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The Experimental Study of Eccentric Loadingfor Piled Raft Foundations Settling on Slope Crest

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Abstract*—In this study, bearing capacities and settlements have been determined for a piled raft foundationsunder eccentric loading conditions. For this purpose, slope models which were safe against collapsing have been used. Pile raft foundations located in the sand have been fixed on slope crest. At experiments, poorly graded sand samples and steel piles have been used and the optimum value of the pile spacing from literature have been selected. For determining the effect of eccentric vertical loading for piled raft foundations, a series of experiments have been carried out to identify the contribution of the bearing capacity and settlement.As a result of this study, it has been determined important effect of eccentric vertical loading at piled raft foundations and design parameters have been proposed for basic engineering applications.
Keywords*—eccentric vertical loading, slope, piled raft foundations.

I. Introduction

Nowadays, there has been a common approval that the use of piled raft foundation. The piled raft foundation is a deep foundations at geotechnical engineering and loading transfer is similar to shallow foundation. It can transfer significant part of the load into the base and has a major advantage of substantial reduction in number of piles and shorten their length, which in turn results in savings of foundation cost and time. It has become an economic necessity to install piles beneath a raft because a lack of bearing capacity of the foundation and excessive settlement problems. The piled raft consists of the three elements piles, raft and the soil. The foundation concept of piled raft differs significantly from that of a single pile and group of piles. Loads are carried either by the raft and the piles, considering the safety factors. In recent years, variational design approaches for analysis of piled raft foundations. All these approaches consist of sophisticate formulations, input parameters and assumptions. But, there is not too much reliable and suitable design practice methods of predicting foundation behaviour about this problem in previous studies. So, this experimental study aim to investigate, effect of eccentric vertical loading of pile raft foundations located in the sand.

II. Previous Studies

There is a lot of studies about determined different parameters at piled raft foundations but there is nostudies about eccentric loading for piled raft foundations settling on slope crest. These studies are presented about different parameters at piled raft foundations:

Whitaker [1] vasanalysed two different systems in a lobaratory medium by in the conditions of both a raft head was used or not (or raft head was not in contact with the soil) in a piled raft foundation in cohesive soils. Consequently, it was pointed out that in the condition where a raft head was not used, bearing capacity of the piled foundation was lower than that for the piled raft foundation. Large-scaled laboratory experiments were performed by Garg [2] in order to examine the behavior of a pile group and piled raft foundation system embedded in a sand soil. Consequently, it was stated that the rigidity of the pile group was lower than that for the piled raft foundation system. It was also defined that the load carried by the pile head was not constant and it was changeable according to the settlement of the piled raft foundation. 10 experiments were executed by Horikoshi[3] on a uniformly loaded piled raft foundation sitting on a clayey soil for the optimum design of piled raft foundation systems. It was specified that differential settlements reduced to a great extent by means of decreasing the number of piles under the center of the base of a raft foundation. On the other hand, it was stated that for the piles which were located under the pile tip, the greatest amount of load was carried by the piles located at the corners while lesser amounts of loads were taken by the piles at the sides. The reason of different load carrying distributions of the piles at the corners, at the sides or in the middle was explained to be the result of the group effect which took place in the condition where the pile spacings remained under a specific value. Eventually, it was proposed that the piles should be located in the center zone or in the range of 16% to 25% of the raft area in order to minimize the differential settlements. Load transfer and settlement behavior in pile groups was modeled by Kempton et al [4] as 2D plain strain model and 3D quarter cell filling and the two models were compared to each other. All of the structural elements were modelled as elastic materials which did not exceed the linear limit and did not approach to the yield stresses. As a result of the conducted investigation, it was pointed out that significant differences occurred even though the graphics formed similar curves. On the other hand, it was stated that the reductions in stresses with depth were lesser in the 3D model compared to that in the 2D model and the values of maximum and total settlement were higher in the 3D model. Site experiments were performed by İsmael [5] on two different kinds of pile groups consisting five piles in order to examine the effects of pile spacing and pile diameter to bearing capacity. The soil type in which the experiments were executed was defined to be cemented sand. As a result of the conducted analyses, it was stated that the settlement of piles where pile spacings were lesser than 2-3 times the pile diameter was

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higher than that for a single pile and elastic settlement increased with the increasing pile group width. On the other hand, it was explained that group effect did not remain for the piles which were placed at ranges that were two and three times the pile diameter and a significant difference was not seen in single and group piles in vertical loading condition in terms of pressure and stress values. The contribution of raft and piles to bearing capacity values were investigated by Ergun and Türkmen[6] by means of laboratory experiments in which model aluminum piles each having an outside diameter of 22 mm, an inside diameter of 18 mm and a length of 200 mm and steel raft having plan dimensions of 132 mm x 132 mm and a thickness of 35 mm. The model piles were equipped with unit deformation gauges in order to measure pile loads. It was pointed out that in the case where a decent design approach was followed; rafts enabled a significant contribution to the total bearing capacities of the pile groups and a decrease could be seen in the production cost of the pile groups with the usage of a raft. A simplistic calculation method was developed by Gök[7] which can be used primarily in a design in order to analyse the behavior of piled raft foundations by utilizing model tests and computer analsyis. Two kinds of experiments were performed throughout the aforementioned experiments. For the fist group of experiments, the effect of a raft which was in contact with a supportive soil layer to the bearing capacity of a foundation system and load-settlement behavior of the related pile group and piled raft foundation were scrutinized. As a second group of experiments, the effect of the piles which were located in the center zone of the raft foundation that was safe in terms of collapsing but having settlement values out of the acceptable ranges to the behavior of the raft foundation was examined and the reducing effect of the piles in the differential settlements of the raft foundation were analyzed. It was observed from the test results that a significant increase occurred in the bearing capacity of the system after the raft-soil contact. On the other hand, in the proposed calculation method, it was accepted that the structural loads were to be carried by the raft and piles in a shared manner and the settlements of the raft and the pile group could be determined separately by means of the load distribution ratio. Non-linear behavior of soil and pile and soil-pile-structure relationship under harmonic loading conditions and real earthquake loads were researched by Alsaleh and Shahrour[8]. In the study, the superstructure was modeled as a three dimensional beam member by using soil and pile Mohr-Coulomb relationship. The values of displacements in time and axial load and torsional moments for the most unfavorable circumstances were determined for both elastic and elasto plastic conditions. Ultimately, it was shown that the plasticity of a soil decreases the degree of energy transfer to the upper structure and the increases in the inertia forces were important. Behavior of piled raft foundations under the combined effect of vertical and horizontal loads was investigated by Yalçın[9] by means of Plaxis 3D Foundation fine elements program. In the aforementioned study, settlements, lateral displacements and the moments that occur in a raft plate were analysed under a multi-storey building on a clay soil for each of the three different foundation systems which were raft foundation, piled raft foundation and piled foundation where the effect of raft foundation to the load distribution was neglected. Eventually, the aspects given below were emphasized; in the case where the foundation system of the structure was designed as piled spread footing, the values of maximum settlements and differential settlements reduced approximately 40 % and 35 %, respectively, The foundation system was designed to have the same pile configuration and pile lengths as the piled raft foundation yet the raft foundation had no part in the load distribution, In the case where the foundation system was modeled as piled raft foundation, the system collapsed when it took 71% of the total load, If the load-displacement curves for the three foundation systems were investigated in the mid and corner points of the raft plate, it was seen that the settlement values which occurred under the load of which having a magnitude degree of the instant when the raft foundation collapsed were lower than that for both the raft foundation and piled foundation, When the moments implemented in the piles were compared, the moment occurred in the piles in the piled foundation were approximately at a magnitude degree of two times than that for the piled raft foundation system, It was pointed out that the number and lengths of the piles should be increased for the vertical and horizontal loads acting on the other two foundation systems were to be safely taken by the piled raft foundation and for the settlement values were kept under the allowable limits. Bearing capacities of piled raft foundations embedded in sand (L/D=10) were examined by Patil et al [10]by means of performed laboratory model experiments. In the experiments, model steel piles each having a dimension of 10 mm and a length of 200 mm and rafts produced from steel having plan dimensions of 160 mm x 160 mm and thicknesses of 5mm, 10 mm and 15 mm were used. Variations in the bearing capacities of piled raft foundations were defined with respect to the thickness of the raft foundation and an increase in the number of piles by taking the pile spacings as 3D for all pile configurations. Ultimately, it was stated that as the raft thickness increased, the values of the bearing capacity also increased approximately 12 % yet a difference was not recorded in the values of settlements. On the other hand, it was observed that an increase in the number of the piles results in increases in the bearing capacity and decreases in the settlement values. In addition, increases in the number of piles were seen to cause improvements in the ratios of load carrying capacities and after a specific value of the number of piles, a significant contribution was not observed in terms of settlements. Pile axis spacings for piled raft foundations embedded in high plasticity clay soil were investigated by Yazıcı[11]from different point of views by means of the programs Plaxis 3D Foundation and Plaxis 2D. In the end, the following aspects were reached; three dimensional finite elements software is more realistic and convenient for the modeling of piled raft foundations in the aspects of defining the parameters, dimensioning and computation phases in terms of examining the field effect of structural elements; shear deformation reaches its maximum values at the edges of the raft foundation while minimum values were seen through the bottom elevation of piles at the edges; as the axial distances between the piles increase, volumetric and shear deformations stay steady beginning from the distance 4D; in the two

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dimensional analsis, while settlement degrees show a significant decrease as the axial distances between the piles increase starting from 6D, they remain constant after decreasing to 6D in the three dimensional analysis; in the values of vertical displacement and volumetric deformation, the results of the three dimensional analysis give higher values compared to that of two dimensional. Improvements in the bearing capacities of foundations sitting on piles with various length and number were analysed by El-Garhy et al [12]. It was stated that in piled foundations which had the same values of rigidity and length, the ratio of improvement in the bearing capacity when there were 9 piles were 55 % while the same ratio reached to 95% as the number of piles were increased to 16. It was observed that significant increases took place in the bearing capacity ratios in all of the rigidities as the number of piles was increased. On the other hand, it was expressed that while increases in the rigidity of the raft foundation had considerable impact in reducing the differential settlements, it did not have any effect in the load sharing between piles and raft and in the values of total settlement. The static response of a foundation supported by a group of 16 piles embedded in a uniform homogeneous soil is investigated using a 3D finite element model by Bağrıaçık and Uysal [13]. The soil and piles are modelled using 3D solid elements. The problem investigated in this study is the static response of a piled raft foundations embedded in a 0,70m deep homogeneous soil deposit. The piles comprises 0,20 m long × 0,10 m diameter 16micro-piles that were rigidly connected to a 0,15m × 0,15m × 0,10 m thick steel pile cap. The following conditions were investigated: bearing capacities and settlement were determined for a piled raft foundation under different pile placement angle. As a result; the maximum deformations have been occurred at soil surface at piled raft foundations, the applied vertical loads have been transmitted deeply through the pile length and the maksimum additional stress values because of the piled raft foundations have been occurred at end point of piles, it has been determined the piles have transferred the building loads deeper, it is evident that bearing capacity ratio increase with pile increasing placement angle, it has been observed that pile placement angle has a significant effect on the bearing capacity ratio and taking account pile placement angle plays a vital role in the behaviour of piled raft foundation concept.

III. MATERIAL AND METHOD

In the examinations, sand samples which were taken from River bed in Adana were used. Experiments were performed at soil mechanics laboratory of Çukurova University on oven-dried sand samples. The sand was classified as uniform clean sand (SP) according to TS 1500. Test results of the sieve analysis are given in Table 1 [14]. Experimental studies were performed at the soil mechanics laboratory of Çukurova University bu using a box having a square cross-section and dimensions of 1.17 m width and 0.5 m height. The test box had a framework consisting steel profiles and its front and rear faces were made out of 0.006 m thick glass. The box's lateral surfaces and bottom were made from 0.02 m thick timber material [14]. Piles and raft foundationwas produced from steel which has stiffness 210000 Mpa, unit weight 77 kN/m^2, diameter 0.01 m.The experiments were performed with a special testing device which was produced to be able to exert tension and compression at various time rates of loading. The loading apparatus was assembled onto the loading beam at the soil mechanics laboratory of civil engineering department. In order to determine the values of the load which were applied on the raft foundation, an electronic load cell was used which was produced by ESIT Company. The applied vertical loads were transferred via the load cell to the data logger device (ADU) which had 8 channel entries. Afterwards, these data were converted into numerical values in a computer environment by using the program called DIALOG. The model testing apparatus and the testing photos is shown in Figure 3 and Figure 4 and the experiments were conducted by taking the following aspects into consideration. Sandy soil was placed into the box as layers and by performing compaction in order for the sand to have a specific gravity of $\square_k$ = 17.06kN/m^3. After the compaction process, the piled raft foundationswas put into sand layer via motor system. Subsequent to the compaction of the sand and after the foundation plate was placed in sand layer, measuring system was placed on raft foundation. It was paid attention for the applied load to have an impact in the vertical direction towards the centre of the raft foundation and to be uniform.

TABLE 1 : SOIL PROPERTIES [19]

Granulometric Parameters	Unit	Value
Percentage of Medium Grained Sand	%	46.40
Percentage of Fine Grained Sand	%	53.60
Soil Class	-	SP
Maximum Dry Specific Gravity	kN/m^3	17.06
Minimum Dry Specific Gravity	kN/m^3	15.03
Specific Gravity	kN/m^3	26.80

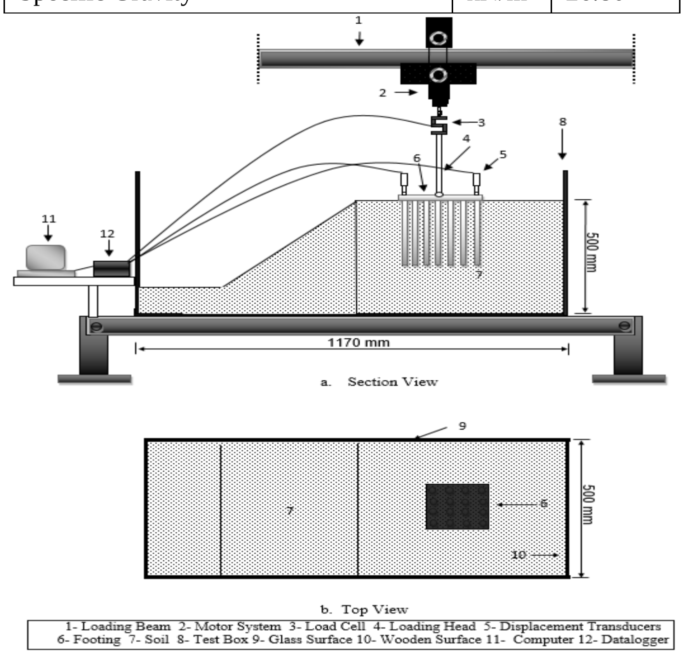

FIGURE 3. MODEL TESTING APPARATUS

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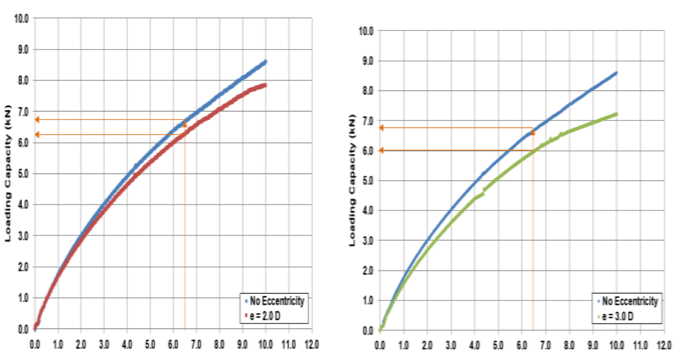
FIGURE 4. TESTING PHOTOS

IV. RESULTS AND AND DISCUSSION

The vertical displacement graphics of bearing capacities for piled raft foundations in vertical loading conditions with 2.0 D eccentricity and non-eccentricity, 3.0 D eccentricity and non-eccentricity, 4.0 D eccentricity and non-eccentricity and 5.0 D eccentricity and non-eccentricitycan be seen in Figure 5 respectively. The bearing capacity is definedas the vertical displacement value corresponding to 5 percent of the pile diameter. All the test results were interpreted using this approach.Bearing capacity values, loss of bearing capacity values for the eccentric loading condition of the piled raft foundation can be seen in Figure 5-6 and Table 2, respectively.



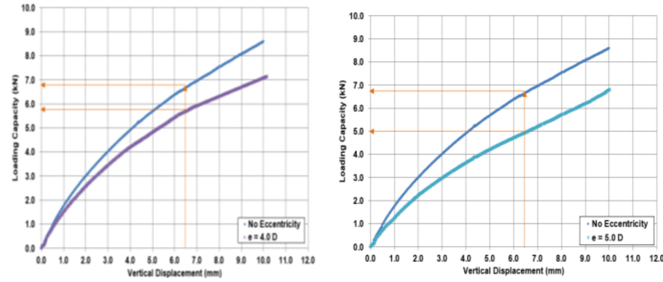


FIGURE 5. LOADING CAPACITY – VERTICAL DISPLACEMENT GRAPHICHS

As seen Figures 5-6 and Table 2,the bearing capacity values were decreased as far as 26,47% when the distance of the vertical load to the centre of the piled raft foundation increased (increasing eccentricity). As a result, a significant decrease occurred in the values of the bearing capacities with the increasing eccentricity. It was observed that it is important to direct the vertical load which was applied on the piled raft foundation towards the centre of the foundation.

TABLE 2

THE BEARING CAPACITY VALUES FOR DIFFERENT ECCENTRICITY

Eccentricity (e)	Bearing Capacity (kN)	Loss of Bearing Capacity (%)
No	6.80	-
2.0 D	6.30	7.35
3.0 D	6.00	11.76
4.0 D	5.80	14.71
5.0 D	5.00	26.47

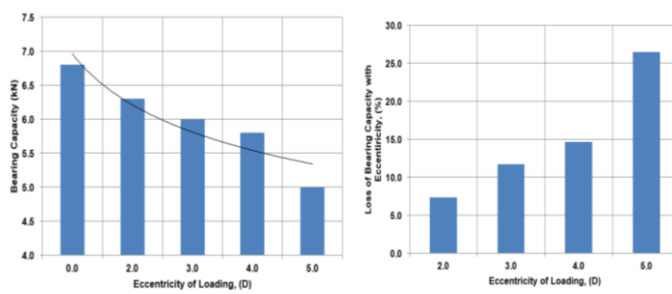


FIGURE 6. BEARING CAPACITY / LOSS OF BEARING CAPACITY– ECCENTRICITY OF LOADING VALUES

V. CONCLUSION

In this study, bearing capacities and settlements have been determined for a piled raft foundations under eccentric loading conditions.It has been determined the piles have transferred the building loads deeper and The maximum deformations have been occurred at soil surface at piled raft foundations. The applied vertical loads have been transmitted deeply through the pile length.Increasing eccentricity from 0 to 5.0 D (D=dimension of piles) resulted in a 26,47 % decrease at bearing capacity in the pile caused by a vertical load.The bearing capacity values were decreased when the distance of the vertical load which was applied on the piled raft foundation from the centre of the foundation was increased (increasing eccentricity). As a result, a significant decrease occurred in the values of the bearing capacities with the increasing eccentricity. It was observed that it is important to direct the vertical load which was applied on the piled raft foundation towards the centre of the foundation as much as possible.It has been observed that eccentric loading has a significant effect on the bearing capacity and play vital role in the behaviour of piled raft foundation concept.

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