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Load Test on Combined Pile and Cap / Pad Foundation System on Compressible Calcareous Sand and Comparison with FEM Modelling

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ABSTRACT An optimum type of foundation is expected to support 2 – 3 stories residential house on reclamation area to avoid deep foundation. The foundation will sit on engineering fill that constructed with calcareous sand which is classified as compressible sand. Below that part, at the original ground medium density sand and very soft marine clay is found stratified. Typical column in the residential building will have about 100 tons load intensity and based on this project, the design load for a single pile is 32 ton. Since no additional compression on soft clay layer is expected after building construction, than combine cap/pad foundation with short pile 6.5 m length is proposed. Load test with stress cell for this combine pile and cap/pad foundation was performed. The load test result show that interpretation using Chin's and Mazurkiewicz's Method obtained that the combined pile and cap/pad foundation's ultimate bearing capacity of 112 – 119 tons. Analysis using stress cell data shows that the cap/pad carry about 31.8 % of the total load. Finite element analysis with axisymmetric condition conducted to study load distribution on combine pile and cap/pad foundation system. Analysis result was show that the cap or pad can carried about 38.1% of design load during testing. The 6.3% deviation between the stress cell and FEM results could be attribute by the assumption when calculating the load acting on cap/pad foundation. The stress cell analysis used the assumption that the load carried by the cap/pad foundation was uniform while the FEM results showed a non-uniform load.

KEYWORDS Pile Foundation; Pad Foundation; Load Test; Finite Element; Calcareous Sand

1 INTRODUCTION

A three-story building located in the Makassar Reclamation Area, South Sulawesi, Indonesia was subjected to foundation planning with a design load of 32 tons. The site is located in a reclamation area with calcareous sand and underneath marine clay with very soft to medium densities. In this case, the use of end bearing piles with a fairly low design load would be costly due to the deep position of the hard soil. Therefore, the building is planned to use a combination of pile and cap/pad foundation.

To verify the foundation capacity to withstand the planned loads, static axial-compression load test were conducted on the combine pile and cap/pad foundation. The results of the tests were compared with a study using the finite element method to obtain the load ratio carried by the cap.

Figure 1. Location of The Project (PT. GEC, 2020)

2 GEOTECHNICAL SITE INVESTIGATION

Site investigation had been conducted at the area using CPTu (piezocone). This test resulted in a soil stratification of calcareous sand which was originally sand filled with a thickness of 8.6 m, underlain with marine clay to a depth of 21.4 m. Figure 1 shows the piezocone test result at the location.

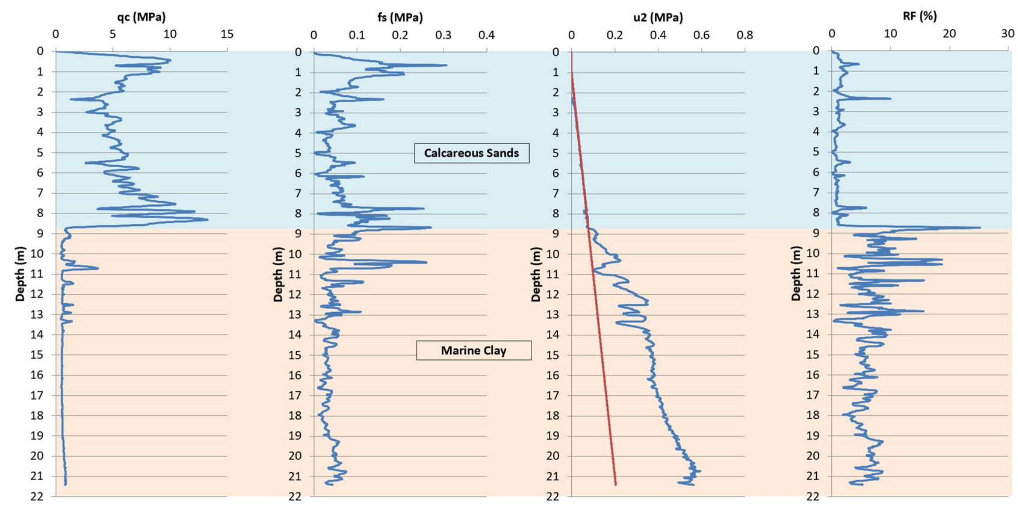

Figure 1. CPTu result (PT. GEC, 2020)

Calcareous sand was formed from the shells of marine life and other marine organisms such as *foraminferan* shells, pteropod shells, *coccolitihic* plants, corals, precipitates, and benthic materials (Chaney et al., 1982). The content of marine biota with the main component of calcium carbonate ($CaCO_3$) makes calcareous sand a compressible sand because this component is easily destroyed when given a load. Tamsir et al. (2020) conducted tests on calcareous sand samples in the Makassar reclamation area, and based on laboratory testing by the Norwegian Geotechnical Institute (NGI) it was found that the calcareous sand used in the Makassar reclamation had a calcium carbonate content in the range of 98-99%.

3 LOAD TEST

Load testing on the foundation with a compression axial static load system has been carried out. The test was conducted for 5 cycles with a planned load of 32 tons and a maximum load of 300% of the planned load of 96 tons. The tested foundation is a combination of a 6.5 m long and 0.4 m diameter circular pile with a 1.6 × 1.6 m square section cap/pad foundation with a thickness of 0.6m that located on a calcareous sand layer with a minimum CBR value of 15%.

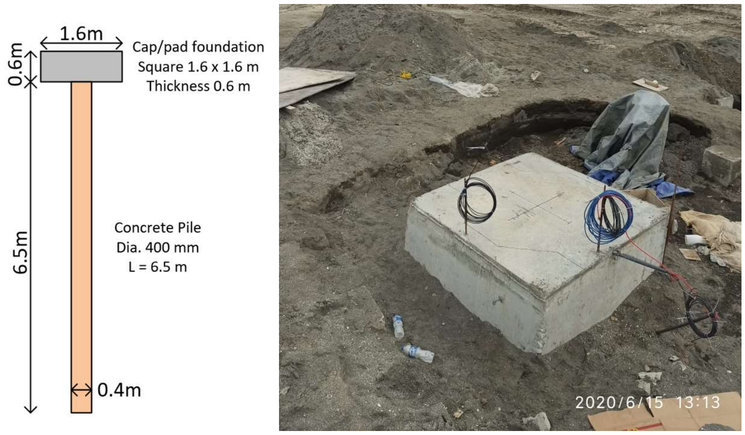

Figure 2. Geometry of the foundation (PT. GEC, 2020)

This test has two objective results, namely the behavior of the foundation receiving loads described in the load – settlement curve and the amount of load carried by the pile cap. There are two kinds of instrumentation installed in this loading test, dial gauges for reading the settlement value and a stress cell for measuring amount of load carried by the pile cap. The location of each instrument is described in Figure 3.

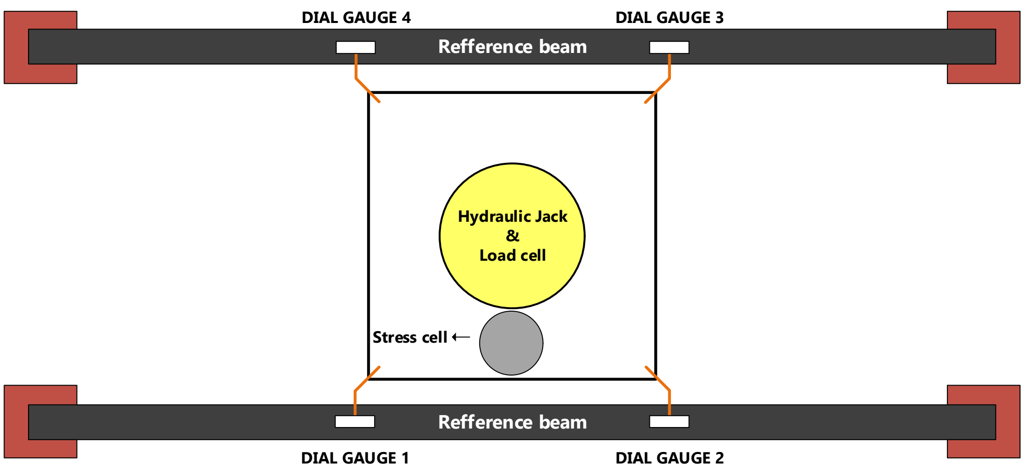

Figure 3. Location instrumentation load cell and stress cell (PT. GEC, 2020)

Figure 4. Load test on combine pile and cap/pad foundation (PT. GEC, 2020)

Figure 6 shows the result of 5 cycles load test for combine pile and cap/pad foundation in the form of load – settlement curve.

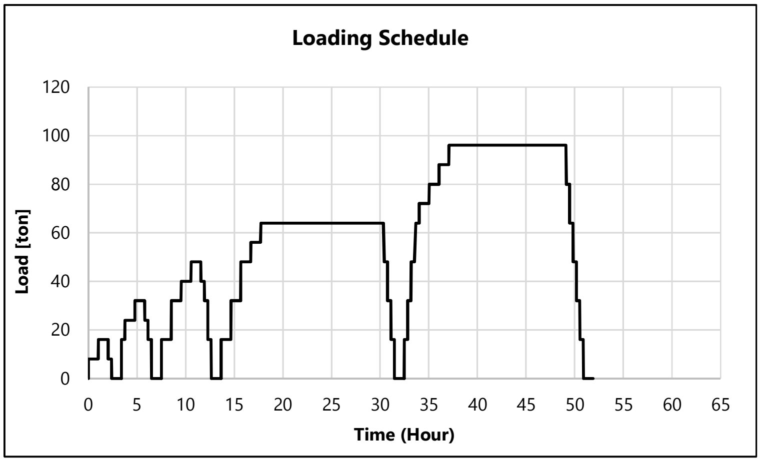

Figure 5. Load test schedule

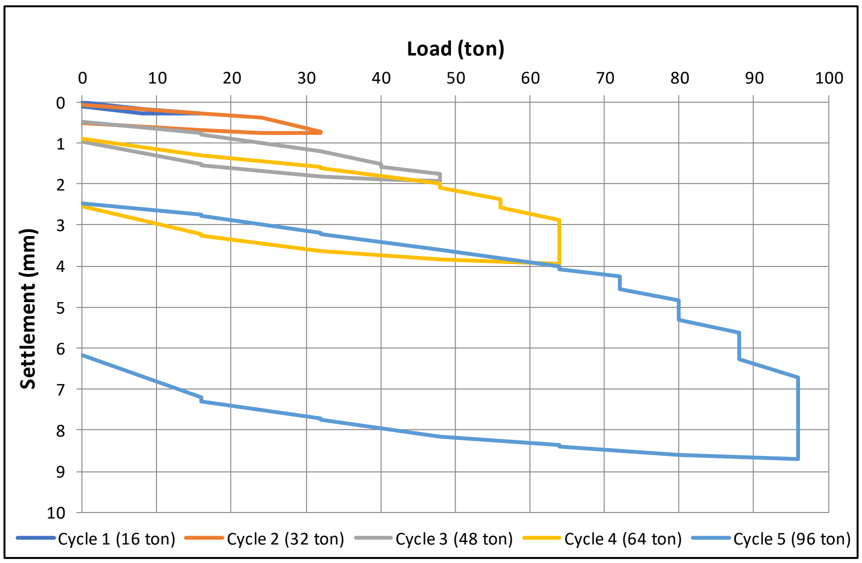

Figure 6. Load test result

3.1 Interpretation Methods

Interpretation of foundation load test data in the form of maximum bearing capacity values of foundation combinations using two methods, namely the Chin's Method (1970) and the Mazurkiewicz's Method (1972).

Chin's Method, first proposed in 1970, is a method of interpreting the ultimate bearing capacity of a foundation from load test data based on the regression line between the ratio of settlement and load to the amount of settlement as shown on Figure 7.

The bearing capacity value of the foundation using the Mazurkiewicz's Method is based on processing load test data by drawing a line as shown in Figure 8. Prakash et al. (1990) mentioned that this method is recommended for driven pile foundations.

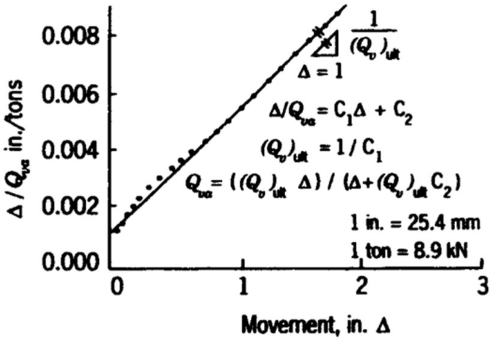

Figure 7. Chin's method interpretation (Prakash et al., 1990)

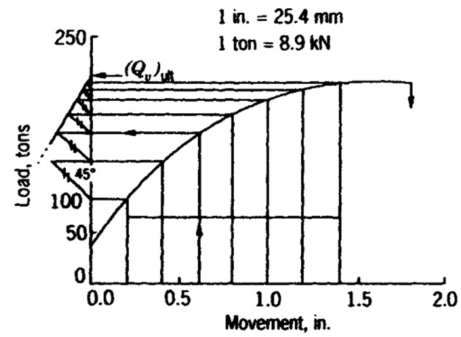

Figure 8. Mazurkiewicz's method interpretation (Prakash et al., 1990)

First step in using the Chin's method is to obtain a linear regression between S/Q and S (S: settlement; Q= load) as shown in Figure 9.

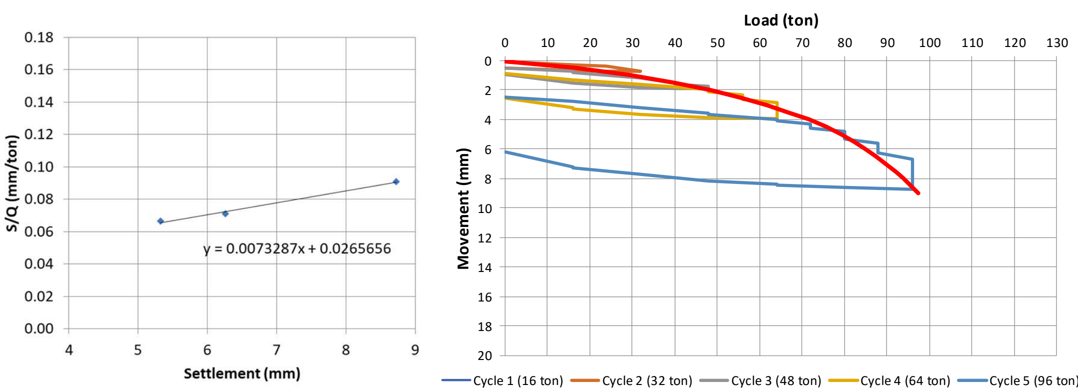

Figure 9. Result and extrapolation curve with Chin's method

Based on the plot in Figure 9, a linear regression equation is obtained in the form of y = 0.0073x + 0.0266 where the variable "y" indicates the S/Q value (mm/ton) and the variable "x" indicates the settlement value (mm) with the following equation:

$$\frac{S}{Q} = C1 \times S + C2 \rightarrow \frac{S}{Q} = 0.0073\,S + 0.0266 \tag{1}$$

C1 value of 0.0073 and C2 value of 0.0266 were obtained. The calculation of bearing capacity at settlement 25 mm, uses the following equation:

$$\text{Qu (ton)} = \frac{S}{C1 \times S + C2} = \frac{25}{0.0073 \times 25 + 0.0266} = 119 \text{ ton} \tag{2}$$

Therefore, the ultimate bearing capacity value of the combine pile and cap/pad foundation using Chin's Method can be obtained as 119 tons.

Using Mazurkiewicz's method, in Figure 10, it can be seen that the blue arrow ends at a load of 112 tons. Therefore, the ultimate bearing capacity value of the combine pile and cap/pad foundation using Mazurkiewicz's method can be obtained as 112 tons.

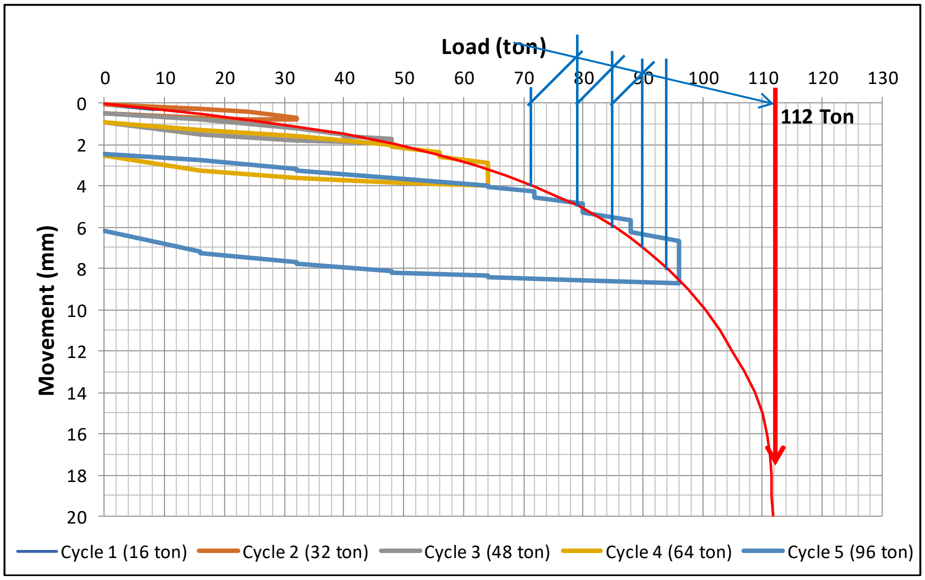

Figure 10. Result with Mazurkiewicz's method

3.2 Interpretation Results

From two interpretation methods that have been carried out, the results are summarized in Table 1.

Table 1. Load test interpretation results

Methods	Ultimate Bearing Capacity (Q_{ult})	Units
Chin (1970)	119*	tons
Mazurkiewicz (1972)	112	tons

(*) at settlement 25 mm

The results of both methods produce close values of the combine pile and cap/pad foundation's ultimate bearing capacity with a range between 112 – 119 tons.

4 EVALUATION OF SOIL REACTION BY STRESS CELL

To determine amount of load carried by the pile cap, stress value at the base of the pile cap is measured for each loading stage using a stress cell. In this analysis, the assumption used is linear pressure distribution beneath a rigid footing (Bowles, 2001) or uniform distribution as shown in Figure 11. The amount of stress that occurs will be multiplied by the net area of the pile cap to obtain the amount of load carried by the pile cap. The net area of the pile cap is the total area of the pile cap minus the cross-sectional area of the pile foundation. An illustration of the net area of the pile cap can be seen in Figure 12.

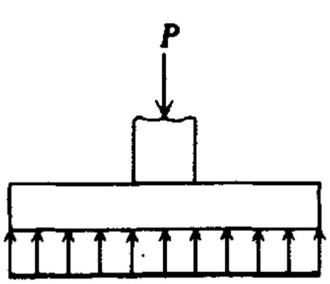

Figure 11. Assumed linear pressure distribution (Bowles, 2001)

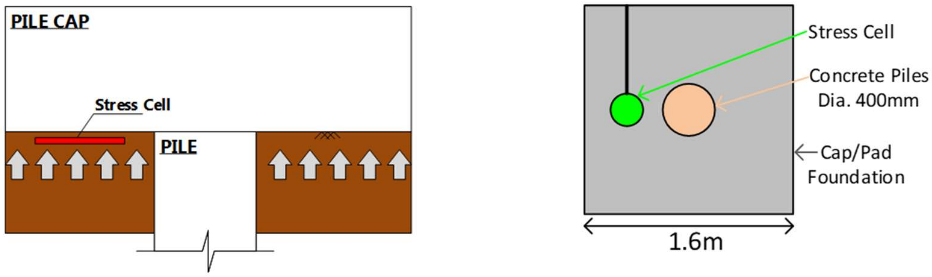

Figure 12. Illustration of an installed stress cell

The results from stress cell measurements plotted against the settlement value of the combine pile and cap/pad foundation (Figure 13). The amount of load carried by the pile cap is also presented in Figure 14. The measured bearing capacity of pile cap is 13.5 tons/m^2 with the ratio of 31.8% from the total load.

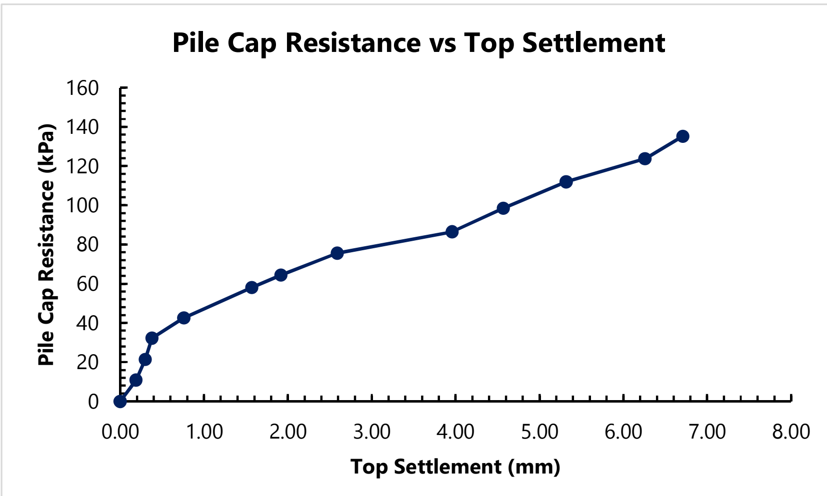

Figure 13. Stress cell result against settlement

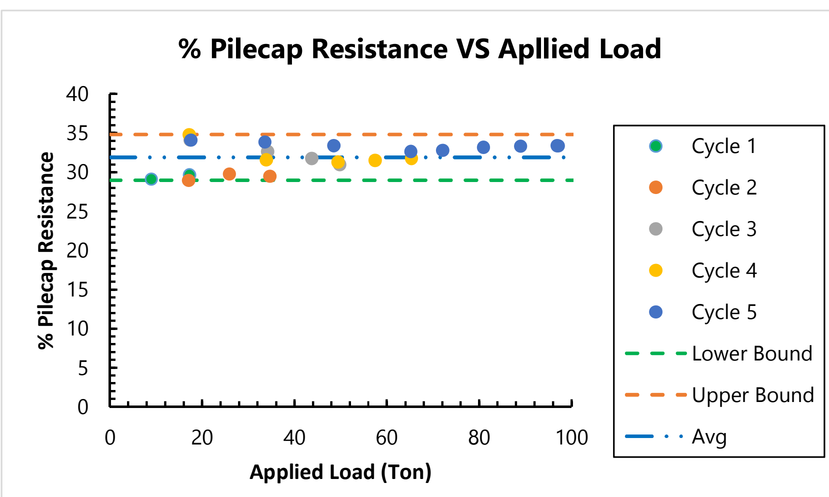

Figure 14. Percentage of pile cap resistance

5 NUMERICAL ANALYSIS

Numerical analysis using the Finite Element Method (FEM) was carried out with the aim of obtaining the ratio of the load ratio carried by the cap and pile at the design load of 32 ton. The analysis was aided by the PLAXIS 2D program using axisymmetric modeling. The foundation was modeled as a solid material with interface and soil parameters were obtained through an approach based on in-situ testing data in the form of CPTu using *Guide to Cone Penetration Testing 6th Edition* (Robertson and Cabal, 2015) as a reference. Figure 15 shows the form of modeling performed in the PLAXIS 2D program.

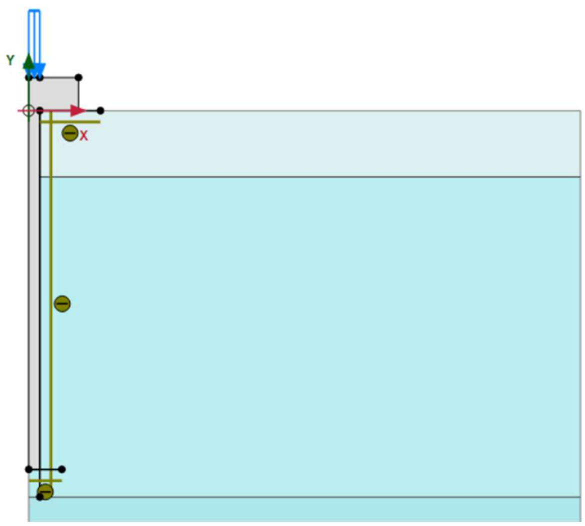

Figure 15. Structure model using PLAXIS 2D

5.1 Back Analysis of Soil Parameters using Load Test Result

To obtain soil parameters that represent the actual field conditions, back analysis was conducted by doing trial and error on the soil parameters and then comparing the FEM output in the form of settlement against load test data. Judgement of the friction angle values was made based on the sensitivity study of the calcareous sand friction angle values shown in Table 2.

Table 2. Friction angle sensitivity study on calcareous sand

Source	φ [°]
Giang et al. (2017)	28.81 – 61.14
He et al. (2020)	38 – 41.5
Salem et al. (2021)	30.5 – 34.6
Ata et al. (2018)	40.9 – 41.34

Based on the back analysis that has been carried out, Figure 16 shows the load and settlement comparison between the load test results and the results of the FEM analysis using the parameters shown in Table 3.

Table 3. Used parameters

Parameters	Concrete	Calcareous Sand (Embankment)			Marine Clay	Units
		Layer 1	Layer 2	Layer 3		
Depth		0 – 1.2	1.2 - 7	7 – 8.61	8.61 – 21.41	[m]
Model	Linear Elastic	Mohr-Coulomb	Mohr-Coulomb	Mohr-Coulomb	Mohr-Coulomb	-
Drainage Type	Non-porous	Drained	Drained	Drained	Undrained B	-

Parameters	Concrete	Calcareous Sand (Embankment)			Marine Clay	Units
		Layer 1	Layer 2	Layer 3		
γ	24	19.52	18.37	19.27	17.58	[kN/m^3]
E	2.1 E+07	68000	66000	69000	19991	[kN/m^2]
v	0.15	0.3	0.3	0.3	0.3	-
c	-	1	1	1	39.98	[kN/m^2]
φ	-	43	42.71	41,61	0	[°]
R_{inter}	1	1	0.8	0.9	1	-
K_{intial}	-	2	2	2	0.5	-

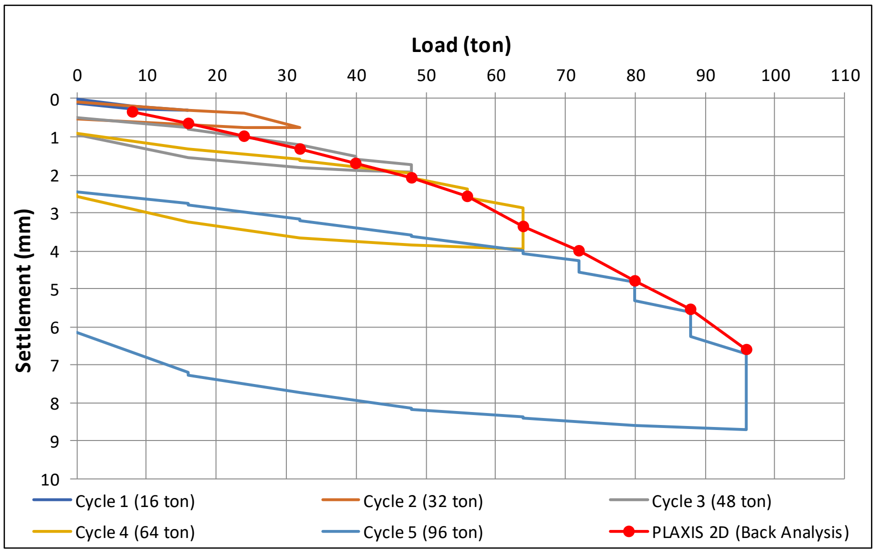

Figure 16. Back analysis results with load – settlement result from load test (FEM Analysis)

5.2 Pile – Cap Load Ratio

FEM modeling with a total load of 32 tons was conducted to obtain a comparison of pile-cap load ratios. The load calculation method utilizes the structure interface with output in the form of total normal stresses (σ_N). Table 4 shows the calculation of the load received by the cap based on the output of the FEM analysis.

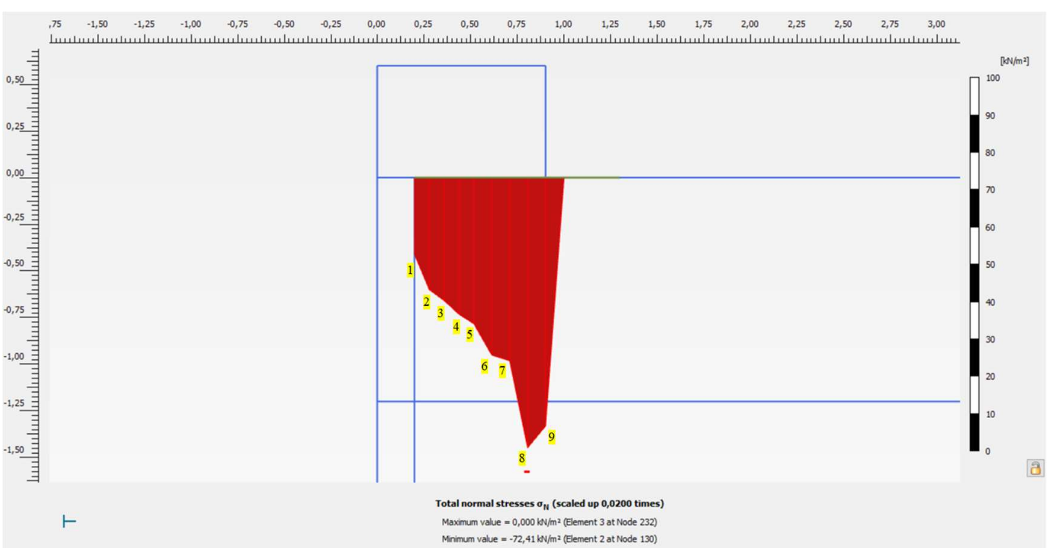

Figure 17. Total normal stresses distribution at design load (FEM Analysis)

Based on the calculation back analysis (Table 4), the load carried by the cap is 12.21 tons. When compared to the total load (32 tons), the pile-cap ratio receives a load of 61.9% for concrete pile (dia. 400 mm) and 38.1% for cap/pad foundation square (1.6 × 1.6 m).

Table 4. Load at cap calculation (FEM Analysis)

Point	σ_N [kN/m^2]	x* m	Area (A) m^2	Load** kN	tons
1	20.57	0.2	0.13	-	-
2	30.05	0.28	0.25	3.05	0.31
3	32.97	0.36	0.40	5.00	0.50
4	36.64	0.44	0.61	6.98	0.70
5	39.17	0.52	0.84	9.00	0.90
6	47.55	0.61	1.18	14.80	1.48
7	49.09	0.71	1.58	19.30	1.93
8	72.41	0.81	2.05	28.08	2.81
9	66.60	0.90	2.56	35.85	3.58
Load at cap/pad [tons]					12.21

(*) distance from point to axis (radius)

(**) Load = $(A_{(i)} - A_{(i-1)}) \times (\sigma_{N(i)} + \sigma_{N(i-1)})/2$

6 CONCLUSIONS

Analysis of combined pile and cap/pad foundation at the Makassar Reclamation Area, South Sulawesi, Indonesia has been performed. The foundation is located on a calcareous sand layer with thickness of 8.6 m.

Static axial-compression test was conducted and the interpretation using Chin's and Mazurkiewicz's Method obtained that the combined pile and cap/pad foundation's ultimate bearing capacity of 112 – 119 tons. Based on these results, the foundation system is sufficient to carry the design load of 32 tons.

Analysis using stress cell data shows that the cap/pad carry about 31.8 % of the total load and FEM analysis shows that the cap/pad can carry load proportion of 38.1% of design load. The differences could be attributed by the different in the assumption when calculating the load acting on cap/pad foundation. When stress cell reading is used for the analysis, it is assumed that the stress acting uniformly below the cap/pad foundation. On the other hand, finite element analysis shows the stress acting below the pile cap is non-uniform. However, the deviation is only about 6.3% which is not significant.

Hence, both analyses proved that combination between pile and cap/pad foundation can be one of the solutions for 2-3 stories buildings constructed on top of compressible soils such as calcareous sand with minimum CBR value of 15%.

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