# LOAD-DISPLACEMENT TEST OF FLOATING RAFT-PILE SYSTEM IN SOFT SOIL

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***ABSTRACT***

*Here, the load test series of the foundation models subjected to vertical axial loading are presented. The loading test of the wooden foundation follows the procedure that is modified from the Constant Rate of Penetration test which provides better results in the expressions of load-displacement curves. Using the modified CRP procedures, the more load-displacement points can be gained every load test. In this investigation, there are two models typically tested; the first model consist of 40cm×40cm raft combined to 4 piles with 3 cm in the diameter of and 60 cm of length, the second one is 30cm×60cm raft combined to 2 piles with the diameter of 7 cm and the length of 150 cm. The centre to centre spacing of the piles is set to be 5 times the diameter of the piles. The maximum capacities of the foundations can be estimated from load-displacement curves resulting from the tests. Then, the behaviour of the raft-pile foundation in term of load-displacement is then investigated. Using the proposed formula, it was found that the efficiency of raft-pile system reach the value more than 100%.*

**Keywords:** Raft-pile foundation, floating pondation, load test

## INTRODUCTION

Recently, the effects of the individual piles and the cap to the bearing capacity of the raft pile floating in soft clay are elaborated (Hakam et al., 2004). The investigation is performed in the basis of the laboratory works. The experiment results of the series test of the foundation models are plotted in the term of load-displacement curves. The raft-pile efficiency formula is nevertheless introduced to outline the load capacity of each element composed a raft pile foundation.

The term of raft pile foundation is adopted when the pile(s) and its cap combined to form a single foundation system. The system interacted with the soil then is used to support the applied load. The load transfer mechanism from the foundation to the supporting soil is highly complicated. However it can be investigated in some way using experiments as well as numerical simulations. The numerical simulation in order to achieved optimum design of raft pile foundation has been conducted by Valliappan et al.,1999. However the effects of each element forms the foundation can not be figured out.

Davis and Poulos, 1972 proposed the method for analyzing and designing the raft-pile system. The scheme for solving the problem is based on the analysis of the pile groups rather than the behaviour of the system. Even the pile cap commonly poured directly on the ground, the contribution of the cap of the pile groups to the bearing capacity is usually neglected due to the simplicity reason. The load capacity of the pile group may not be the same as the sum of the load capacity piles. The effects of grouping the piles raise the ratio of the group capacity and the sum of the piles in term of efficiency of the pile group. A number of references have suggested the formulas to estimate the pile group efficiency (ex. Das, 1990 and Bowles, 1988). Theoretically the pile group efficiency is restricted and always less than 100%.

The efficiency of the raft-pile system is found greater than the sum of pile and raft capacities. Hakam et al. 2005, proposed a procedure to estimate the load capacity of floating raft-pile foundation in soft clays. The proposed bearing capacity evaluation procedure is resumed in the following section. In the last of this paper, the test results are compared to the calculated bearing capacity using the suggested formulas.

## RAFT-PILE BEARING CAPACITY

In the past, Davis and Poulos (1972) proposed the analysis procedure to estimate bearing capacity of a raft-pile system. The complexity is the weakness of the procedure to be adopted for practical purpose. Moreover, the proposed scheme is inadequate to be adopted for describing the behaviour of the raft-pile system.

Based on several tests of foundations in laboratory, Hakam et. al, 2004 analyzed the efficiency of the raft-pile foundation which is defined as ratio of the system compared to the sum of the individual pile and the raft. The efficiency of the raft-pile system , $E_{rp}$, is written as;

$$E_{rp} = \frac{\text{the raft - pile capacity}}{\text{the sum of the individual pile and raft capacity}}$$

Using the above equation, the efficiencies of the raft-pile system from a number of tests are found higher than 100%.

Since the efficiency of the raft-pile system is greater than the sum of pile and raft capacities, it is proposed the use the sum value of the piles and the raft to estimate the load capacity of raft-pile foundation (Hakam et all. 2005). Afterward, for particular raft-pile foundation floating in soft soil, the total load capacity of the system can be estimated as;

$$Q_T = Q_R + \Sigma\,(Q_P + Q_S)$$

Where $Q_R$ is the load capacity of the raft (in pile groups cases, it is the cap), $Q_P$ and $Q_S$ are the bearing capacities of the pile at the tip and the skin resistance respectively.

The simple confessional term of ultimate equation for spread footing is thereafter used to predict the raft ultimate load capacity in the form;

$$Q_R = A_b\, F_t\, Cu\, N_c^*$$

Where $A_b$ is the cross section area of the foundation at the base, the bearing capacity factor $N_c^*$ equals to 5,14 and the value of the type factor $F_t$ is 0.45 which represents the value for the punch failure. Cu is the undrained cohesion strength which can be obtained from unconfined compression shear test. For strip foundations with length-width ratio equal or greater than one and a half, the ultimate load capacity $Q_R$ must be reduced by the factor of 0,77.

The ultimate point bearing capacity of pile can be estimated by;

$$Q_P = A_P\, Cu_{(p)}\, N_c$$

Where $Cu_{(p)}$ is undrained cohesion soil strength at the pile tip, $A_P$ is the cross section area of the pile tip and $N_c$ is the bearing capacity factor, it is 9 for Meyerhof's and 5,7 for Janbu's one. Since for soft soil the piles are considered as floating one, the tip resistance will not be significant to contribute the pile capacity. Then, any values of bearing capacity factor $N_c$ can be adopted arbitrary.

The skin resistance for pile with the perimeter, $\Theta$, is the sum of the resistance every length section, $\Delta L$, that is calculated using;

$$Q_S = \Sigma\,(Cu\, \Theta\, \Delta L)$$

**SCALED FIELD TEST**

The loading test of the foundation stick to the procedure that is modified from the Constant Rate of Penetration test. The constant rate procedure forces the foundation to deflect at 0.5mm per minute. Since the model foundations are small, consequently the load increment must be applied in relative small amount as well. As a result, the displacement of 0.5mm is predicted will not be reached in a minute. In these tests, the foundations are then loaded in a number of equal load increments and the displacement is recorded every 10 seconds for one minute. This modified CRP test procedure provides better results in the expressions of load-displacement curves. Using this technique the more load-displacement points can be gained every load test. Moreover, the displacement recorded every minute is less than the criterion of 0.5mm.

The models of foundation are loaded in the field by a hydraulic jack. Firstly, the models of single piles are driven into the soil. Then the load is incrementally applied on the top of each pile. The load and the displacement of the piles are recorded along the loading process. The loading is terminated when the above criterion is reached, it is indicating the maximum restraint of the pile. The maximum capacity of every single pile can be estimated from load-displacement curves resulting from the tests.

By placing the cap on the top of the piles, the pile groups are then pushed in the same way in to the soil. The increment axial load applied on the centre of the cap and the displacement of the group is obtained. Subsequently the maximum load of the group obtained from the load-displacement curve of the foundation. In the same procedure, the raft pile foundation and the separate plate on the soil are tested.

In this investigation, a number of wooden pile models are tested. There are two models typically tested to obtain the load-displacement curve of the raft-pile system. The first model consist of 40cm × 40cm raft combined to 4 piles with the diameter of 3 cm and the length of 60 cm. The second model is composed of 30cm × 60cm raft combined to 2 piles with the diameter of 7 cm and the length of 150 cm. The centre to centre spacing of the piles is set to be 5 times the diameter of the piles. The rafts are made of wood and have the thickness of 8cm.

The soil has the parameters as shown in the Table 1. Since the soil is classified as very soft soil, the strength and the elasticity of the piles and the raft materials can be assumed to be much stiffer than the soil. Then the properties of the foundation are not necessarily to be examined. The behaviour of the soil-foundation system depends on the entire system than the material of the structures.

**Table 1** The soil properties

| No. | parameter | value | unit |
|---|---|---|---|
| 1 | natural water content | 75.6 | % |
| 2 | unit weight | 1.71 | ton/m$^3$ |
| 3 | specific gravity | 2.75 | - |
| 4 | plastic index | 26 | % |
| 5 | soil particles | 35 | % |
| 6 | $q_u$ | 0.14 | kg/cm$^2$ |

**Figure 1** Field test models of the foundations.

## RESULTS

The results of the series load tests are plotted in graphs represent the increment vertical load against the corresponding displacement. For the first typical model of raft-pile test series, those load-displacement curves are shown in Figure 2 to 5. The maximum loads that representing the ultimate load of the foundation are determined from the corresponding graphs. The displacement of the tested foundation may rise with the load up to a certain point, beyond which the load-displacement curves become linear. The load corresponding to the point in where the linear portion starts is taken as the ultimate load for the foundation. To assist on finding the ultimate points, the guide dot lines are drawn in some results.

Figure 2 shows the results of the load test for four separate piles named P1 to P4. Even the load-displacement graphs of the piles are not matching each other, they present exactly the same ultimate load. The curves met in the point that is for the load of P=135 kg and taken to be the ultimate load for these test series.

The four piles P1 to P4 then are fixed together with a cap to perform a pile group. The load test of the group in terms of load-displacement graph is shown in Figure 3. The ultimate load of the group is 500kg. In the term of group efficiency, this group has the efficiency of 93% which performs a very good value.

The load displacement of the 40cm x 40cm raft is presented in Figure 4. The ultimate load for the raft is 440kg. Figure 5 shows the load-displacement curve for the raft-pile system which is the last test for these set. The raft-pile system gives the ultimate load of 1080kg. Figure 6 shows the load-displacement curve of the pile group (from Figure 3), the curve of the raft (from Figure 4) and the raft-pile (Figure 5) are plotted in the right ways together. Interestingly, this figure shows that load-displacement of the raft-pile consist of two graphs that made up the system. The raft tends to work prior to the piles and there is transition between them that is indicated by transparent area (Figure 6). The combination of the group and the raft in the term of raft pile system increases the ultimate load of the raft pile by 115%. Using the proposed formula, the raft-pile efficiency is 110% (it is still more than 100%).

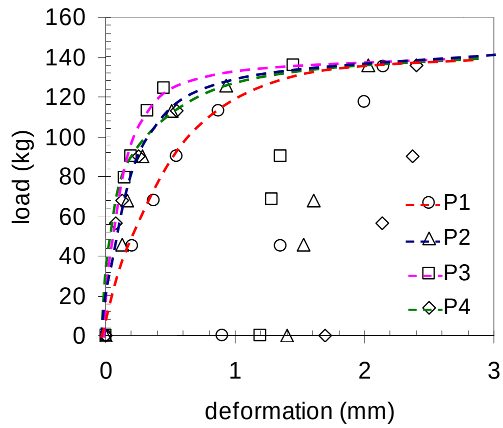


**Figure 2** Piles 3-60 (P=135kg d=2.2mm)

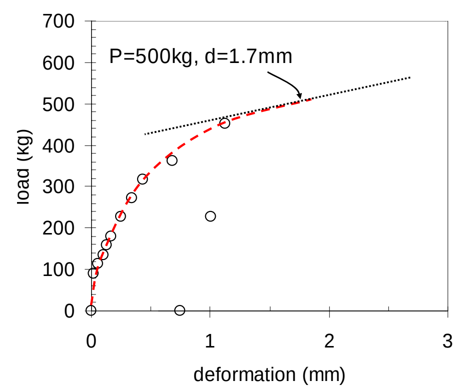


**Figure 3** Piles group (4×3-60)

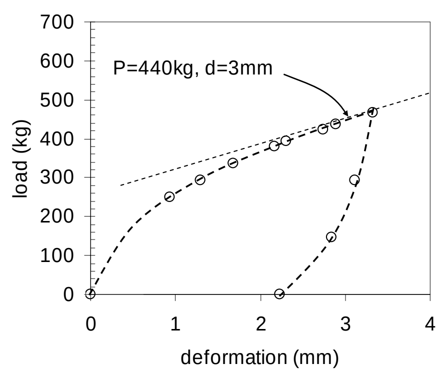


**Figure 4** Plate 40cm ×40cm

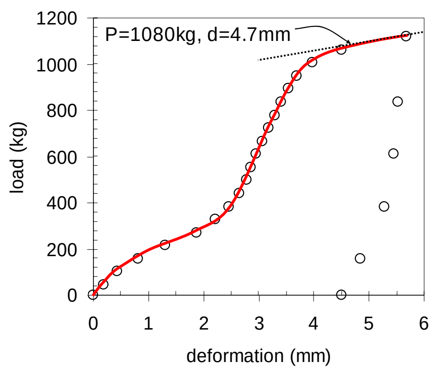


**Figure 5** Raft-Piles - 1st model

**Figure 6** Raft and group curves in the raft-pile (1st model)

In the same way as the previous test model, the load test series are conducted to the second model of raft-pile system. Figure 7 shows the results of the load test for two separate piles that are P5 to P6. Again, even thought the load-displacement graphs of the piles are not matching each other but they present the same ultimate load. The load capacity of the each pile is 320 kg (Figure 8). The load test of the group (P5 and P6) has the ultimate load of 600kg. The group has the efficiency of 94% which also performs a very good value.

The load-displacement of the 30cm x 60cm raft is presented in Figure 9, it gives the ultimate load of 415kg. For the raft-pile system, the load-displacement curve is presented in Figure 10 with the ultimate load of 1100kg. In the same way as the first model, the curve of the pile group (from Figure 8), the raft (from Figure 9) and the raft-pile (Figure 10) then are plotted in the right ways together (Figure 11). Even it is not as clear as before, this figure again shows that load-displacement of the raft-pile made up of two graphs. The initial slope of the raft still met the initial slope of the raft-pile. Also the raft tends to work prior to the group. There is transition between them as well that is marked by transparent area (Figure 11). The combination of the group and the raft also increases the ultimate load of the raft pile by 108%. Using the efficiency formula it is 104% which is still more than 100%.

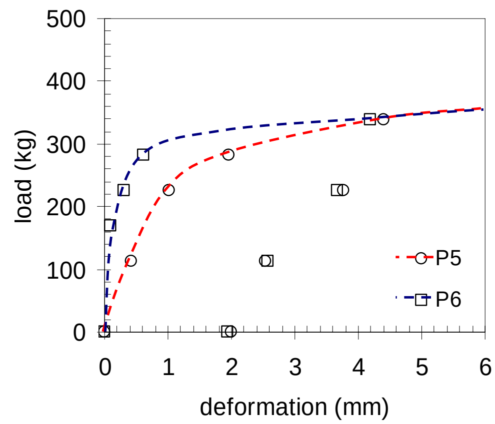


**Figure 7** Piles 7-150 (P=320kg, d=5mm)

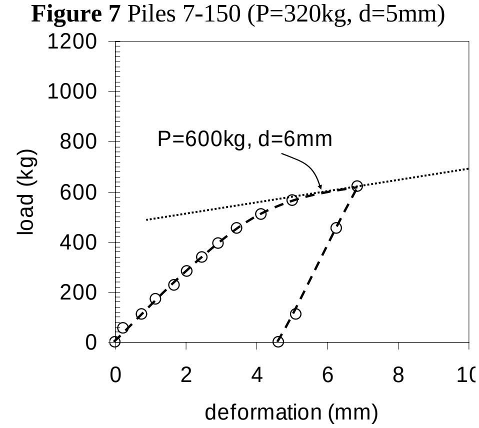


**Figure 8** Pile Group 2×7-150

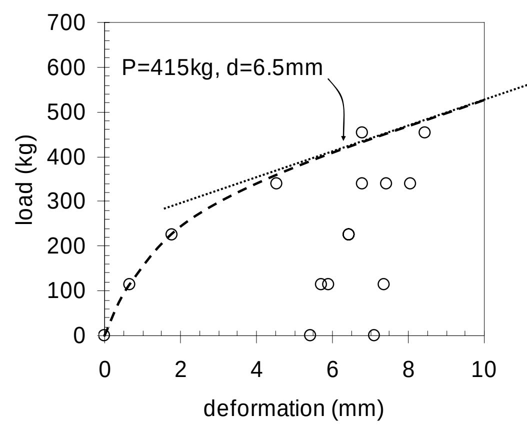


**Figure 9** Plate 30cm × 60cm

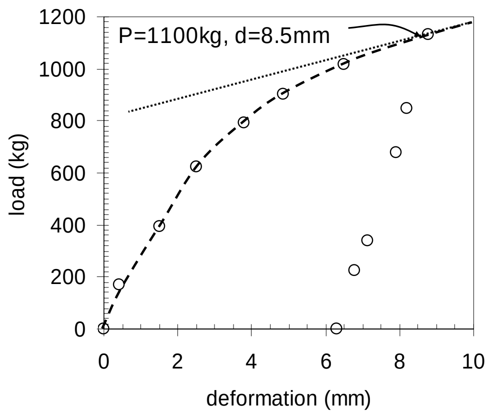


**Figure 10** Raft-Pile - 2nd model

**Figure 11** Raft and group curves in the raft-pile (2nd model)

**CONCLUSIONS**

The load test series to the model of foundations subjected to vertical axial loading have been presented in this paper. The loading test of the foundation follows the procedure that is modified from the Constant Rate of Penetration test. This modified CRP test procedure provides better results in the expressions of load-displacement curves. Since the more load-displacement points can be gained every load test, this technique resulting better performance in terms of load-displacement curves. Moreover, the displacement recorded every minute is less than the criterion of 0.5mm.

Based on the result of the tests, the behaviour of the raft-pile foundation in term of load-displacement is then investigated. It is found that load-displacement curves of the raft-pile consist of two graphs that made of the rafts' and the pile groups'. To transmit the applied load to the underneath soil, the rafts tend to work prior to the pile groups. It also can be observed that there are transition curves between them. The combination of the group and the raft in the term of raft pile system increases the ultimate load of the raft pile more than 100%.

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