Load sharing under 1-g model rigid piled rafts

Répartition de la charge sous le modèle de 1-g des radiers empilés rigides

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ABSTRACT
In this study load bearing and sharing behavior of piled raft foundations are investigated by performing laboratory model tests. Model aluminum piles with outer\inner diameters of 22\18 mm and a length of 200 mm were used. The raft was made of steel plate with plan dimensions of 176 mm x 176 mm and a thickness of 10 mm. The model piles were instrumented with strain gages to monitor pile loads in a tank 410 mm in diameter. Model piled raft configurations with 2,4,7,9 piles were tested. The behavior of a single pile and the plain raft were also investigated. Tests were repeated in each group. It is observed that when a piled raft is loaded gradually piles take more load initially. Load is transferred from piles to the raft with the increasing settlements. The proportion of load that is carried by the raft decreases with the increasing number of piles, and the load per pile is decreased. The decrease is more at smaller settlements and has a limiting value for increased number of piles. Piles under the raft may carry more loads compared to single piles due to load transfer and confinement. Center, edge and corner piles are not loaded equally under rafts. It is found that rafts share foundation loads at such levels that should not be ignored.

RÉSUMÉ
Dans cette étude le comportement de porter et de partager la charge des bases de radier empilées sont examinés en éxécutant des tests sur les modèles de officine. Des piles exemplaires en aluminium avec diamètres extérieurs\intérieurs de 22\18 mm et une longueur de 200 mm ont été utilisées. Le radier a été fait de plat en acier avec des dimensions de plan de 176 mm x 176 mm et une épaisseur de 10 mm. Les piles exemplaires ont été équippées avec des jauges de tension pour surveiller des charges de pile dans un réservoir 410 mm de diameter. Des configurations de radier empilées exemplaires avec 2,4,7,9 piles ont été analysées. Le comportement d'une pile singulière et de radier plat ont été aussi étudiés. Les essais ont été répétés dans chaque groupe. On observe que quand un radier empilé est chargé graduellement, les piles prennent plus de charge au début. La charge est transferrée des piles au radier avec les tassements grandissants. La proportion de charge qui est portée par le radier diminue avec le nombre de piles, et la charge par pile est diminuée. La diminution est plus à plus petits tassements et a une valeur limite pour le nombre de piles augmenté. Les piles sous le radier peuvent porter plus de charge par comparaison avec les piles singulières, à cause du transfert de charge et de l'emprisonnement. Les piles de centre, de bord et de coin ne sont pas chargées également sous les radiers. On trouve que les radiers partagent les charges de base à tels niveaux qui ne devraient pas être ignorés.

Keywords : piled raft, load sharing, laboratory model study, 1-g model, sand clay mixture

1 INTRODUCTION

Piled foundations are extensively used to transfer heavy structural loads to stronger subsoils to reduce total and differential settlements and to avoid tilting of the high rise buildings. Conventional pile groups are designed so that all structural loads are carried by piles. Generally contact of pile cap to the ground is neglected, and its contribution to the total load bearing capacity of the pile group is not considered. In reality the load carrying mechanism of a piled raft is very complex, and the load is shared between the piles and the raft if the raft is in contact with the ground. In recent years contribution of raft to total load bearing capacity is being considered in design approaches and in some local codes which leads to considerable reduction in the pile construction costs.

In this study, the load bearing behavior of piled raft foundations is investigated through laboratory tests. Model foundations were instrumented in the laboratory in order to investigate load-settlement behavior and load-sharing mechanism of piled raft foundations (Türkmen, 2008). Different configurations of piled raft foundation models were tested in the laboratory. Load sharing mechanism and effect of settlements on this mechanism were investigated.

2 LABORATORY MODEL TESTS

Load sharing and distribution of loads on piles in different configurations of pile groups were investigated. Compression behavior of the piled rafts was also measured. The tests were performed on models of piled rafts, plain raft and single pile. The number of piles varied in the piled raft tests. Every test was repeated two to four times. Model piled raft configurations are presented in Figure 1.

2.1 *Soil properties and preparation*

The soil mixture used in the tests was composed of 50 % kaolinite type remolded clay and 50 % sand by weight. The powdered kaolinite clay (Tekin, 2005) was mixed with sand by means of a mixer to have uniform mixture and water was added in the mixture to have optimum water content (w=17 %). Particle size distributions of clay and sand used in model tests are shown in Figure 2.

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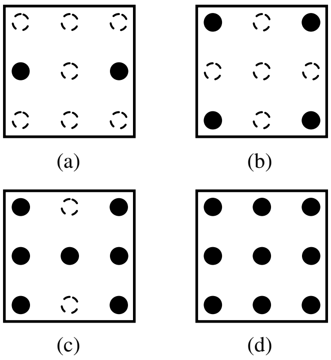

Figure 1. Model piled raft configurations: a) piled raft with two piles, b) piled raft with four piles, c) piled raft with seven piles, d) piled raft with nine piles

Tests were conducted in a steel circular container which has a diameter of 410 mm and a height of 380 mm. Six layers of soil mixture was placed in the container and each layer was compressed by a hydraulic jack. The applied pressure for compression was controlled by a load cell. In order to apply pressure and compress the placed layer of soil in the container in a controlled way easily, wooden blocks having a thickness of 56 mm were manufactured. Each layer had an equal weight of 15 kg and equal applied compressive force of 4800 kg.

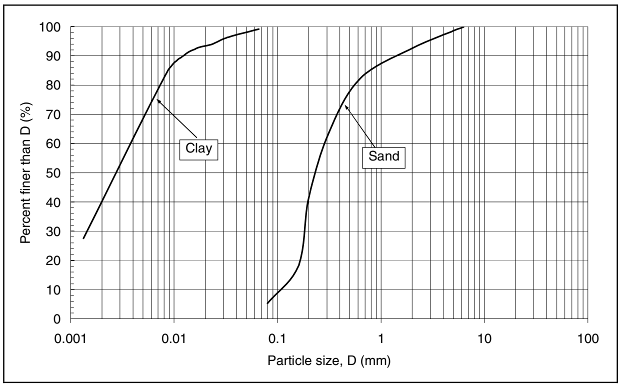

Figure 2. Particle size distributions of clay and sand used in model tests

2.2 *Model test setup, instrumentation and test procedure*

Model piles were made of aluminum having an outer diameter of 22 mm and an inner diameter of 18 mm. The length of the pile below the soil surface was 200 mm. The smooth surface of the aluminum model piles were roughened with lathe and the tips of them were closed. The piles were instrumented with strain gages at the upper section, below the raft level, in order to measure the load transferred from the raft to the piles. Full bridge configuration was used for the connection of the strain gages. It is insensitive to the bending loads but sensitive to the axial loads. Instrumented model piles were calibrated in the laboratory using a mechanical press with known loads.

The model raft was made of steel, 176 mm square and 10 mm thick. The raft had nine holes to fix the piles. The piles were connected to the raft with manufactured fixing elements.

Load was applied by a pneumatic air cylinder as shown in Figure 3. The cylinder was a single action air cylinder and powered by an air compressor. The pressure applied was controlled with a valve. Load applied to the model foundation was measured by a load cell and recorded using the data acquisition system.

Settlements were measured using mechanical dial gages. They were placed at two sides of the raft as shown in Figure 3 and displacements were observed and recorded during the test.

After placing and compressing the soil for an hour the pressure was released and the guide holes for the piles, simulating the bored pile process, were drilled by hand augers. The model piled raft was placed on the holes and it was pushed into the soil using the hydraulic jack till the raft was in contact with the soil. The load cell and the pneumatic air cylinder were then assembled to the system. After plugging the load cell and strain gage cables to the data acquisition system and placing dial gages on the raft load was applied at the center of the model piled raft foundation. Load was kept constant for 5 minutes at every increment of load, and three settlement readings were recorded during this period. The waiting period to take readings was considered sufficient because the displacements did not increase with time on the 50 % sand and 50 % clay mixture.

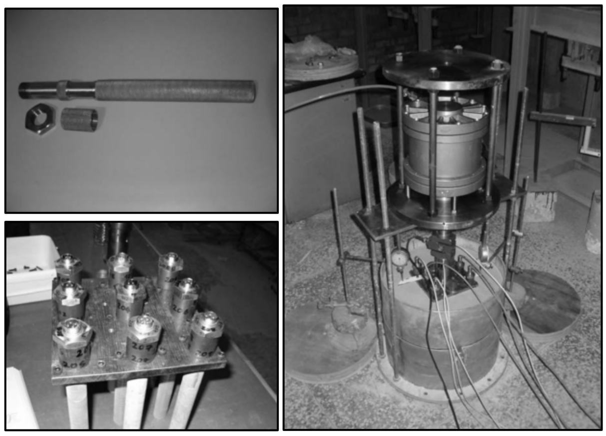

Figure 3. Model pile, piled raft and the loading system

2.3 *Discussion of laboratory model test results*

Settlements (s) and applied loads (Q_{Total}) were measured in every test. Settlements were measured at two points and the average of those values is given as total settlement. In the tests with piles the forces at the upper section of the piles were also measured.

The difference of the total applied load and the total pile reactions (Q_{Pile}) is equal to the load carried by the raft (Q_{Raft}). Settlements are presented in a dimensionless form dividing them by the width of the footing (B) in the following sections.

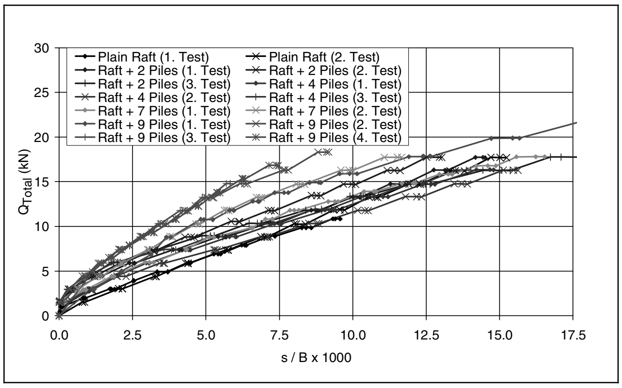

Figure 4. Load – settlement relationships of piled rafts and plain raft

Figure 4 shows the load-settlement behavior of different piled raft configurations and plain raft. As the number of piles increases load carrying capacity of the combined foundation improves. Increasing the number of piles reduces settlements which affect the load sharing mechanism of piled rafts. A raft with less number of piles settles more at the same load.

If the average pile loads are considered shown in Figure 5 for the piled raft with nine piles, more load is carried by center piles and the least by the corner piles. This shows that position of the pile in a group is also significant in the distribution of loads on piles.

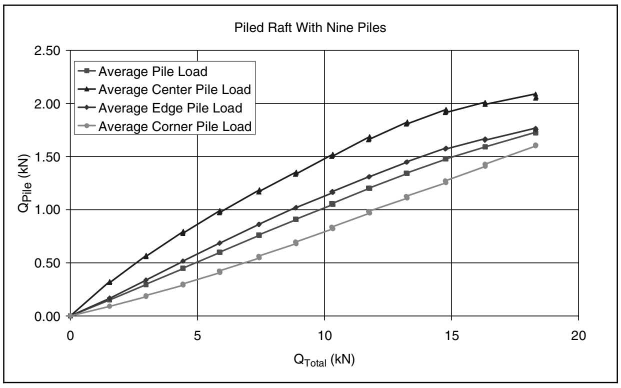

Figure 5. Average single pile loads for different locations of piles in the piled raft with nine piles

Raft load coefficient is the ratio between the raft load (Q_{Raft}) and the total vertical load. Figure 6 shows variation of the raft load coefficient with settlement for the piled raft with seven piles. Raft load coefficient of zero indicates the case of a piled foundation with no contact pressure between the raft and soil mass, and all load is carried by piles. On the other hand, raft load coefficient of one indicates the case of a plain raft without any piles. At the initial stages of loading raft load coefficient remains constant. With increasing displacements raft load coefficient increases.

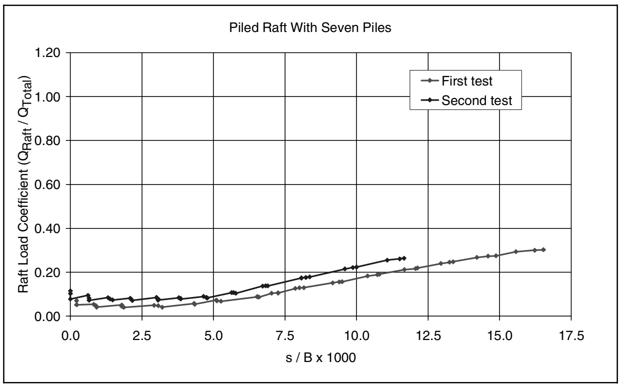

Figure 6. Raft load coefficient–settlement relationship of piled raft with seven piles

At the initial stages of loading nearly the entire applied vertical load is carried with piles for the piled raft with seven piles. After some displacement occurs, piles start to carry more load. Up to a certain point, load carried by the raft remains nearly constant. As settlements increase, the full capacities of piles are mobilized and raft shares more load. After piles reach their full capacity, the load carried by piles remains nearly constant and additional loads are carried by raft.

Variation of the raft load coefficient with settlement for the piled raft with two piles is shown in Figure 7. Unlike the previous case, piles and raft share the nearly equal loads at the initial stages of loading. Piles reach their full capacity at a lower load and settlement level compared to the case with seven piles.

It is observed that initial load sharing proportion depends on the number and capacity of piles. Initial raft load coefficient of the piled raft with two piles is higher than that of the piled raft with seven piles.

Isolated single pile behavior under load is compared with the behavior of a pile under piled raft foundations. The pile load-settlement behavior of single piles and piles in different pile configurations (rafts) are presented in Figures 8 and 9.

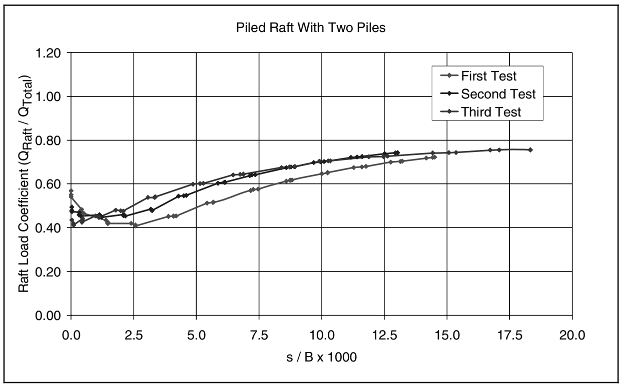

Figure 7. Raft load coefficient–settlement relationship of piled raft with two piles

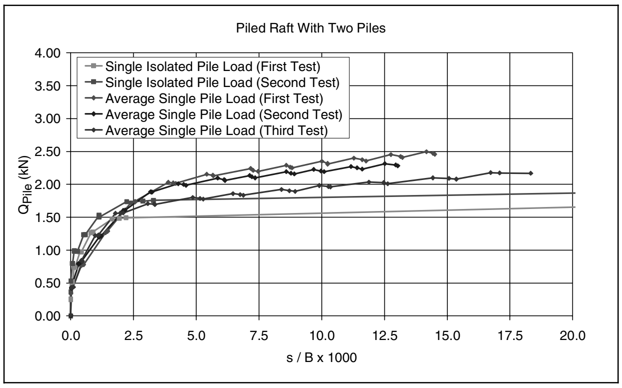

Figure 8. Load–settlement behavior of single pile in the piled raft with two piles

If these figures are examined it can be seen that load bearing capacity of a single pile is improved under the piled rafts with small number of piles. With the decreasing number of piles in the group, the piles are used up to a load level higher than ultimate load of the single isolated pile. This improvement may be due to larger raft contact with the ground. Raft transfers some of the applied loads to piles, and the confining stress around the pile shaft increases.

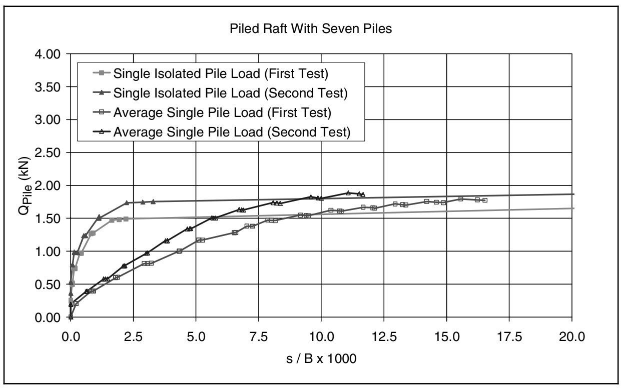

Figure 9. Load–settlement behavior of single pile in the piled raft with seven piles

In Figure 10 effect of pile number to the load carried by piles is presented. With the increasing number of piles, the load carried by single piles decreases. In the piled rafts with seven and nine piles load carried by a single pile is nearly half of the ultimate load capacity of the single isolated pile at the low settlement levels. At the high settlement levels it is nearly equal to the ultimate load capacity of single isolated pile. For the small number of piles, the piles can be used up to a load level higher than the load capacity of a single isolated pile. This shows that additional improvement of pile capacity due to increase of the contact pressure of the raft is not observed if larger numbers of piles are used due to high safety factors (See Figure 8 vs. Figure 9). In a way pile efficiency decreases due to interaction of piles in piled rafts with large number of piles.

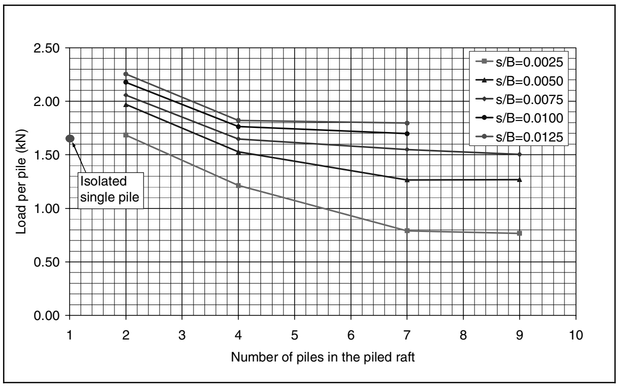

Figure 10. Effect of number of piles to the load carried by piles in piled rafts

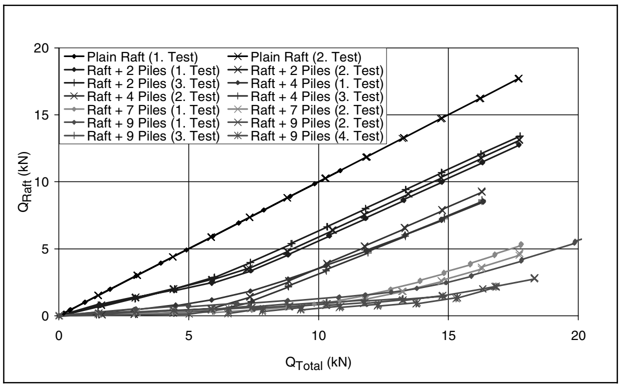

Figure 11. Load transferred by raft in different piled raft configurations

The load transferred by raft with different pile configurations at different load levels is presented in Figure 11. With the increasing pile number, the contribution of the raft to the total load bearing capacity is decreased. This shows that the contribution of raft to the load bearing capacity can be increased by reducing the number of piles to a predetermined serviceability (settlement) limit. This behavior is also presented in Figure 12. With the increasing number of piles, raft load coefficient decreases which means that load carried by the raft decreases. Raft loads are increased with increasing settlements.

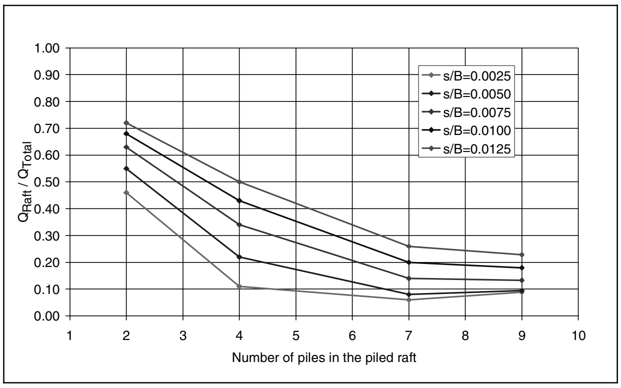

Figure 12. Effect of number of piles to the load carried by raft in piled rafts

3 CONCLUSIONS

In this study, laboratory tests were performed and the load bearing behavior of piled raft foundations was investigated. The conclusions drawn from this study are as follows:

1. When a piled raft is loaded gradually piles take more load initially and after they reach their full capacity additional loads are taken by raft.
2. Initial load sharing proportion depends on the number and capacity of piles.
3. Raft load coefficient (Q_{Raft}/Q_{Total}) decreases with increasing number of piles. The decrease is more at smaller settlements and has a limiting value. For an increased number of piles (9) load shared by the raft is between 6 % and 23 % depending on the settlement level. For smaller number of piles, raft load coefficient is higher.
4. When the number of piles is increased, load per pile is decreased. The decrease is more pronounced at smaller settlements.
5. It is observed that the behavior of a pile as a part of the piled raft is different from its behavior as a single pile. If the pile group is designed as a piled raft and the raft transfers stresses to the ground, a pile in that group carries a load which is higher than the ultimate load capacity of a single isolated pile. This improvement may be due to increase in the confining stresses due to the contact pressure of the raft.
6. The load is applied at the center, and center piles carry more load than edge and corner piles in the model tests. Corner piles carry the least amount of load in the tests. These observations show that concentration of piles under heavily loaded areas may be a good practice for an optimized design of a piled raft.
7. Finally, bearing contribution of raft is not insignificant and negligence of it (which has been the case until present) should not be practiced in piled raft foundation design. Level of factor of safety used is important in order to optimize the design of a piled raft foundation. Factor of safety specified determines the number of piles and the number of piles play an important role in using the piles and the raft effectively. In conventional design methods high safety factors are considered. This causes low settlements and accordingly low load sharing of the raft. As a result piled foundations are designed conservatively and not economically. In recent years, low factor of safety values are considered especially for foundations in which piles are used as settlement reducers. In order to optimize the design of a piled raft foundation, low factors of safety should be used resulting in acceptable settlements.

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