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RELATIONSHIP BETWEEN OBTAINED ULTIMATE BEARING CAPACITY RESULTS BASED ON N-SPT RESULTS AND STATIC LOAD TESTS

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ABSTRACT: The foundation is a part of building construction that serves to place the building and distribute the load of the building to the ground to support the building. For the foundation, there should be no local settlement or any larger settlements that exceed a certain limit. This study aims to determine the correlation between load and foundation settlement, the ultimate load capacity, the soil elasticity and rebound, and the bearing capacity result from Meyerhof and Reese compared with the result from the Chin method. Two points are being compared on the foundation since they obtain the maximum load. The static axial compressive test took place after 28 days of curing. The ultimate load capacity based on standard penetration test result is 123.5 and 120.01 tons for Meyerhof and Reese at al., respectively, and the ultimate load capacity from the load-deformation curve is 124.22 and 119.4 tons for the Chin method. Based on these results, every three methods have a good agreement result with the ratio of ultimate load capacity from Meyerhof and Reese et al to Chin method is 1.01: 0.99: 1.

Keywords: Bored pile, Bearing capacity, Loading test, Axial force

1. INTRODUCTION

In planning a construction project, the building foundation is the most significant element to keep in mind. It strongly influences the strength and balance of a building. The building foundation transfers loads from the upper buildings to the subgrade/hard soils. Building foundations are broadly classified as shallow foundations and deep foundations. The selection criteria for building foundations depending on the soil compaction and the planned structure of the building. Shallow foundations are suitable for a location where hard soils are close to the soil surface. Otherwise, deep foundations are needed for a place where hard soils are far from the surface. The building foundation must be planned properly to avoid differential settlement across the building.

In choosing the type of foundation, it is necessary to consider whether the foundation is suitable, affordable, and possible to complete following the working schedule. In general, the subgrade soil and foundation have various characteristics. Numerous parameters affect the soils' properties, including the groundwater level.
Even if both are from the same type of soil, the characteristics of waterlogged soils are different from those of non-submerged soils. Soil types with different physical and mechanical characteristics provide a different soil bearing capacity. Thus, when selecting the type of foundation, one must consider various aspects of the soil in the location where the building will be built. The research location was on a building with a GIS solution 150 kV in Padang. The project is located in soft soil, where the predominant period is > 1 sand the Vs30 < 150m/s [1-4] (Fig. 1(a) and (b)). which means that the area has a high potential to receive amplified ground motion from an earthquake event and affected to earthquake-resistant building [5-7].

The project location is adjacent to the community settlement and a public health center (*Puskesmas* Lapai), (Fig.1). Based on the results of soil testing using the SPT (standard penetration test), hard soil is at 28 meters under the ground. Considering the depth and the location of this building that is adjacent to settlements and health centres, the proper foundation is a bored pile foundation (Table 1).

Bore pile foundations has the same function as pile foundations or other deep foundations. The difference is in the way it is carried out. Work on the bore pile foundation begins with making holes in the ground, first employing a soil drill, then installing reinforcing iron into the hole, and continuing the casting process with them. Tremie pipe is a galvanized pipe with a certain diameter to assist in bored pile foundation casting. The diameter of the pipe depends on the dimensions of the bored pile foundation being cast. The pipe is inserted into the borehole foundation, almost reaching the bottom of the borehole. Then, a bucket is attached to pour concrete at the top of the pipe. The way the pipe works is that fresh concrete poured into the bucket is delivered directly to the bottom of the drill the hole through the pipe and the mud that fills the

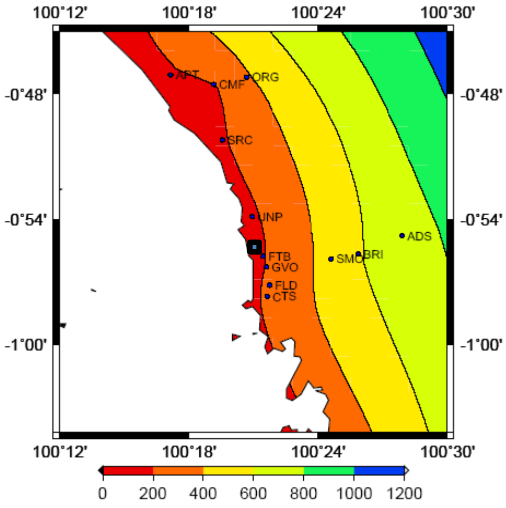

Fig.1 The shear wave velocity of V_{s30} for Padang city, the black rectangles indicate the project location.

drill hole comes out of the hole through the outside of the pipe.

After finishing the casting process and waiting for the concrete to be in good enough strength after 28 days. There are several ways of testing the load on a deep foundation. In this research, the static loading test was applied by giving a static axial compressive load to the foundation target. The static axial load prepared was a particular size of concrete blocks or cubes as the load. The pile head settlements were measured vertically due to the addition and reduction of static load on the test based on a specific load and duration. The load testing process needs a hydraulic jack, oil pressure sensor, and pump. The settlements measurement uses four dial gauges. Controlling the load cycle and record-keeping were accomplished using the Static Load Tester System and control box. Therefore, we can produce the load-settlements graph to interpret the ultimate axial capacity of the test[8].

1.1 Soil Bearing Capacity

Bearing capacity is the strength of the soil to support the load applied to it and distributed through the foundation. Ultimate bearing capacity (Q_{ult}) is the maximum pressure that can be supported by the soil without causing sliding or a failure below and around the foundation. The soil bearing capacity is influenced by soil shear strength, and the shear strength is influenced by the cohesion and soil shear angle. When shear stress acts on a soil mass, normal stress will occur. The shear stress will increase if the deformation reaches the elastic limit. When we correlate the elastic limit to three different normal stresses, we can conclude that the cohesion is constant, normal stresses are variables, and the slope of the line is defined by the type of foundation followed the N-SPT result shown in Table 1.

In Table 1, the type of soils at the investigation site using N-SPT shows that the soil at a 1–20 m depth is classified as soft/loose soil and from 26–28 m, it is classified as gravel and well-graded sand.

Since the surroundings of the project location is a densely populated area and many buildings, the proper foundation to use is the bored pile, there was almost no vibration generated during the installation, so it does not damage the soil structure or buildings around the project site.

Table1 Soil investigation, N-SPT result

Depth(m)	N-SPT Value	Type of soil
1.20	4	Sand and Gravel
2.0–4.40	10	Silty Sand
4.40–6.60	8	Well graded sand, sand and gravel
6.60–10.30	8	Clay, well graded sand
10.30–24.35	2	Loam sandy
26.45	28	Gravel and well-graded sand
28.45	57	Gravel and well-graded sand
30.45	8	Gravel and well-graded sand

The bearing capacity of a bored pile foundation based on N-SPT result is calculated by applying the equations from Reese and Wright [9] and Meyerhof [10] :

$$Qp = 9 \text{ x} C_u \text{ x } A_p \text{ (ton)} \quad (1)$$

The bearing capacity equations of the pile end (Qp) for non-cohesive soils are:

$$Q_p = \frac{40}{0.3048^2} x A_p \ (ton) \ for \ N_{SPT} > 60 \quad (2)$$

$$Q_p = \frac{1}{0.3048^2} x \ N \ x \ A_p \ (ton) \ for \ N_{SPT} < 60 \quad (3)$$

The bearing capacity equation of the blanket (Qs) for cohesive soils is:

$$Q_s = C_u x \ \alpha \ x \ p \ x \ \Delta l \ (ton) \quad (4)$$

The bearing capacity equations of the blanket (Q_s) for non-cohesive soils are:

$$Q_s = 0.32 \ x \ N \ x \ p \ x \ \Delta l (ton) for \ N_{SPT} < 53 \quad (5)$$

$$Q_s = \left(\frac{N-53}{450}\right) x \ \frac{1}{0.3048^2} x \ p \ x \ \Delta l \ (ton) \ for \ N_{SPT} \geq 53 \quad (6)$$

The total bearing capacity equation is:

$$Q_u = Q_p + Q_s \quad (7)$$

$$Q_p = q_p . A \quad (8)$$

Where:
Qp = Ultimate bearing capacity of the pile (ton)
Qs = Pile blanket bearing capacity (ton/m^2)
Ap = bore pile cross-sectional area (m^2)
Qu = Max bearing capacity
Cu = soil cohesion (ton /m^2)
P = distance around the pole
α = correction factor
N = Npt. value
△l = the depth of the pole being studie

Tabel 2 Bearing capacity (Qult) results from two methods based on N-SPT value.

Sample number	Pile Diameter (cm)	Depth (m)	N-SPT value (ton/m2)	Ultimate bearing capacity (ton) Meyerhof	Reese, Wrigh t
1	60	28	28	123.5	120.1

1.2 Bored Pile Foundation

A bored pile foundation is a type of foundation whose depth is more than 2 meters. It is commonly used in the construction of tall buildings because using bored pile foundations includes a single bored pile that can be used on group piles or a pile cap with varying pile depths. During drilling, ground vibrations causing damage to nearby buildings can be prevented, and no noise is generated. Additionally, the bored pile foundation has a high resistance to lateral loads.

For a bored pile foundation, the distance between the drill piles in the piles' group will affect the bearing capacity of the piles' group. When the piles are close to each other, the soil stress due to the pile's friction affects the bearing capacity of the other pile. The minimum distance between the two piles of the foundation is S>2D, where S is the distance between the piles and D is the diameter of the pile. The axial bearing capacity of the deep foundation generally consists of two parts: the bearing capacity due to friction distributed on the pile, and the bearing capacity of the end (base) of the pile.

1.3 Piles Load Bearing Capacity Test

If a pile foundation has been chosen, the piles' dimensions (cross-section and length) are calculated based on the amount of load that must be supported and the soil conditions where it is installed. The next thing to do is calculating the bearing capacity (Q_{ult}) of the pile foundation based on the planned dimensions and by conducting vertical loading experiments on pile foundations to find out how far the foundation drops after bearing the planned loads. The experiment also aims to test whether the pile foundations are strong enough to support the loads. Additionally, it can prove that there were no failures in the project implementation. It can also determine the real ultimate bearing capacity as a control of the static and dynamic formulas calculations.

Pile foundation testing is needed as quality insurance that the bearing capacity of the foundation meets the planned bearing capacity. There are three methods for calculating the foundation's axial bearing capacity: the full-scale load test, often called the Static Loading Test (SLT); the static method (using basic principles in soil mechanics); and the dynamic method (Pile Driver Analyzer).

1.4 Axial Static Loading Test Method

The axial static loading test is carried out by placing vertical loads above the pile cap. Then, the vertical deformation is measured using a measuring watch installed on a magnetic stand. The deformation can be both elastic and plastic. Elastic deformation is caused by elastic shortening of the pile foundation and soil, whereas plastic deformation is caused by the supporting soil collapse at the end or around the pile.

Loading equipment for vertical loading experiments, with 2 x 85 tons of capacity for 600 mm diameter drill piles, is placed on the platform. The test was carried out on a foundation after 28 days of curing. It is important to allow the soil to return to its original state, which also allows the pore pressures after pile installation returned to normal. Two alternative loading tests often used are unused pile test or failure test (carried out until the pile collapses), and test on a working pile (used pile) of 200% design capacity (the collapse load commonly cannot be obtained during this test).

The pile bearing capacity based on the SLT was analyzed using the Chin method (1971). Measuring the ultimate bearing capacity based on the Chin method is done by drawing a curve between the ratio of the load decreases (S/Q) to the pile foundation settlement. Then, we can draw a straight line that represents the points with the following equation:

$$S/Q = mx + C \tag{9}$$

C is a predetermined line equation and ultimate load (Q_{ult}) can be drawn with this equation:

$$Q_{ult} = 1/m \cdot (Fk) \tag{10}$$

Where:
S = settlement
Q = load
C = slope of a straight line
Fk = correction factor (1.2 – 1.4)
The correlation between load and settlement can be analyzed from the results of the loading test.

2. RESEARCH METHOD

This study is quantitative descriptive research, which is located in a GIS solution 150 kV in Padang city. This project uses a bored pile foundation type. The dimensions of the pile used are 600 mm in diameter and 28 m long. The planned load is 85 tons. The foundation will be tested with 200% of the planned load. In the diagram below, the tested foundation is marked with a blue dot, P1 for foundation test 1, and P2 for foundation test 2 [11].

The foundation is a sample specially made to be tested. They are identical to the building foundation that will be used. The tested pile foundation will not be used in the real building foundation because it will be tested until there is a plastic deformation/collapse. Hence, it does not reduce the quality of the building foundation. The foundation testing was carried out until a certain point considered to have the greatest load.

A negative skin friction influences to arise as a result of the settlement of soil around the pile. A soil deforming around the pile tends to pull the pile down thus reducing its bearing capacity. In this research, the skin friction has been taken into account in the calculation for each method.

2.1 Static Loading Test

Compressive load testing is a test of pile foundations where the position of the loads has the same direction as gravity. Considering the effectiveness and efficiency of this test, the Kentledge load testing method is suitable.

The common procedure for doing a compressive load test is to measure the displacement of the pile cap due to loading and unloading based on the load cycle within a certain time. This test used the cyclic loading test procedure. Generally, there are four cyclic tests, namely:

a. Cyclic test I : 0% - 25% - 50% - 25% - 0%
b. Cyclic test II : 0% - 50% - 75% - 100% - 75% - 50% - 0%
c. Cyclic test III: 0% - 50% - 100% - 125% - 150% - 125% - 100% - 50% - 0%
d. Cyclic test IV: 0% - 50% - 100% - 150% - 175% - 200% - 175% - 150% - 100% - 50% - 0%.

After the four cyclic loading tests, if the load-displacement graph is still within the elastic limit of the soil, the maximum load given should be increased until it reaches load failure. To get the maximum load, we can add load cycles (cyclic test V: 250%, cyclic test VI: 300%). This cyclic test needs to take into account the permitted capacity of the test pile material and does not cause any adverse health and safety effects. It will help in interpreting the ultimate axial capacity test. The loading test schema is shown in fig.2.

Table 3 Required equipment

Equipment	Number of Unit/ Capacity
Static Load Pile Tester System	1 unit
Control Box	1 unit
Hydraulic Jack Ø 200 mm	1-4 unit/ 200 ton
Hydraulic Pump	1 unit/80 MPa
Dial Gauges with an accuracy of 0.001 mm	4 unit/0.01–50 mm
Magnetic Stand	4 unit

The data are recorded at times before and after the addition/reduction of the load. At the maximum load of 200, 250, or 300% of the planned load, the readings are at 10-minute intervals for the first 2 hours. After two hours, the readings are at 1-hour intervals for 12–24 hours. When the load is 0% of the planned load, readings are carried out every 10 minutes for 1 hour.

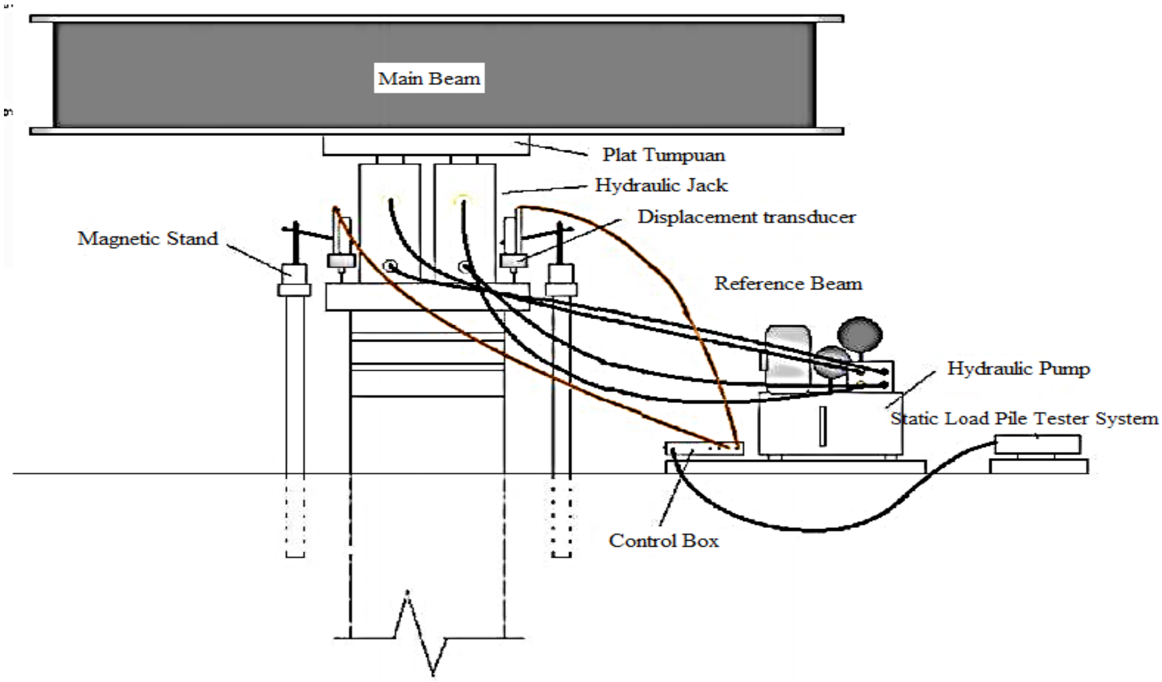

Fig.2. Loading test schema

3. RESULTS AND DISCUSSION

3.1 Settlement of Bored Pile Foundation 1

All reference beams for scale reading on the bar must stand alone and be supported by supports planted firmly on the ground at a net distance of not less than 2.5 m from the test pile. Dial gauges must be placed perpendicular to one another. Dial gauges must have a capacity of 2 in (= 50 mm) with an accuracy of 0.01 in (= 0.25 mm). The axial load test was performed at a point on the bore pile with the G16-LineB-C foundation code (foundation 1, Dia 600 mm). The load vs settlement of foundation is shown in Tables 4 to 7.

Table 4 Foundation settlement on cyclic test 1

Load (kN)	Percentage of planned load (%)	Loading duration (min)	Settlement (mm)
213	25	60	0.91
425	50	60	1.87
213	25	20	1.63
0	0	60	0.91

Max. settlement: 1.87 mm,
Max. amount of spring-back: 0.96 mm

This test presents the results obtained from the axial static loading test capacity of 170 tons or 200% of the planned load (85 tons).

Table 5 Foundation settlement on cyclic test 2

Load (kN)	Percentage of planned load (%)	Loading duration (min)	Settlement (mm)
425	50	20	1.40
638	75	60	2.35
850	100	60	3.82
638	75	20	3.76
425	50	20	3.36
0	0	60	1.36

Max. settlement: 3.82 mm
Max. amount of spring-back: 2.46 mm

Table 6 Foundation settlement on cyclic test 3

Load (kN)	Percentage of planned load (%)	Loading duration (min)	Settlement (mm)
425	50	20	1.36
850	100	20	2.48
1063	125	60	4.08
1275	150	60	42.23
1063	125	20	42.28
850	100	20	42.13
425	50	20	41.01
0	0	60	39.21

Max. settlement: 42.28 mm
Max. amount of spring-back: 3.02 mm.

Table 7 Foundation settlement on cyclic test 4

Load (kN)	Percentage of planned load (%)	Loading duration (min)	Settlement (mm)
425	50	20	4035
850	100	20	41.61
1275	150	20	43.41
1488	175	60	89.75
1700	200	720	164.01
1488	225	60	164.02
1275	250	20	164.02
850	200	20	163.54
425	150	20	162.04
0	50	20	158.09

Max. settlement: 164.01 mm
Max. amount of spring-back: 5.92 mm

3.2 Settlement of Bored Pile Foundation 2

The settlement of foundation 2 in each cycle can be seen on the following tables.

Table 8 Foundation settlement on cyclic test 1

Load (kN)	Percentage of planned load (%)	Loading duration (min)	Settlement (mm)
213	25	60	0.43
425	50	60	1.54
213	25	20	1.24
0	0	60	0.52

Max. settlement: 1.5 mm
Max. amount of spring-back: 1.02 mm

Table 9 Foundation settlement on cyclic test 2

Load (kN)	Percentage of planned load (%)	Loading duration (min)	Settlement (mm)
425	50	20	0.99
638	75	60	1.91
850	100	60	4.06
638	75	20	3.84
425	50	20	3.37
0	0	60	1.24

Max. settlement: 4.06 mm
Max. amount of spring-back: 2.82 mm

Table 10 Foundation settlement on cyclic test 3

Load (kN)	Percentage of planned load (%)	Loading duration (min)	Settlement (mm)
425	50	20	1.36
850	100	20	3.04
1063	125	60	6.25
1275	150	60	26.80
1063	125	20	26.74
850	100	20	26.33
425	50	20	24.73
0	0	60	21.24

Max. settlement: 26.80 mm
Max. amount of spring-back: 5.56 mm

Table 11 Foundation settlement on cyclic test 4

Load (kN)	Percentage of planned load (%)	Loading duration (min)	Settlement (mm)
425	50	20	1.91
850	100	20	3.95
1275	150	20	6.64
1488	175	60	37.79
1700	200	720	120.97
1785	225	60	157.51
1870	250	20	162.45
1700	200	20	162.99
1275	150	20	162.64
425	50	20	159.52
0	0	60	155.39

Max. settlement: 162.45 mm
Max. amount of spring-back: 7.06 mm

3.3 Interpretation of the Chin Method

Chin's method assumed a relationship existed between the applied load (P) and the settlement (Δ) is hyperbolic [8]. The bearing capacity is determined based on the load-settlement, and the load-settlement is calculated to obtain the settlement relationship (S) with a reduction in load (S/Q) ratio. The interpreted data are the settlements data in the 4th cycle. The following table shows the relation of load (Q), settlements (S), and the ratio of settlement and load (S/Q) for Foundations 1 and 2

Table 12 Relationship of load (Q) and settlement (S) for Foundation 1

Level of Settlement (mm)	Load(Q) (ton)	Total (S) Settlement (mm)	(S/Q) (mm/ton)
0.00	0	0.00	0.00
1.36	42.5	1.36	0.0320
1.12	85	2.48	0.0292
1.60	106.25	4.08	0.0384
38.15	127.5	43.23	0.3312

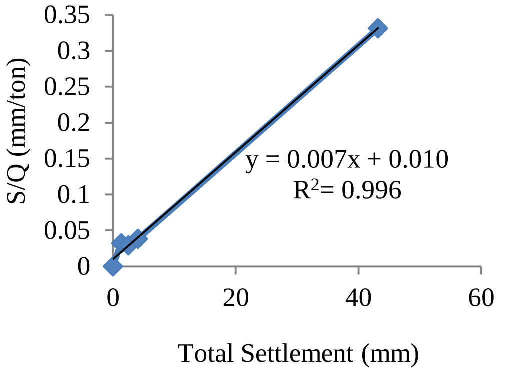

Fig.2 Settlement load ratio and settlement relationship

The ultimate bearing capacity of the foundation was found by applying Eq. (9 and10). Generally, this method produces a high Q_{ult}, so it needs to be corrected with a correction factor between 1.2–1.4.

M = 0.007
Q_{ult} = 1/(m.FK)
Q_{ult} = 1/(0.007 x 1.2)
= 119.04 ton

Table 13 Relation of load (Q) and settlement (S) for Foundation 2

Level of Settlement (mm)	Load (Q) (ton)	Total (S) Settlement (mm)	(S/Q) (mm/ton)
0	0	0	0
1.91	42.5	1.91	0.0449
2.04	85	3.95	0.0465
2.69	127.5	6.64	0.0521
31.15	148.75	37.79	0.2541
83.18	170	120.97	0.7116

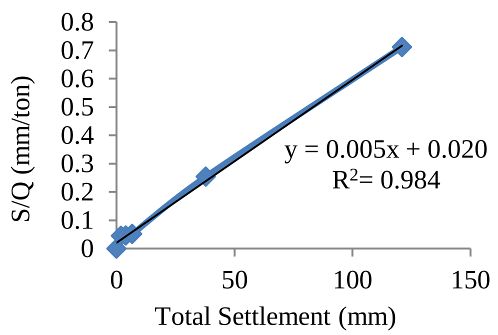

Fig3. Settlement load ratio and settlement relationship

The bearing capacity for Foundation 2 is:
Correction Factor (FK) = 1.4

M = 0.00575
Q_{ult} = 1/(m.FK)
Q_{ult} = 1/(0.00575 x 1.4)
= 124.22 ton

Table 14 The comparison bearing capacity results between the three methods are:

Method	Q_{ult} (Ton)
Meyerhof	123.5
Reese and Weigh	120.1
Chin (p1)	119.04
Chin (p2)	124.22

From Table 14, the ultimate bearing capacity results from three analysis methods; Meyerhof, Reese et al and Chin show a good agreement. The number of bored piles is two from two observation sites, with a 60 cm diameter for each. The Meyerhof and Reese et al. methods applied the N-SPT result from soil investigation to determine the bearing capacity, while the Chin method interpreted the static loading test results. The ultimate bearing capacity results are from 2 columns with diameter 60 cm and the skin friction is taken account in the calculation.

4. CONCLUSION

The ultimate bearing capacity results from three analysis methods; Meyerhof, Reese et al., and Chin show a good agreement, even though N-SPT from soil investigation was applied for Meyerhof and Reese et al methods and interpreting the static loading test results was used for the Chin method. with the ratio of ultimate load capacity from Meyerhof and Reese et al to Chin method is 1.01: 0.99: 1. This obtained relationship among 3 methods is from two columns with diameter 60 cm and skin friction is taken account in the calculation.

5. ACKNOWLEDGEMENTS

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