [6]. This method relates the ratio of the probable non-uniform settlement to the overall settlement of the system to the relative stiffness of the Raft. In the initial approximations, this ratio can also be used for combined Raft and pile systems. Simplified graphs have also been provided by Horikoshi and Randoph to estimate non-uniform settlements [9].

Description of modeling

This model, whose geometric and physical characteristics have been clearly indicated in the following tables, was loaded in two different states of saturated and unsaturated. The behavior of the piled raft system in sticky and saturated environments is very significant because in saturated sticky environments, the probability of occurrence of consolidation settlements is very high, and since the process of effective behavior of the piled raft system is dependent on the involvement of the entire Raft section throughout the life of the structure of the foundation system with the soil under the Raft, the presence of such very critical settlements in the Raft subsystem causes the subsystem soil to separate from the foundation, and during the consolidation period, it will decrease the efficiency of the Raft system. In the following, by carefully examining the system using two specific phases in the plastic condition and also in the saturation state, considering the consolidation analysis mode, the effect of variations in these forces on the efficiency of the piled raft system will be examined. Now, in this section, we will examine the desirable and undesirable cases in designing piled raft foundations.The most common use of raft pile foundations is when the Raft alone can provide sufficient resistance to incoming loads; but, to avoid total or excessive settlement of the foundation, the pile group under it is made use of. Polous In 1991, after examining several ideal soil profiles, found that the following items are desirable in designing.

Desirable items in designing the piled raft foundation

A: Stiff clay profile is formed.

B: The soil profile consists of dense sand, in the mentioned cases of its spread footing is able to withstand the loads alone, and the pile group only bears the reinforcing tension.

Undesirable items in the designing piled raft foundation

A: Soil profile consists of soft clay near the ground level.

B: The soil profile consists of loose sand near the ground level.

C: Soil consists of compressible layers near the ground.

D: Soil profile has the capability for consolidation due to the external factors.

E: Soil profile has the capability for inflation due to external factors.

It should be noted that in the first two cases, the soil under the spread footing is not able to provide sufficient bearing capacity and suitable stiffness, while, in the third case, long-term settlement of the soil in the weak lower layers will decrease the participation rate in the long-term stiffness of the spread footing. That is, over time, the contribution of the Raft to the stiffness of the entire system will be decreased and reinforcement settlements or cases that occur as a result of water loss or shrinkage of active clay layers decrease the contact between the foundation and the soil and this phenomenon will increase the load on the piles, this occurrence will increase the overall settlement of the system.

3D modeling in plaxis 3d fondation program

Plaxis 3d foundation software is a software based on finite element mathematics that can analyze different foundation and excavation issues in a three-dimensional environment. In this project, the following model has been used to examine the 3d model.

To study the behavior of the piled raft system, first a simple system of four piles is modeled under a square Raft, so that the model is subjected to two modes of plastic and consolidation, and the trend of variations in internal forces created in Raft and piles in sticky soil in both cases were analyzed. To model the Raft, the plate element is used in 3d mode by applying the thickness, bulk modulus and Poisson ratio in the analysis. To model the piles, linear plastic non-porous medium was used and applied to the appropriate depth. The connection between the piles and the beam is direct and the piled raft is not of disconected piled raft type.

Results

Investigation of vertical displacement changes:

For investigating the results of the settlement that took place in the plastic analysis mode, the initial bearing capacity of the Raft in the piled raft system was examined. Due to the simultaneous operation of the Raft with the piles, the soil under the Raft data will be examined to investigate this issue. As can be seen in Figure 1, the variations that occurred in the two modes of analysis were very large, and occurred approximately 3 cm in the total settlement, which indicates the effect of the type of analysis on the result of bearing capacity.

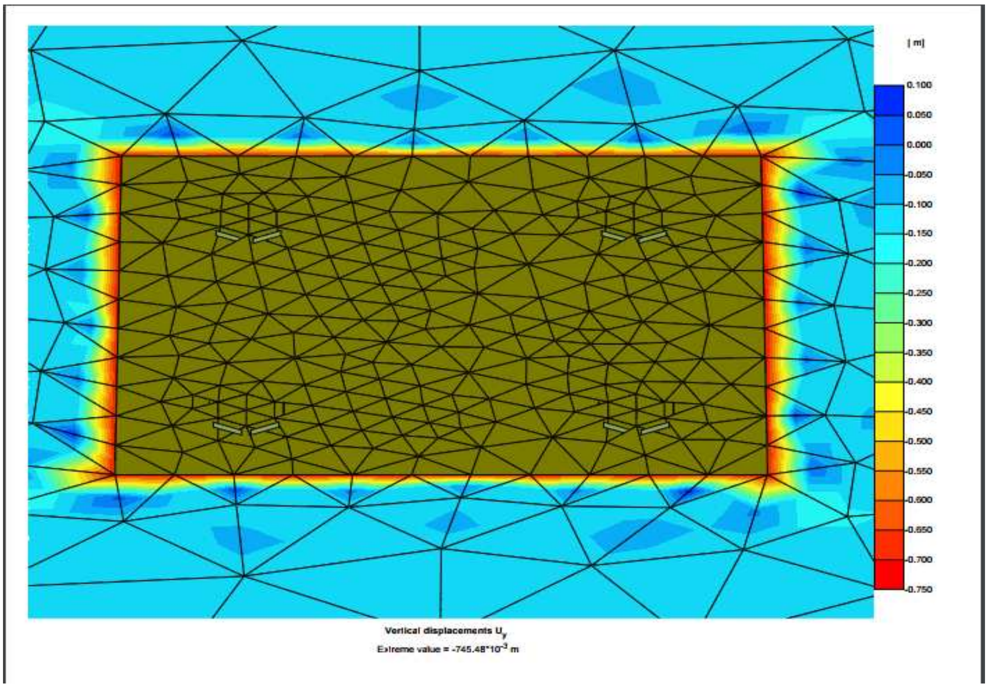


Figure 1: Vertical displacement variations in the plastic environment

Figure 2 displays the variations that occurred in the shear strain of the soil around the piled raft system in the plastic analysis mode.

As shown in the figure, the amount of gamma variations or shear strain is very far from each other in two analysis states of plastic and consolidation. As can be seen, in the plastic state, the shear strain has a value equal to 250%, but in the consolidation state, this value is equal to 7%.

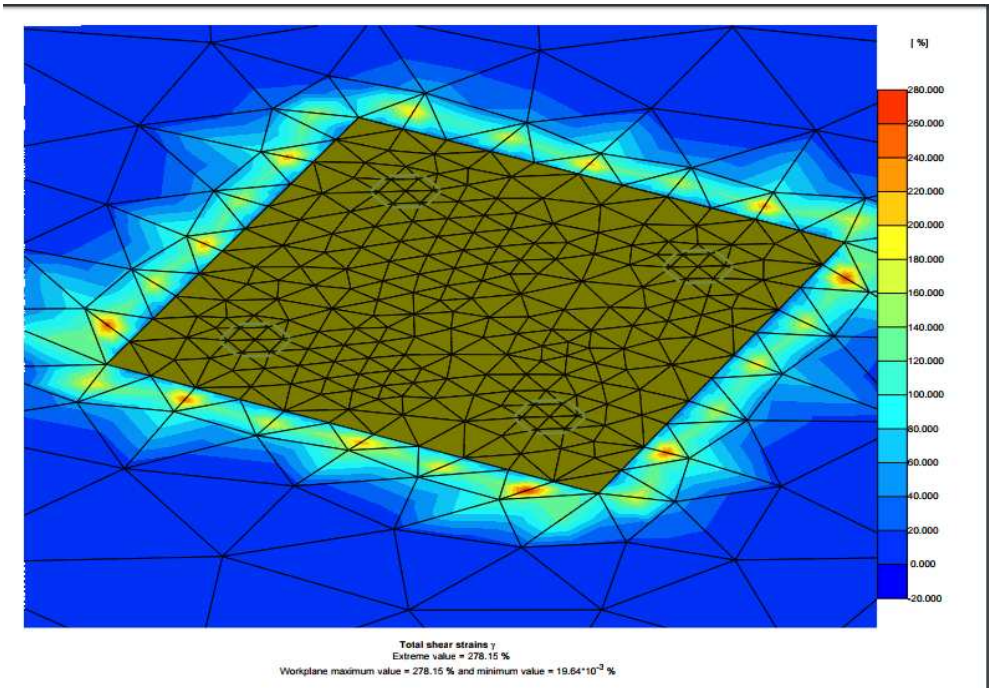


Figure 2: Shear strain variations in the plastic environment

General examination of Raft structures

In Figure 3, the lateral behavior that occurred in the Raft has been shown, which indicates that the Raft had 5 cm displacement in its lateral direction, this change in motion in this particular direction causes an additional anchor in the Raft and the head of the piles, and this happens in the state of plastic analysis. But in the form of rotational behavior occurred in such a way that the upper side of the right Raft by 3 cm and the lower part by 5 cm moved to the left and one of the factors causing this displacement is the resistance of the piles in order to prevent asymmetric total settlements.

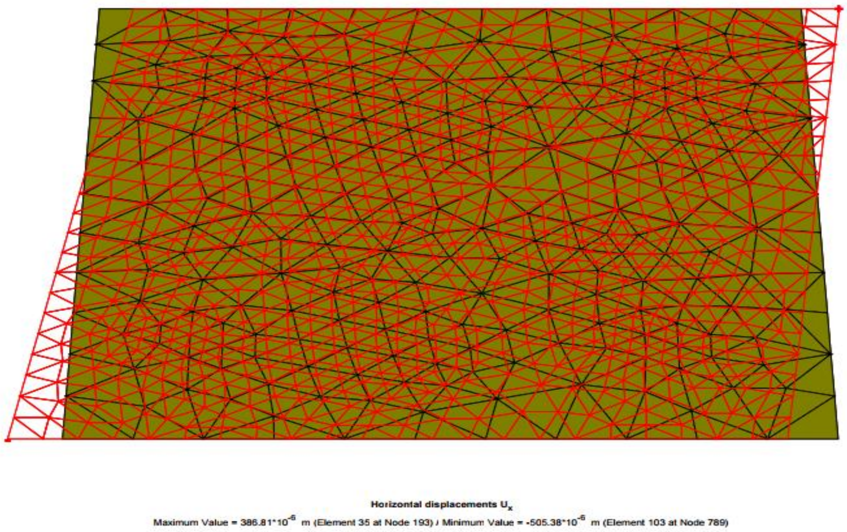


Figure 3: Variations in horizontal displacement in the plastic environment

Examining the settlement occurred on the Raft itself

In Figure 4, in the behavioral environment of plastic analysis, the integrated settlement of the Raft has been clearly shown to be at the maximum amount of 7 cm. These variations can be well observed in the consolidation state that occurred in the system, which have been shown in Figure 4-8. Is a radio system. These variations in the settlement are 11 cm, which show the effect of the consolidation settlement that occurred in a certain period of time on the radio system.

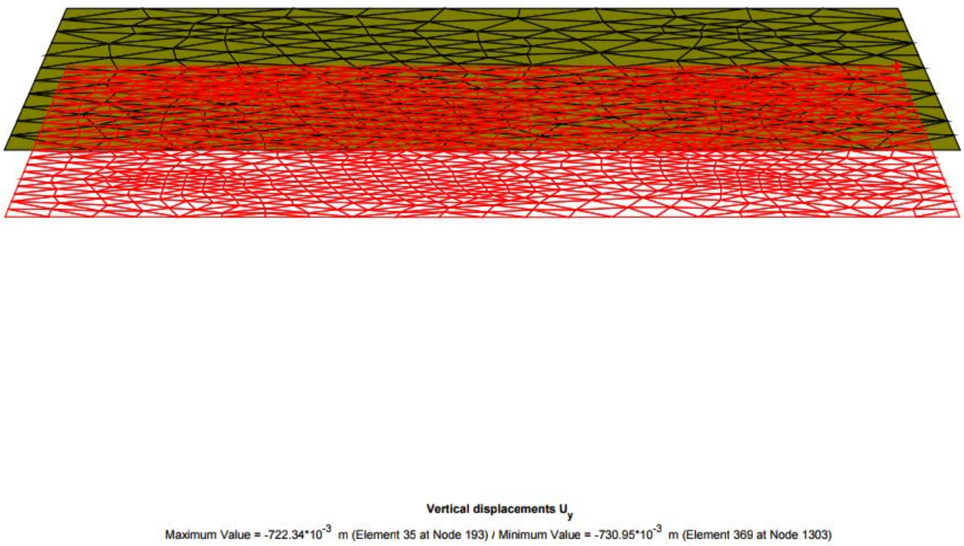


Figure 4. Variations in vertical Raft displacement in the plastic environment

Variations occurred in the internal force of the radio system

Figure 5 shows that the areas where the piles are located have a very powerful axial force; but, in this part, the axial force created in these areas is not considered, and the focus is on the axial force created in the center of the radio system.

In this figure, the value of max = 1.97 * 103 kN / m was observed and the amount of min = 458 kN / m was also considered. But compared to the consolidation state shown in Figure 10, it is much higher because this force is affected by the settlement of its substrate. In the consolidation state, the maximum and minimum values are much lower.

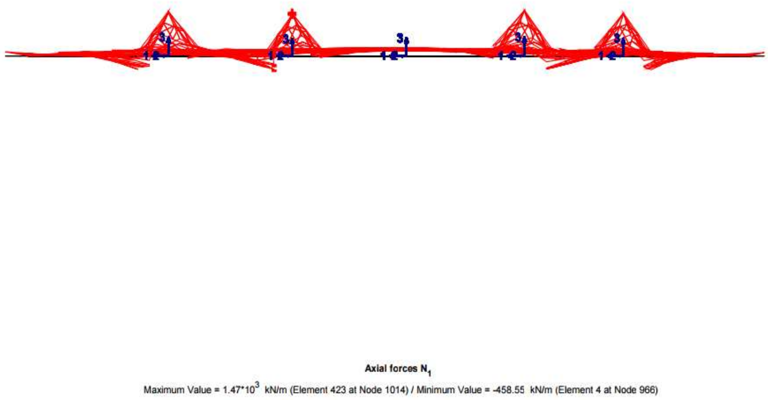


Figure 5. Axial force variations in Raft in the plastic environment

Examining shear forces occurred in the system

As has been shown, all the radii in this section, in the direction (3-2) of the coordinate axis located on the screen were checked. Now, as shown in this figure, the variations that have occurred in the whole system have reached a maximum of 3.6 x 103 kN. As shown, the amount and the power the force occurred in the whole system is variable, and should be given much attention because in these conditions, the design is very heavy and gets out of the optimum design mode. (Figure 6) Figures 7a and b show these general changes.

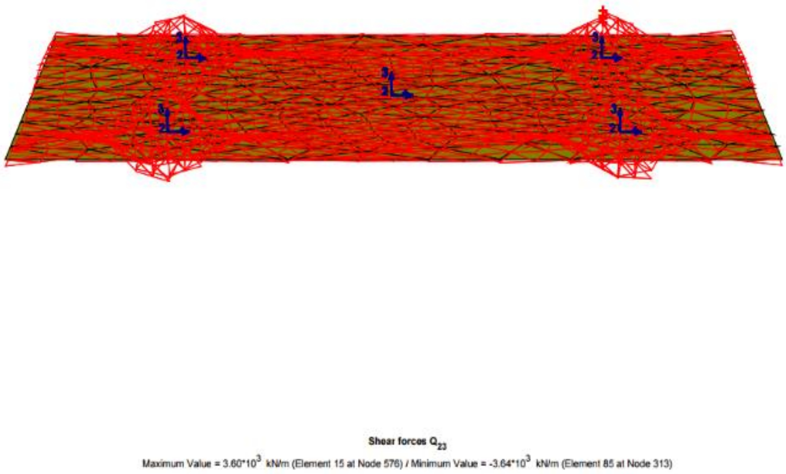
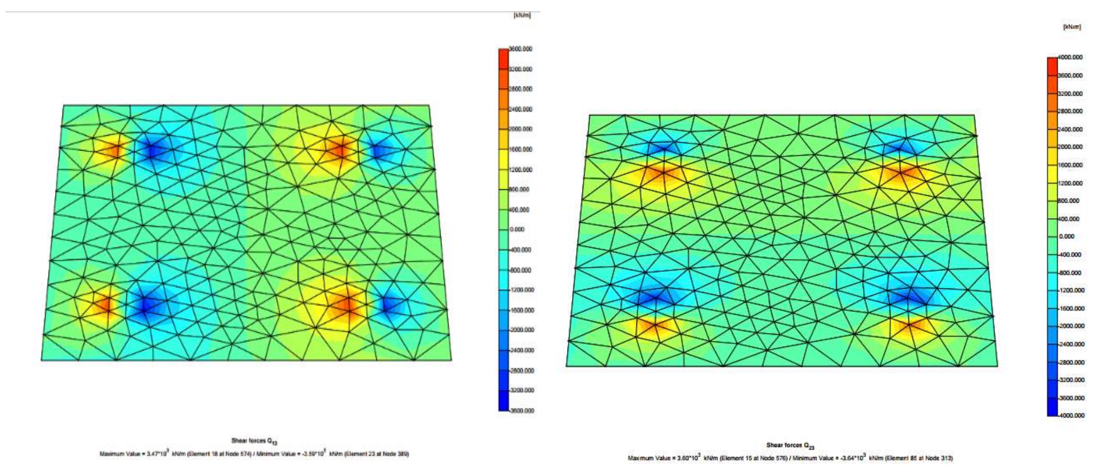


Figure 6: Shear force variations in Raft in section 2-3 in the plastic environment



a b

Figure 7 a) variations in the analysis of the plastic environment, b) variations in the plastic environment

Examining the variations in internal forces occurred inside the piles

As can be seen in Figure 8, the characteristics of the internal forces in each pile can be observed separately, in a way that in each pile, the axial force has been well represented. As it is clear, in the plastic analysis, the maximum amount of axial force in the piles is equal to 10 * 11 and its minimum value is equal to 1.17 * 103 kN / m.

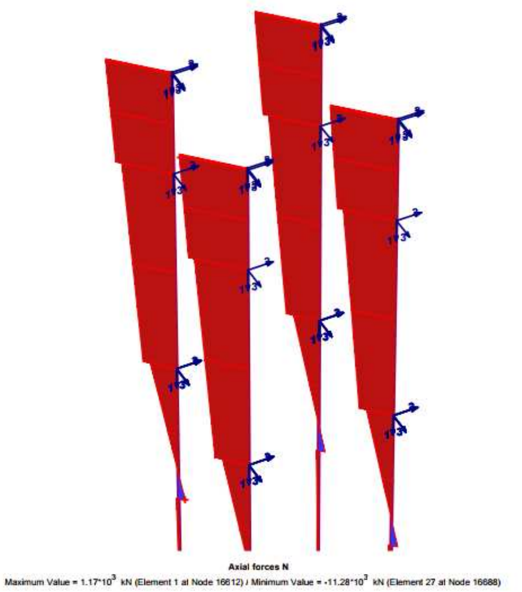


Figure 8: Axial force variations in piles in plastic analysis

In the next study environment, in the pile elements, two general coordinate directions were used in the axes of [1-2] and [1-3]. First, the values of shear forces in the system have been specified as shown in Figure 9 in the area of plastic analysis. The maximum values in piles in this case are equal to 452 kN and the minimum value can be seen which is equal to 429 kN.

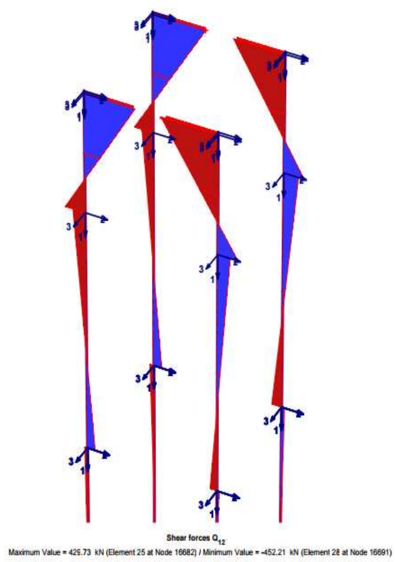


Figure 9 Shear force variations in piles in section 2-1 in plastic analysis

In the following, the shear force variations in the coordinate region [1-2] were investigated. The general trend of variations is completely different from the previous coordinates, so that it is very different and less than the previous sample in the plastic analysis state. In Figure 10, these variations can be seen in the coordinates [1-3] in all four piles. The values of shear forces in both plastic analysis and consolidation states are very different from each other.

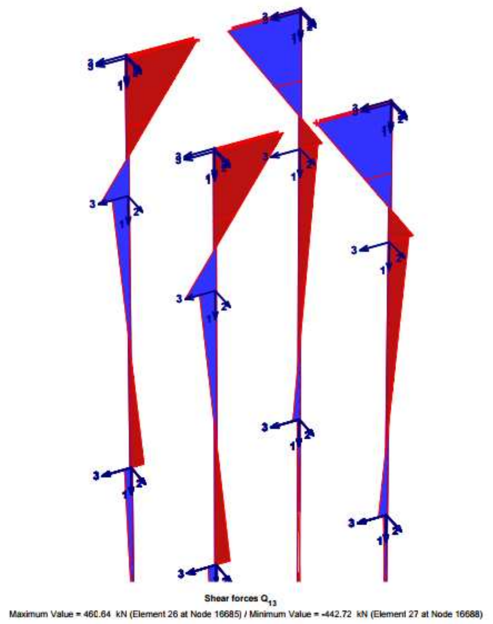


Figure 10 Shear force variations in piles in section 1-3 in the plastic environment

An overall examination of these variations in flexural anchor phases occurred in piles

In the flexural axis [2], which is also shown in the figure, the maximum value is = 435 and the minimum value is 586 kN / m, which has been represented in Figure 11.

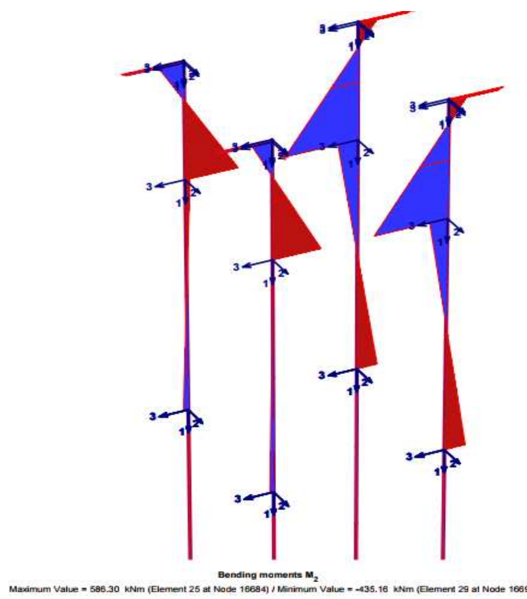


Figure 11 Flexural moment variations in piles in plastic analysis

Conclusion

The goal of this study was to examine the effect of variations in internal forces on the behavior of the piled raft system in the plastic environment. It should be noted that the complex piled raft system will have a very economical and safe performance, and this requires establishing accurate relationships between the components of the system and the interaction factor of soil and structure. After carefully examining the piled raft foundation system and recognizing its performance against variations in internal forces, the following results were obtained.

- The piled raft system by considering the function of its multiple interactions that occur between its components and the soil, has a very effective function in transferring the superstructure loads to the substrates and the integrity of the deep foundation behavior.
- Variations in internal forces will have a profound effect on the optimization process. This is a very accurate issue in order to calculate and recognize the detailed behavior of the deep foundation of the pile Raft.
- Based on the studies and research conducted before, and of course the examinations done in this study, it can be considered that complex but high-performance systems have shortcomings in their behavior; currently, one of these shortcomings is the complex function of the permanent interaction of soil and structure between the Raft and the soil, that if this system is interrupted, the behavior will change a lot and can lead to instability.
- Variations in internal forces are one of the main causes of variations in different strains that can occur in the system. The way of variations in forms and focal points of tensions and forces had made this issue clearer, and this in itself, is a turning point for the analyzer in understanding the behavior of the piled raft system which can be attained by using finite element software such as the work conducted in this dissertation.

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