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BEARING CAPACITY OF RAFT-PILE FOUNDATION USING TIMBER PILE ON SOFT SOIL

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ABSTRACT: Problematic soil (soft soil), generally require a soil improvement techniques. One of the concepts of soil reinforcement is to utilize timber as a material for raft-pile foundation. In this study, a circular containers were used as testing medium for the various model of reinforcement techniques (i.e. pile with different length embedded, raft and raft-pile foundation) including unreinforced model sample. The small-scale model tests were carried out in the laboratory and the numerical analysis conducted by using Plaxis 3D. The raft and pile material using a locally available timber. The results show that the raft-pile foundation shows the smallest vertical deformation (settlement) compared to other types of foundations. The highest settlement reduction was observed in the raft-pile foundation which is almost 65% compared to unreinforced soil. Good agreement results were found between small-scale laboratory model test and numerical modelling, thus indicating the potential used of this foundation type by using local timber.

Keywords: Timber pile, Raft-pile foundation, Bearing capacity, Settlement, Numerical analysis

1. INTRODUCTION

The rapid development of road infrastructure caused the need of land development also continue to grow. In big cities, the development must be carried out on the problematic soil (soft soil), sometimes even having to reclaim the coastal area which is characterized by soft or very soft soil. The soft soil or very soft soil have properties such as highly compressible, low shear strength resistance, low permeability and low bearing capacity. These characteristics are the main problems to build a road infrastructure on it.

The use of piles is commonly used to overcome the condition in which shallow foundation could not applied due to the soft soil layer [1,2]. The piles provide the stiffness to the soil layer and subsequently increase the bearing capacity and reduced the settlements [3,4]. The raft-pile foundation is a composite structure consist of bearing elements, raft, piles and subsoil. Study of interaction between the foundation's elements also conducted by many researchers. The simplified methods were proposed in order to evaluate the interaction between soil profile and load on the raft [5-8]. In recent years, numerical modelling has been widely applied for the analysis of raft and pile foundation [9-13].

This study used a circular containers as testing medium for the various model of reinforcement techniques (i.e. pile, raft and raft-pile foundation) including unreinforced model sample. The small-scale model tests were carried out in the laboratory and the numerical analysis conducted by using Plaxis 3D. The settlement behavior between reinforced and unreinforced soil were discussed.

2. MATERIALS AND METHOD

The loading test of foundation model using a plate bearing test in the laboratory was carried out with 4 different foundation models using a drum container of 60 cm in diameter and 60 in height, respectively. The raft and pile material using a locally available wood. Fig.1 is a soil model without foundation reinforcement, this model aimed to analyze the soil conditions that receive a load as an analysis parameter for other foundation models.

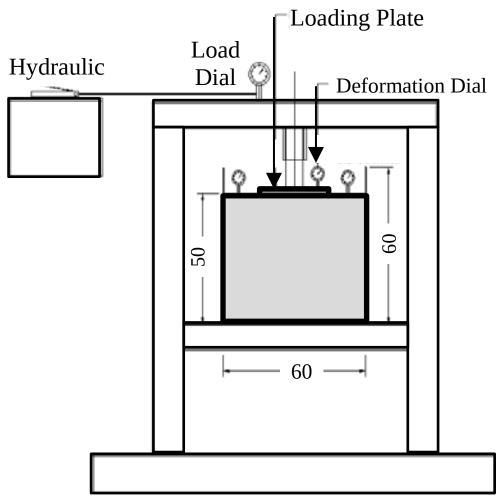

Fig.1 Schematic diagram loading test without reinforcement

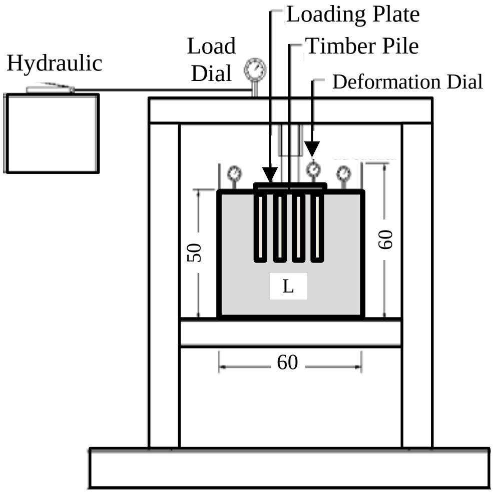

Fig.2 Schematic diagram loading test with various pile length (L)

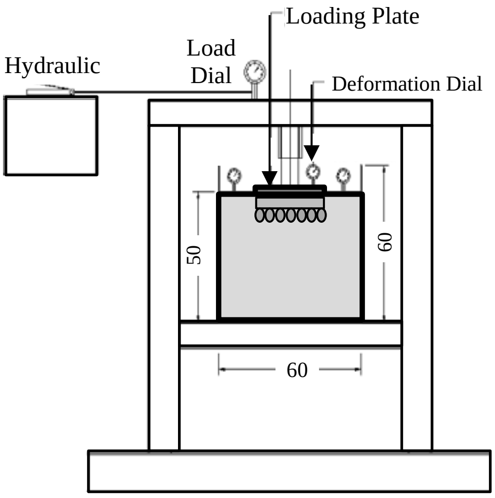

Fig.3 Schematic diagram loading test of raft foundation

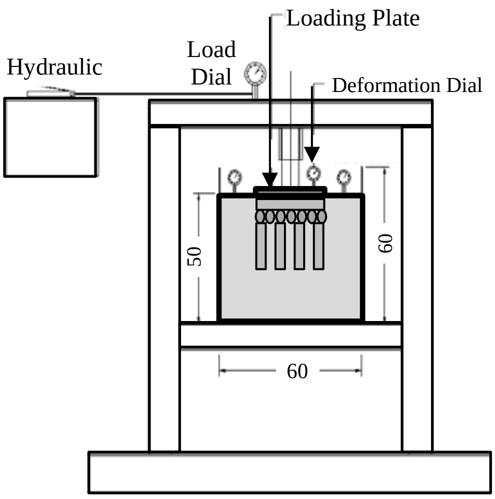

Fig.4 Schematic diagram loading test of raft-pile foundation

Fig. 2 is a single pile foundation model with the varying length of the timber pile (L) varied such as 20 cm, 30 cm, and 40 cm. The third is a raft foundation model with a raft width of 30 x 30 cm as shown in Fig. 3. The fourth loading test is a pile-raft foundation model reinforced by two layers of timber rafts and timber poles with a distance between the piles of approximately 10 cm as illustrated in Fig.4, the timber raft used was two layers crossing the cross-section and longitudinal-section direction. The LVDT (Linier Variable Differential Transducer) used to measure the deformation of the subsoil. The wire was used to tighten between the wooden posts and the wooden rafts. The soil used in this study was classified as a clay with high plasticity (CH). The mechanical properties of timber which is used in this study was presented in Table 1.

Table 1 Local timber characteristics

Properties	Value
Water content	23.9 %
Compressive strength	
- Parallel	23,5 MPa
- Perpendicular	14,2 MPa
Tensile strength	18,1 MPa
Bending strength	105,3 MPa

The numerical analysis in this study was simulated by using Plaxis (3D) software with the hardening soil model to calculate the settlement of the model foundations. The soil stiffness vary with the stress in the subsoil and consistent with the many types of the soil behavior [14]. The soil's parameters in the hardening soil model is presented in Table 2.

Table 2 Soil parameter hardening – soil model

Properties	Soil Layer	Foundation
Type	Drained	Linear elastic
γ_{unsat} (kN/m^3)	14.7	20
γ_{sat} (kN/m^3)	16,5	-
E_{50}^{ref} (kN/m^2)	2855	3x10^6
E_{oed} (kN/m^2)	2775	-
E_{ur}^{ref} (kN/m^2)	7530	-
m	1	-
ν_{ur}	0.3	0.2
c (kN/m^2)	7.3	-
ϕ (^{o})	17.2	-
ψ (^{o})	1.3	-
p_{ref} (kN/m^2)	300	-

3. RESULTS AND DISCUSSION

3.1 The Small-scale Laboratory Model Test

The early stage of loading stage, the settlement was relatively small. The settlement was caused by the elastic deformation of the surrounding soil. The unreinforced soil shows that the increasing of load, the settlement occurred at faster rate until it reached its maximum limit and the soil experienced failure. The maximum load that for the unreinforced soil model can accommodate without foundation is 60 kN with a settlement rate of 57.5 mm.

The utilization of timber pile as a reinforced soil has a significant effect in reducing the amount of settlement of soft soil. It can be seen that the length of the timber pile has an effect on the decrease in extend of the settlement as shown in Fig.5. The reduce of settlement by presence of timber pile mainly due to the pile provide the friction resistance between pile and subsoil, subsequently increase the bearing capacity of subsoil layer [15]. The longer of a pile, the greater the impact of settlement reduction, The maximum load for the longest timber pile (40 cm) foundation model can accommodate is 77.5 kN with a settlement of 35.5 mm.

The settlement of raft foundation is higher than the settlement of the longest pile in this study. For the initial load, the settlement of the raft foundation is relatively the same. However, for larger loads, the effectiveness of raft foundations in reducing settlement is less that that of timber piles as shown in Fig.5. The maximum load that the raft foundation can accommodate is 72.5 KN with the amount of settlement of 37.5 mm.

The lowest settlement was observed in the raft-pile foundation. This mainly due to the vertical pile has confines the subsoil and reduces the lateral deformations and subsequently reduce the settlement of the subsoil. Moreover, load is transmitted by pile to the lower part of the subsoil

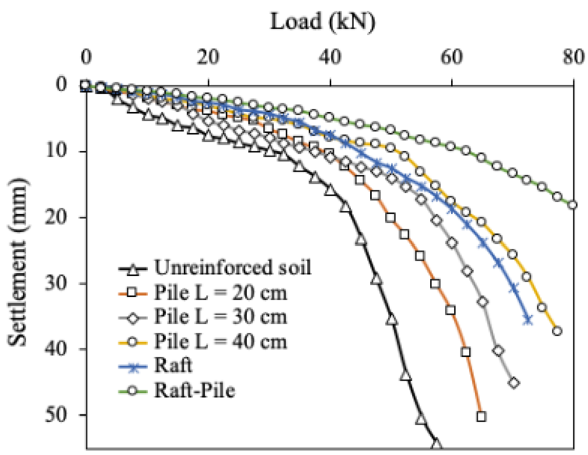

Fig.5 Relationship between applied load and vertical deformation

and a larger bearing area. Since the thickness of the compressible subsoil layer (soft soil) reduced, the smaller settlement observed in the small-scale model test. For the raft-pile foundation model only about 21.5 mm of settlement occurred under the pressure of 85 kN. There is no sign of collapse was observed even at the maximum loading applied (85 kN). The above findings have shown the effectiveness of raf-pile foundation in increasing the bearing capacity and reducing settlement.

Tabel 3 shows the comparison between magnitude of settlement reduction and the maximum applied load. The ratio between settlement of each types of foundation and settlement of subsoil without reinforcement was also presented. The highest settlement reduction was found for raft-pile foundation.

Table 3 Magnitude of settlement of foundation types

Foundation Model	Max. Load (kN)	Max. Settlement (mm)	Ratio (%)
Unreinforced	60	57.5	-
Pile, L = 20 cm	65	50.5	12
Pile, L = 30 cm	70	45.0	22
Pile, L = 40 cm	77.5	35.5	38
Raft	72.5	37.5	35
Raft-Pile	85	20.5	65

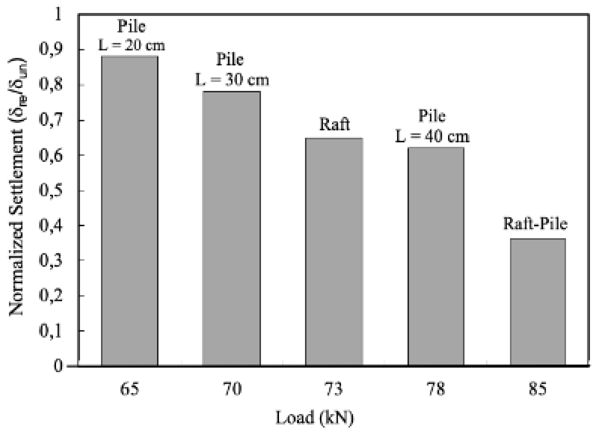

Fig.6 Normalized settlement for various types of Foundation

The normalized settlement between types of reinforcement and unreinforced soil (δ_{re}/δ_{un}) shows in the Fig.6. It can be seen that the lowest ratio was found to be the raft-pile foundation. According to the test result of raft-pile foundation, the subsoil did not show a failure pattern even the maximum applied load of 85 kN. Moreover, the settlement was concentrated at the area of applied load, there is no significant heave near or beside the foundation observed for the raft-pile foundation. This indicates that the bearing capacity of the raft-pile foundation increasing during the loading stage.

3.2 Surface Vertical Displacement (Heave)

The measurement of surface vertical displacement (heave) is carried out at a distance of 7.5 cm from the loading plate and the results are shown in Fig.7. For a load of 30 kN, the unreinforced soil shows a significant increase in the heave value. The longer pile foundation (L = 40cm) indicates that the effect of pile length can reduce heave compared to shorter piles and even for raft foundation. The lowest heave is observed in the type of raft-pile foundation and heave reduction of the raft-pile foundation was significant compared to the unreinforced soil. The lateral ground movement is restrained by embedded timber pile in the subsoil, so that the lateral pressure is also reduced. Therefore, for controlling deformations effectively, longer piles are more suitable.

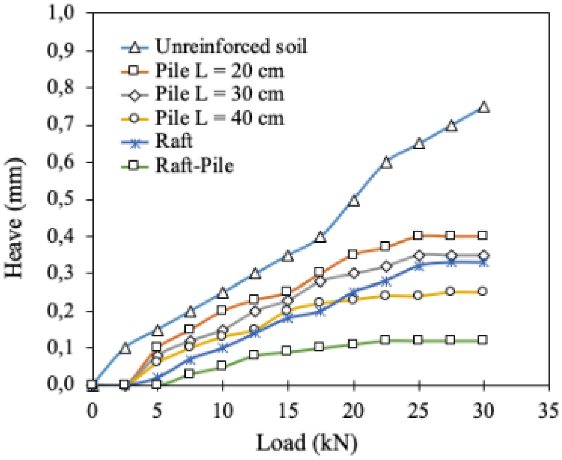

Fig.7 Heave displacement for various foundation types

The ratio between heave and settlement (δ/S) versus applied load is shown in Fig. 8. For the unreinforced soil, the heave – settlement ratio (δ/S) significantly increase when the applied load toward to the failure state. When the applied load approached 30 kN, the δ/S value increases exponentially. Furthermore, the value of δ/S for unreinforced soil is 0.3 which is indicated that unreinforced soil will fail if the heave value reaches 30% of the subsoil settlement.

However, the value of δ/S for the raft-pile foundation shows a relatively small value (0.08) even though the raft-pile foundation has received the maximum load. This indicates that the raft-pile foundation is effective in reducing the settlement and heave significantly. In addition, this correlation is very useful in predicting the magnitude of the settlement if heave occurs on the soil surface around the foundation.

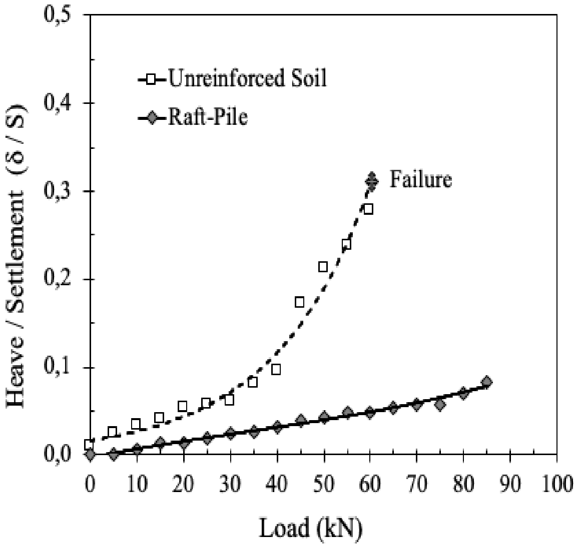

Fig.8 Ratio of heave-settlement curve

3.3 Failure Pattern

From the loading test towards the foundation model in the laboratory, it was found three phases of the failure pattern that occurred in the model. The first phase is that at the beginning of the loading of the soil under the foundation, there is a settlement followed by lateral and vertical downward deformation of the soil, the decrease is proportional to the amount of load applied. In this condition, the soil is still in a state of elastic equilibrium. The soil mass under the foundation experiences compression/compaction which results in an increase in soil shear strength and increases its bearing capacity.

The second phase occurs when the load is continuously increased, the settlement is identified right at the base of the foundation and the plastic deformation of the soil becomes dominant. The soil movement in a plastic position starts from the edge of the foundation. As the load increases the plastic zone develops, the shear strength of the soil develops. The lateral movement of the ground is increasingly evident, resulting in small local cracks and soil shearing around the edge of the foundation. In the plastic zone, the shear strength of the soil is fully developed to withstand the working load.

In the third phase, it is characterized by an increasing deformation rate proportional to the increase of load followed by an outward movement of the soil causing the soil heaving. The soil experiences collapse with a plane of collapse in the form of curves and lines called radial and linear shear planes.

3.4 Bearing Capacity

In determining the ultimate bearing capacity (Q_{ult}) for each foundation model, plate loading test was used. The first tangent line is the initial straight line which assumed to be an elastic pressure line. The second tangent line was obtained by plot other straight line in the higher load which assumed as a plastic line. The intersection of these two lines will be considered as the failure point. The corresponding value of load to the failure point is considered as the ultimate bearing capacity. The method in determining the ultimate bearing capacity of raft-pile foundation is shown in Fig.9.

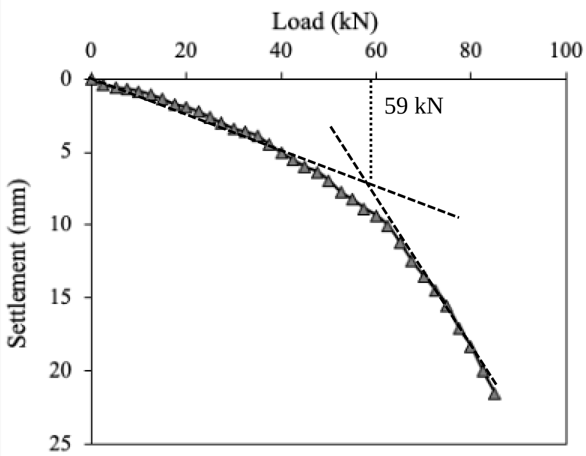

Fig.9 Determination of ultimate bearing capacity of raft-pile foundation from load settlement curve

The ultimate bearing capacity of each foundation type is presented in Table 4. These results indicate that in line with the results of plate load test, the raft-pile foundation provides the highest bearing capacity compared to other types of foundations. The bearing capacity of longer timber pile is higher than other timber pile as shown in Table 4.

Table 4 Ultimate bearing capacity of various foundation types

Foundation Model	Max. Load (kN)	Q_{ult} (kN)
Unreinforced	60	38
Pile, L = 20 cm	65	50
Pile, L = 30 cm	70	53
Pile, L = 40 cm	77.5	56
Raft	72.5	54
Raft-Pile	85	59

3.5 Validation with the Numerical Analysis

The simulated (numerical analysis) and measured subsoil settlement with incremental load are discussed in this section. The load-settlement curve for unreinforced soil is shown in Fig.10. For the unreinforced case, the numerical analysis shown an overpredicted value for the load exceeded 40 kN compared to the laboratory value. This result partially due to the adopted soil model and parameters may not be fully represent the behavior of subsoil. This behavior due to the progressive development of shear strain in the subsoil. Thus, when the subsoil towards to the failure state, the consolidation coefficient is changed due to the reduction of the soil stiffness in accordance with reducing of the dissipation rate of excess pore water pressure [16]. However, when the failure state is reached, the simulated and laboratory result show a similar value.

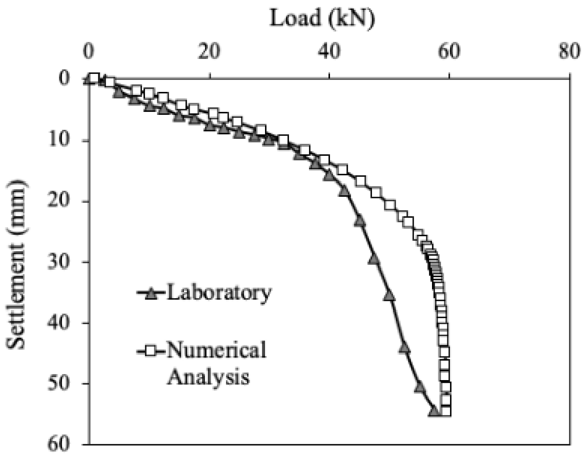

Fig.10 Load-settlement curve for unreinforced soil

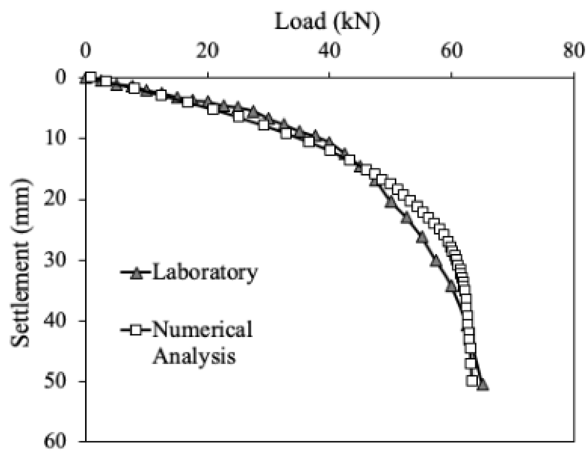

Fig.11 Load-settlement curve for pile group foundation (L=20cm)

Moreover, the simulated (numerical analysis) and observed (measured) subsoil settlement versus applied load for pile group with various pile length (L = 20, 30 and 40 cm) are shown in Fig. 11-13. The simulated and measured value was found fairly well. The settlements for pile group foundation cases are identical until the load reached about 50 kN. Furthermore, the load exceeded 50 kN, the result of measured and simulated case show a slightly different value. However, both simulated and measured value show a similar value at the failure state.

Similar to the group pile foundation, the raft and raft-pile foundation also shows both measured and simulated result indicate that there is no significant difference on the settlement value as shown in Fig.14 and 15. This results indicate that the numerical analysis conducted in this study could simulate well the testing of laboratory model test.

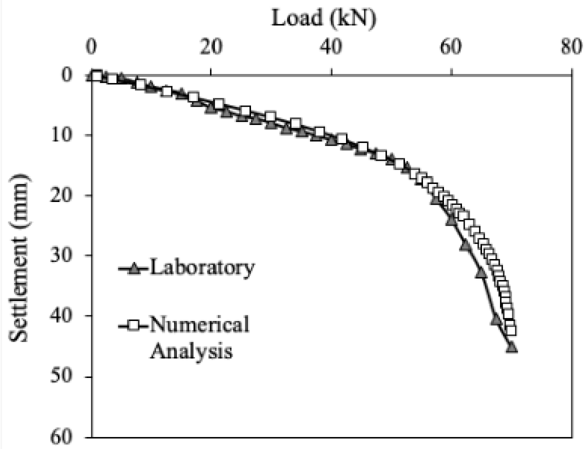

Fig.12 Load-settlement curve for pile group foundation (L=30cm)

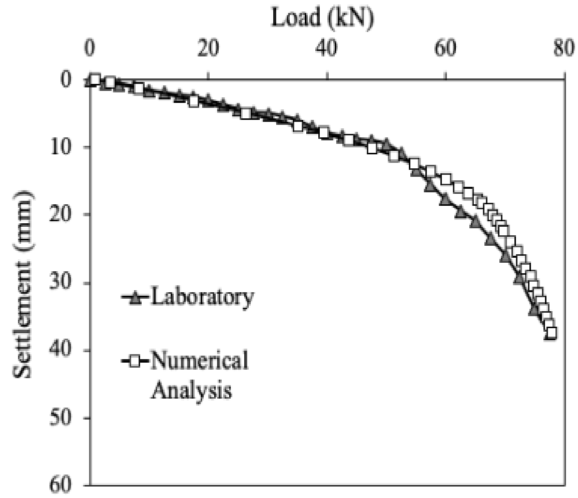

Fig.13 Load-settlement curve for pile group foundation (L=40cm)

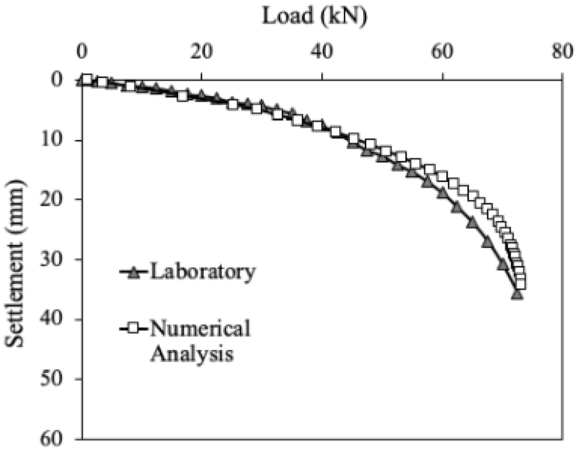

Fig.14 Load-settlement curve for raft foundation

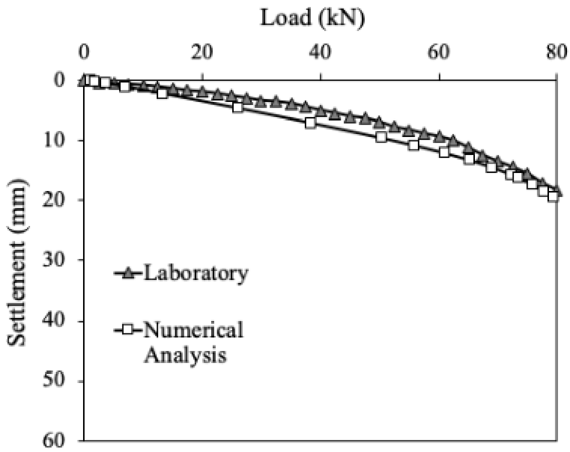

Fig.15 Load-settlement curve for raft-pile foundation

4. CONCLUSIONS

According to the findings in this study, the bearing capacity of raft-pile foundation is sufficient to support the load without any excessive settlement. The highest settlement reduction was observed in the raft-pile foundation which is almost 65% compared to unreinforced soil. Moreover, there is no significant lateral movement observed beside the foundation The longer pile are effective to reduce the settlement due to the pile provide the friction resistance between pile and subsoil and also increase the stiffness of the subsoil. Moreover, the numerical analysis conducted in this study could simulate well the testing of laboratory model test. An overpredicted value compared to the laboratory test was found. This result partially due to the adopted soil model and parameters may not be fully represent the behavior of subsoil. However**,** in general both simulated and measured test value show a similar value at the failure state. Utilization of local timber as a soft soil reinforcement material shows a very good performance in increasing the stability of the subgrade. Therefore, this reinforcement type can be utilized in the field applications.

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