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SOIL BEARING CAPACITY ANALYSIS TO DETERMINE PILE FOUNDATION DESIGN ON ALLUVIAL SOILS IN SEMARANG CITY, INDONESIA

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ABSTRACT: Semarang City is one of the largest cities in Indonesia and has experienced land subsidence for decades, with the second-fastest rate in the world at 20–30 mm per year. This issue can significantly affect the stability of building structures. One infrastructure project that requires attention due to this condition is the revitalization of Baiturrahman Mosque, located in Semarang City. Designing an appropriate foundation structure based on geological and geotechnical conditions is crucial. The foundation type must be determined according to localized soil conditions by calculating the bearing capacity using Standard Penetration Test (SPT) data, core drilling, and laboratory tests. Based on soil consistency, the pile foundation tips should be embedded at a depth of 20–30 meters at four locations within the study area. The Meyerhof method is used to analyze the required number of driven pile foundations, while the Poulos method is applied for bored-pile foundations. The analysis recommends 24 driven piles of 600 mm diameter at BM-1, 48 driven piles of 600 mm diameter at BM-2, 15 bored piles of 600 mm diameter at BM-3, and 15 bored piles of 600 mm diameter at BM-4. For the geological and geotechnical conditions of the study area, the Meyerhof equation is the most suitable method for determining the number of driven piles, while the Poulos equation provides a more accurate estimation for bored piles.

Keywords: Soil bearing capacity, Laboratory tests, Driven pile, Bored pile, Foundation.

1. INTRODUCTION

Tectonically, the Indonesian archipelago seats on the three earth's main plates collision, namely the Eurasian continental plate, the Indo-Australian continental plate, and the Pacific oceanic plate, which lead to present natural disasters such as earthquakes, liquefaction, tsunamis, and others. All these natural disasters, especially earthquakes may affect the building's foundation, resulting in the upper structure's instability.

Semarang City is one of the big cities with a significant level of development recently. Apart from that, many important buildings in the city of Semarang were built on soft soil. In terms of physiography, Semarang City, which is a research area, is mostly composed of alluvial deposits (Qa) with a thickness of more than 120 meters [1]. The alluvial deposits encountered in the coastal areas in Semarang consist of beach, floodplain, tidal, near-shore, and alluvial fan deposits [2]. Referring to the previous study at Baiturrahman Mosque, there are 120 meters of thick clayey soil.

Furthermore, the lithology is a product of the lagoonal environment that is dominated by a bay-thick clay layer [3]. Moreover, the city of Semarang is one of the cities with the second fastest land subsidence in the world with a settlement rate of 20-30 mm/year. The subsiding area is composed of alluvium, which is loose, unconsolidated soil, or sediment that has been eroded, reshaped by water in some form, and redeposited in a nonmarine setting. Furthermore, the subsidence in Semarang is likely caused by water extraction [4]. Changes in soil conditions due to groundwater extraction will affect the existing buildings on it. Therefore, it is necessary to provide an adequate foundation design related to the localized engineering geology and geotechnical setting.

The foundation is part of the building that connects the building to the ground, ensuring its stability against its own loads, live loads, and external forces such as wind pressure and earthquakes [5]. Therefore, good foundation planning can minimize or prevent the impact of land subsidence and potential damage to a foundation at the study site. This paper explains good foundation planning so that the foundation can withstand the load of the building according to the plan by comparing several calculation methods. A comparison of several calculation methods will provide a more objective assessment of the condition of the site. So that the calculation results can be more accurate to determine the appropriate foundation.

2. RESEARCH SIGNIFICANCE

The revitalization of Baiturrahman Mosque in Semarang City, Central Java, Indonesia, requires a thorough analysis of soil-bearing capacity to ensure structural stability. This study determines the most suitable foundation type by evaluating localized soil conditions using Standard Penetration Test (SPT) data, core drilling, and laboratory testing. A properly designed foundation enhances resilience against ground instability and reduces structural risks. The findings support the mosque's long-term stability and offer valuable insights for future infrastructure projects in similar geotechnical conditions, promoting safer and more sustainable construction practices.

3. METHODOLOGY

The methodological approaches used in these analyses are by exposing some literature reviews as follows.

3.1 Literature Review

3.1.1 Soil Classification

In the Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System, USCS) as designated in ASTM D2487-00 [6], the coarse-grained soils are indicated by soil materials more than 50% retained on sieve #200. Meanwhile, the fine-grained soils are characterized by soil materials of 50% or more passing #200 sieve and the highly organic soils are characterized by primarily organic matter, dark in color, and organic odor. The sieve analysis is commonly used to determine the gradation of the soil or rock materials based on the uniformity coefficient (c_u) and curvature coefficient (c_c) controlled by D_{10}, D_{30}, and D_{60}. Those determinations can classify the soils as well-graded, poorly graded, or gap-graded.

3.1.2 Engineering Characteristics of Soils

In standard geotechnical engineering practices, the characteristics of soils are distinguished into granular and fine-grained soils [8]:

A) Coarse-grained soils (Sands and Gravels)

The soils are generally excellent as a foundation material for supporting structures and roads. Furthermore, the soils are also ideal for embankment material, as the best backfill material for retaining walls which might settle under vibratory loads or blasts. A dewatering implementation may be difficult in open-graded gravels due to high permeability and generally not frost susceptibility.

B) Fine-Grained Soils (Inorganic Clays)

Inorganic clay soils generally have the characteristics of low shear strength, plastic, and compressible. The part can lose its shear strength upon any wetting and disturbance, shrink upon drying, and expand upon wetting. Hence, the soils are determined as a poor material for backfill and embankments which are practically impervious and cause clay slopes to be prone to landslides.

C) Fine-grained soils (Inorganic Silts)

Inorganic silt soils have relatively low shear strength with high capillarity and frost susceptibility, low permeability, and frost heaving susceptibility, which are difficult to compact.

D) Organic Soil

Organic soils are the term organic materials (other than topsoil) that contain an appreciable amount of vegetative matter and occasionally animal organisms in various states of decomposition. In general, organic soils, whether peat, organic clays, organic silts, or organic sands, are not used as construction materials.

Each type of soil has a different bearing capacity. The difference in bearing capacity can be correlated with different land subsidence. Parameters distribution of soil engineering properties can describe the bearing capacity of land in Semarang city, which can be used as an instrument to determine the bearing capacity of the environment and evaluate spatial use from aspects of land-use suitability and land capability [9].

3.1.3 Geotechnical Investigation

To investigate and identify the subsurface soils or rocks, some references can be used as a standard guideline, such as ASTM D420-98, D1452-80 (2000), D1586-99, D1587-00, D2113-99, D3441-98, D5778-95(2000) [6], and D6066-96e1[7]. Regarding the guide to site characterization for engineering, design, and construction purposes, a standard practice for soil investigation and sampling by auger borings, standard test method for penetration test and split-barrel sampling of soils, standard practice for thin-walled tube sampling of soils for geotechnical purposes, standard practice for rock core drilling and sampling of rock for site investigation, standard test method for deep, quasi-static, cone and friction-cone penetration tests of soil, and standard test method for performing electronic friction cone and piezocone penetration testing of soils, and standard practice for determining the normalized penetration resistance of sands for evaluation of liquefaction potential, respectively.

A geotechnical investigation has an objective to obtain the data required to create a 3D model from the field and affect project construction [10].

Aligned with Whitaker (1976), that the drilling activity could be done alone, or it could be combined with the SPT (standard penetration test) or CPT (cone penetration test) methods. [11]. The geotechnical investigation in this study is divided into two, listed below:

A) Field Investigation

Some in-situ tests were conducted through SPT to examine the soil consistency using a split-barrel sampler, referring to the procedure in ASTM D1586 [6]. In this method, a 63.5 kg hammer was repeatedly dropped from 0.76-m height to achieve three successive increments of 150-mm each [12]. The first increment was recorded as seating, while the number of blows which to advance the second and third increments were summed to give the N-value (blow count) or STP N-resistance (reported in blows per foot). If the sampler cannot be driven 450-mm, the number of blows every 150 mm increment and per each partial increment would be recorded on the boring log. For partial increments, the depth of penetration was recorded in addition to the number of blows [13]. The N-SPT should be corrected by considering the efficiency of the hammer, sampler lining, rod lengths, and borehole diameter as designated in ASTM D4633-16 [14, 15]. The CPT is commonly used in very soft clays to dense sands. It provides more accurate and reliable numbers for analysis in which the undrained shear strength (τ_u) is represented by total friction from cone resistance (q_c) and sleeve friction (f_s) [16].

B) Laboratory Test

The laboratory tests were used to obtain the geotechnical input parameters in order to calculate the bearing capacity of the driven-pile and bored-pile, such as triaxial, direct-shear, and Atterberg's limits in some volumetric tests. Regarding the standard test method from ASTM D2850-95 (1999), D4767-11 (2020), and D7181 (2020) [6], determining unconsolidated-undrained (UU), consolidated un-drained (CU), and consolidated-drained (CD) triaxial compression tests for cohesive soils are widely used to produce the cohesion (c) in kPa and angle of internal friction (φ) in degree (°) either within total stresses (undrained) or effective stresses (drained) conditions. The direct shear test referring to the ASTM D3080-98 examining the standard test method for a direct shear test of soils under consolidated-drained (CD) may produce the shear strength parameters in an effective stress since the pore-water in the soil specimen is released out during the test [7].

Some volumetric tests, i.e., specific gravity (G_s), unit weight (γ) in kN/m^3, and Atterberg's limits within the percent of water content (ω), could be determined by laboratory testing. The ASTM D4318-00 regarding standard test methods for liquid limit (LL), plastic limit (PL), and plasticity index (PI) of the soils [6] are commonly used to identify the index properties and its behaviors, also to predict the potential swelling of the soils using PI value [17]. The ASTM D421-85 (1998) and D422-63 (1998) regarding standard practice for dry preparation of soil samples for particle-size analysis, determination of soil constants, and the standard test method for particle-size analysis of soils [7], are respectively used for further analyses.

3.1.4 Deep Foundation Type

The types of deep foundations that are taken into consideration in this study include:

A) Driven Pile

The driven pile commonly applies to the deep foundations on near-shore and offshore. In addition, the footing is usually used to transmit load pressure from buildings to deeper parts or for weak soil layers [18].

B) Bored Pile

The bored pile is quite similar to the driven pile. It is constructed by excavating a hole using a drill machine that is equipped with a large barrel, auger, or tricon bit [19]. That construction is sometimes called a drilled shaft, drilled piers, caisson, cast-in-drilled-hole piles, and others.

The foundation, as constructed, supports axial forces through a combination of side shearing (skin friction) and end-bearing resistance [20].

3.1.5 Allowable Bearing Capacity

The bearing capacity is commonly discussed in allowable bearing capacity (Q_{all}) and ultimate bearing capacity (Q_{ult}) terminologies in which the relationship between permissible bearing capacity and ultimate bearing capacity is shown in the following Eq. (1).

$$Q_{all} = Q_{ult} / FoS \tag{1}$$

where Q_{all} is the allowable bearing capacity, Q_{ult} is the ultimate bearing capacity, and FoS (2.5 – 4.0) is a factor of safety. To calculate the bearing capacity of a single pile, the soil shearing resistance of the pile tip (Q_p end bearing) and frictional resistance of the pile blanket (Q_s skin friction) are considered.

3.1.6 Bearing Capacity of Pile Foundation

The bearing capacity analyses of single piles commonly use Meyerhof and Tomlinson's method, shown in the following Eq. (2) and Eq. (3).

A) Meyerhof

The bearing capacity analysis of a single pile [21].

$$Q_{ult} = Q_p + Q_s \quad (2)$$
$$Q_p = A_p\ q_p \text{ and } Q_s = A_s\ (0.02\ p_a\ \ N_{60})$$

where A_p (m^2) is the cross-section area of the pile tip, A_s (m) is the pile blanket area, q_p (kN/m2 or kPa) is the end resistance, p_a (100 kPa) is the atmospheric pressure and N_{60} is the average N-SPT value.

B) Tomlinson (Alpha Method)

The bearing capacity analysis by means of the alpha method uses the cohesion value (c) and skin friction on the clay soils [22]. By this method, the Q_s is a function of interface friction between piles and soils as follows.

$$Q_u = Q_s$$
$$Q_s = \alpha\ c\ p\ L \quad (3)$$

where c (kPa) is the cohesion, α is the adhesion factor, p (m^2) is the pile circumference, and L (m) is the pile depth.

3.1.7 Bore Pile Foundation Bearing Capacity

To calculate the bearing capacity of a single bored-pile, there are three common equations i.e., Decourt, Poulos, and O'neil & Reese equations as shown in the following Eq. (4), Eq. (5), and Eq. (6) [23].

A) Decourt

The bearing capacity of the bored-pile foundation [24].

$$Q_u = Q_p + Q_s$$
$$Q_u = \alpha\ \ (K\ N_p\ A_p) + \beta\ ((N_s/3 + 1)\ A_s) \quad (4)$$

where α is the coefficient of pile base, β is the coefficient of pile blanket, K (kPa) is the soil type coefficient, A_p (m^2) is the area of bored pile's blanket, A_s (m^2) is the area of bored pile's cross section, N_p is the corrected N-SPT at pile base and Ns ($3<N<50$) is the average of N-SPT along the pile

B) Poulos

The bearing capacity of the Bore Pile foundation [25].

$$Q_u = Q_p + Q_s$$
$$Q_u = K\ .\ N + (\alpha + \beta.N) \quad (5)$$

where K (kPa) is the soil type coefficient, N ($3<N<50$) is the average of N-SPT along the pile, α is the coefficient of pile base and β is the coefficient of pile blanket.

C) O'neil & Reese (Beta Method)

The bearing capacity of the bored pile according [26].

$$Q_u = Q_p + Q_s$$
$$Q_u = A_p\ (0.6\ \sigma_v'\ N_{60}) + A_s\ (\sigma_v'\ K \tan \delta) \quad (6)$$

where A_p (m^2) is the area of bored pile's blanket, A_s (m^2) is the area of bored pile's cross-section, σ_v' (kPa) is the effective stress in soils at depth, N_{60} (($>$ 50 bl/ft) is the corrected N-SPT between base of bored-pile and 2B below the base, K (kPa) is the earth pressure coefficient and δ (°) is the friction angle between pile and ground.

3.2 Research Methods

It commenced with a literature study to obtain alternative methods to analyze the bearing capacity of driven-pile and bored-pile foundations by adapting the data availability and consistency with in-situ soils and/or rocks characteristics in the Baiturahman Mosque project. Several secondary data, i.e., regional engineering geologic setting, previous geotechnical reports from the project owner, and some supporting data, were collected to enlarge a point of view on the site-specific characteristic comprehensively.

In this study, we analyze the type of foundation that is suitable for conditions in the field based on the location of the foundation and the processing time.

4. RESULT AND DISCUSSION

4.1 Core Drilling and SPT

The core drilling and SPT were conducted at four drill points, namely BM-1 to BM-4 points (Fig. 1). In every drill point, the SPTs were performed every 2 m depth interval. Meanwhile, the core and

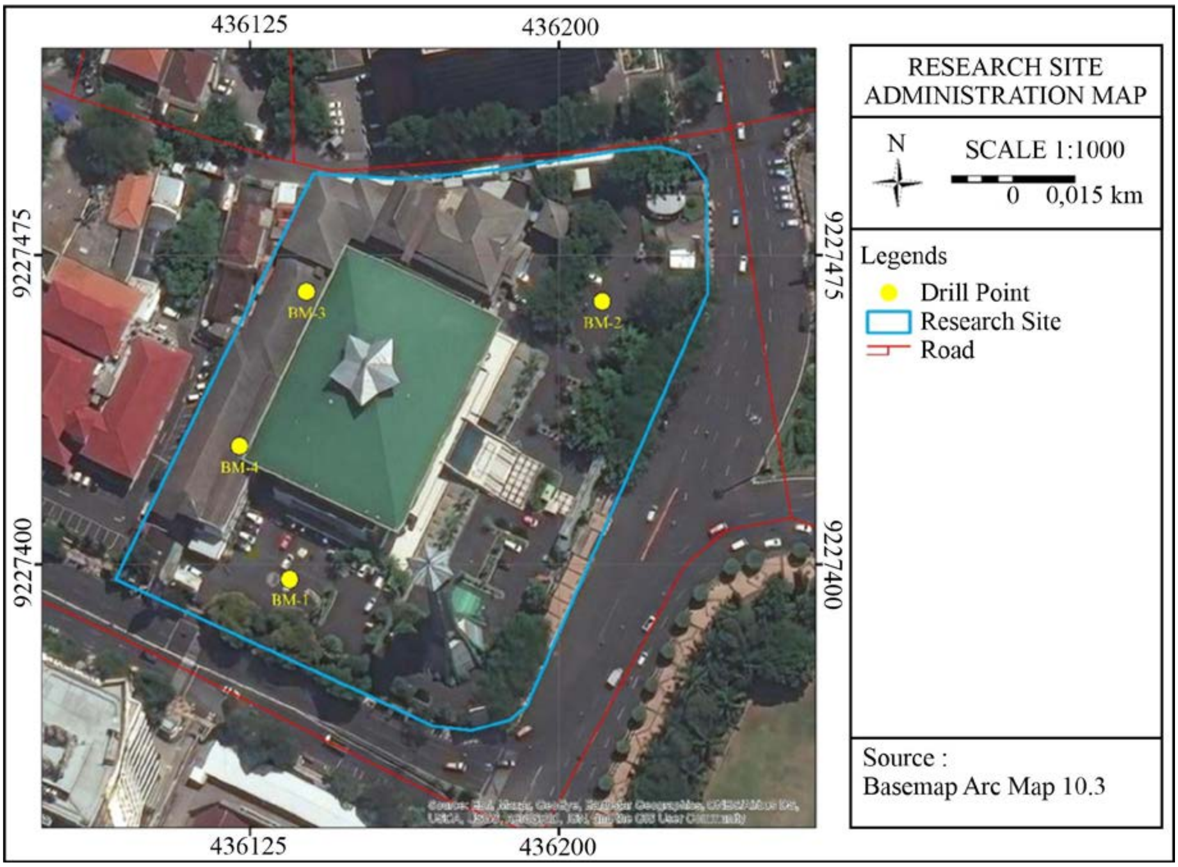

Fig. 1 Map of drill point locations at the research sit

undisturbed soil sampling was conducted every 5 m depth intervals at BM-1 - BM-2 and every 10 m depth intervals at BM-3 – BM-4. The subsurface correlations of the drilling points are shown in Fig. 2, where a sandy silt soil material dominated the first ten meters depth, and the deeper position consisted of silt and sandy silt materials.

4.2 Laboratory Test

There were several laboratory tests conducted to obtain some geotechnical parameters, including:

4.2.1 Grain-size Distribution Analysis

The grain-size distribution and hydrometer analysis on BM-1 to BM-4 show sand-gravel soil and fine-grained soil (silt-clay) materials. By plotted into the PI chart, then, there are potential swellings (from moderate to high swelling potential) on the soils as the following classification (Table 1).

4.2.2 Shear Strength Test

Some triaxial compression tests were conducted on the undisturbed soil samples BM-1 to BM-4. The result is shown in Table 2.

In the drill points of BM-3 and BM-4, the soils at 39.5 to 40.0 m depth were very hard, with an N-SPT value of more than 60 bl/ft and an angle of internal friction of more than 35°.

Table 1 The relationship between the plasticity index and swelling potential of the soils [18]

Index Plasticity (%)	Swelling Potential			
0 – 15	Low	-	-	-
10 – 35	Moderate	1	3	4
20 – 55	High	1	3	4
> 35	Very High	2		

Note: Red = BM-1, Yellow = BM-2, Blue = BM-3, Green = BM-4.

Table 2 Mechanical properties of soil samples

	Cohesion (kPa)	Internal friction (°)
BM-1	27.8 – 38.2	10.5 – 12.6
BM-2	11.9 – 33.5	11.9 – 23.5
BM-3	20.4 – 32.1	11.6 – 20.9
BM-4	25.0 – 32.4	12.7 – 20.1

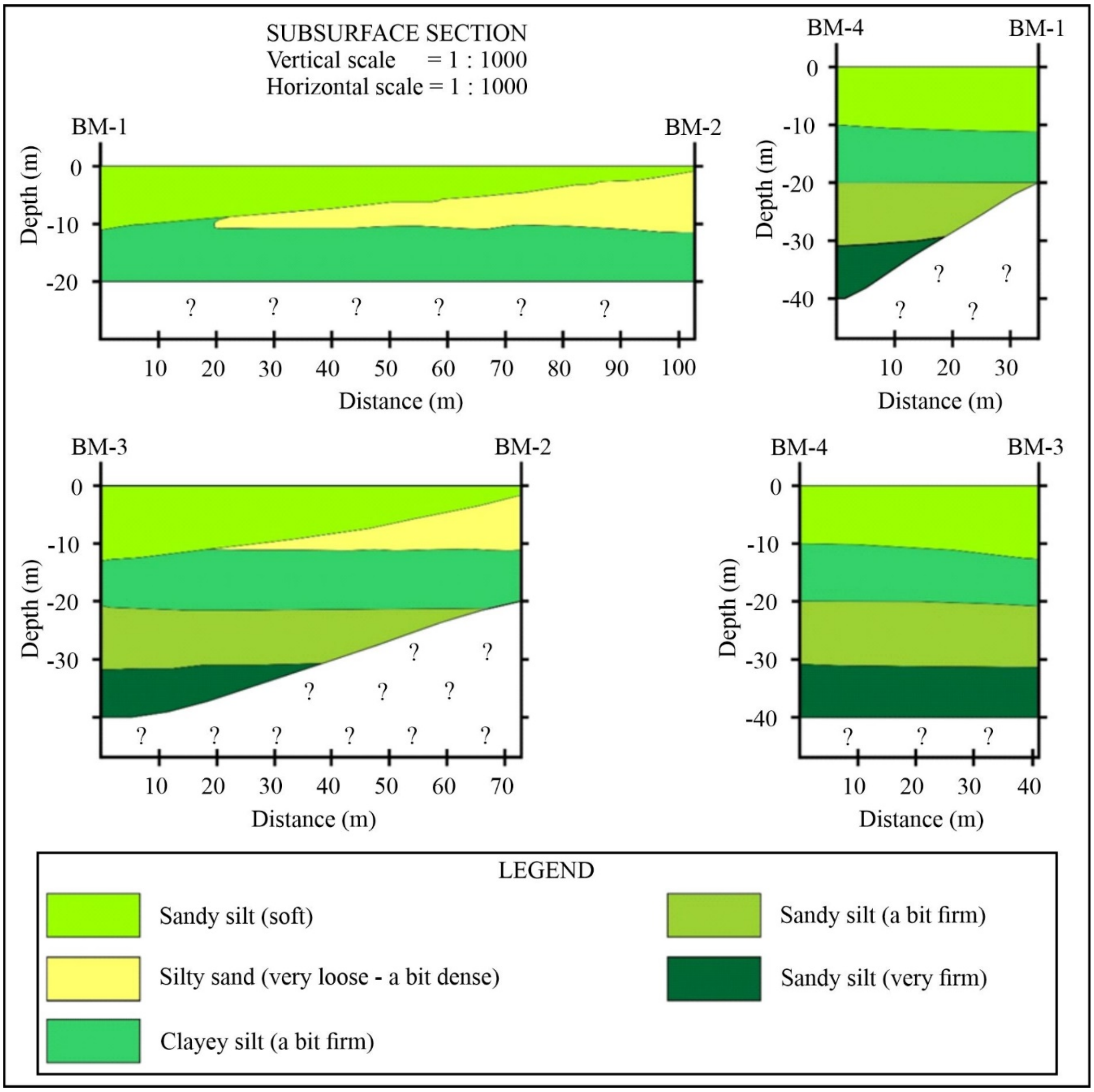

Fig. 2 Sub-surface lithological correlations of the drilling point

5. DISCUSSION

5.1 Calculation of Foundation Bearing Capacity

The bearing capacity of a single pile was calculated based on N-SPT of core drilling and laboratory data. The Meyerhof and Tomlinson methods are used to calculate the ultimate bearing capacity of the driven pile (Q_{ult}). Meanwhile, Decourt, Poulos, and O’neil & Reese methods are used to calculate the bored pile foundation's ultimate bearing capacity (Qult). Based on the analyses, the pile foundations of the BM-1 and BM-2 shall be driven piles from 6 to 20 m depth to support the basement (substructure).

The Meyerhof and Tomlinson methods are used to calculate the ultimate bearing capacity of the driven pile (Q_{ult}). Meanwhile, Decourt, Poulos, and O’neil & Reese methods are used to calculate the bored-pile foundation's ultimate bearing capacity (Qult). Based on the analyses, the pile foundations of the BM-1 and BM-2 shall be driven piles from 6 to 20 m depth to support the basement (substructure).

Furthermore, the bored pile shall be applied on BM-3 and BM-4 from 6 to 34 m depth to support two-story buildings. The axial load stresses on the BM-1 were about 3,428-kN, BM-2 4,766-kN, BM-3 6,868-kN, and BM-4 3,428-kN.

5.2 Bearing Capacity of Driven-Pile

5.2.1 Meyerhof

The Meyerhof's bearing capacity analyses on a single driven pile and a pile group are shown in Table 3 and Table 4.

5.2.2 Tomlinson (Alpha Method)

Tomlinson's bearing capacity analyses on a single driven pile and a pile group are shown in Table 4 and Table 5. Both Meyerhof and Tomlinson (α method) results have relatively the same with allowable bearing capacity (Qall). Adding more, the pile-group (Qgp) calculation is also relatively the same. However, Meyerhof's equation can be used to determine the number of piles required [28].

5.3 Bearing Capacity of Bored-Pile

5.3.1 Decourt

The Decourt's bearing capacity analyses on a single pile and a pile-group are shown in Table 6 and Table 7.

5.3.2 Poulos

The Poulos's bearing capacity analyses on a single pile and a pile group are shown in Table 8 and Table 9.

5.3.3 O'neil & Reese (Betha Method)

The O'neil & Reese calculation results of a single pile bearing capacity and a group pile bearing capacity are shown in Table 10 and Table 11. According to Decourt, the equation for calculating the allowable bearing capacity (Qall) and the bearing capacity of the group pile (Qgp) has quite different results compared to the Poulos and the O'neil & Reese equations. Subsequently, it cannot be used as a reference for determining the number of foundations due to unsuitable potential concerns when applied to soil conditions at the research site. Furthermore, if applied to the Poulos and O'neil & Reese equations, the allowable bearing capacity (Q_{all}) and group pile bearing capacity (Q_{gp}) are quite similar.

However, according to Poulos, the equation can be used as a reference for determination. This is because the O'neil & Reese calculation is influenced by several factors, including good or bad working methods (K value) and the use of pile types.

Those factors will affect some discrepancies not in accordance with the in-situ conditions and have little effect on calculation.

The Meyerhof and Tomlinson methods were used to calculate the ultimate bearing capacity of the driven-pile (Q_{ult}). Meanwhile, Decourt, Poulos, and O'neil & Reese methods are used to calculate the bored-pile foundation's ultimate bearing capacity (Qult). Based on the analyses, the pile foundations of the BM-1 and BM-2 shall be driven-piles from 6 to 20 m depth to support the basement (substructure). On the other hand, the bored-pile shall be applied on BM-3 and BM-4 from 6 to 34 m depth to support two-story buildings. The axial load stresses on the BM-1 were about 3,428-kN, BM-2 4,766-kN, BM-3 6,868-kN, and BM-4 of about 3,428-kN.

5.4 Recommendation of Foundation

In planning the foundation, we need to know the live load and dead load plan of the building on it. Based on the calculation results of the live load and dead load plan at each point, it shows that point BM-1 has a load of 349,6 tons, point BM-2 has a load of 486 tons, and points BM-3 and BM-4 have a load of 700,4 tons.

Foundation planning is carried out to prevent settlement due to soil conditions at the study site. Based on the research on consolidation settlement soils in the city of Semarang, it is known that potential consolidation settlement of the light structures (i.e. residential, school, office building, hospital, and terminal with built-in 1 floor only) is about 1,42 cm; meanwhile, for medium structures (i.e. light manufacturing and warehouse, 2–3 floors of buildings, museum, and library, etc.), those have potential consolidation settlement until 2,90 cm, and for heavy structures (i.e., heavy manufacturing, and warehouse, high-rise building of hotel, apartment, hospital, public offices, etc.), those have potential consolidation settlement about 4,38 cm [29].

5.4.1 Driven-Pile Foundation on BM-1

Based on the analyses using both driven piles and bored piles, the recommended type of foundation to use in the buildings at point BM-1 is driven piles (D=60 cm) of about 20 piles with a 5x4 pile-group arrangement.

5.4.2 Driven-Pile Foundation on BM-2

Based on the analyses using both driven-piles and bored-pile foundations, the recommended type of foundation for the buildings at point BM-2 is the driven-pile (D=60 cm) of about 16 piles with a 4x4 pile-group arrangement.

5.4.3 Bored-Pile Foundation on BM-3

Based on the analyses using both driven-piles and bored-piles foundations, the recommended type of foundation for use in buildings at point BM-3 is the bored-pile (D=60 cm) of about 4 piles with a 2x2 pile-group arrangement.

Table 3. Bearing capacity of a single driven pile based on Meyerhof

No	Q_{ult} Meyerhof (ton)				Q_{all} Meyerhof (FoS=3), (ton)			
	Round (D=50)	Square (S=40)	Round (D=60)	Square (S=45)	Round (D=50)	Square (S=40)	Round (D=60)	Square (S=45)
BM-1	76.40	75.80	95.17	87.07	25.47	25.27	31.72	29.02
BM-2	105.42	94.66	142.22	114.08	35.14	31.55	47.41	38.03
BM-3	314.38	279.02	426.88	337.71	104.79	93.01	142.29	112.57
BM-4	390.09	341.46	535.11	416.26	130.03	113.82	178.37	138.75

Table 4. Bearing capacity of pile group based on Meyerhof

No	Load (σ_v) ton	Q_{gp} Meyerhof (ton)			
		Round (D=50)	Square (S=40)	Round (D=60)	Square (S=45)
BM-1	349.6	412.991	409.735	433.052	396.171
BM-2	486.0	569.819	511.661	525.469	519.080
BM-3	700.4	892.600	792.209	846.884	736.441
BM-4	700.4	850.664	744.609	814.464	825.812

Table 5. Bearing capacity of a single driven pile based on Tomlinson

No	Q_{ult} α Method (Tomlinson)				Q_{all} α Method (Tomlinson) (FoS=3)			
	Round (D=50)	Square (S=40)	Round (D=60)	Square (S=45)	Round (D=50)	Square (S=40)	Round (D=60)	Square (S=45)
BM-1	76.37	75.77	95.13	87.03	25.46	25.26	31.71	29.01
BM-2	111.01	100.44	148.93	120.60	37.00	33.48	49.64	40.20
BM-3	298.18	262.39	407.45	319.00	99.39	87.46	135.82	106.33
BM-4	372.14	232.04	513.57	395.52	124.05	107.68	171.19	131.84

Table 6. Bearing capacity of pile group based on Tomlinson

No	Load (σ_v) ton	Qgp α (Tomlinson), (ton)			
		Round (D=50)	Square (S=40)	Round (D=60)	Square (S=45)
BM-1	349.6	412.814	409.545	432.866	395.990
BM-2	486.0	505.094	542.909	550.264	548.723
BM-3	700.4	846.618	745.013	808.329	905.720
BM-4	700.4	811.524	704.436	781.681	784.569

Table 7. Bearing capacity of a single bored pile based on Decourt

No	Q_{ult} Decourt (ton)		Q_{all} Decourt (FoS=3), (ton)	
	Round (D=50)	Round (D=60)	Round (D=50)	Round (D=60)
BM-1	115.33	146.88	38.44	48.96
BM-2	80.22	101.92	26.74	33.97
BM-3	284.17	374.92	94.72	124.97
BM-4	278.32	365.64	92.77	121.88

Table 8. Bearing capacity of pile group based on Decourt

No	Load (σ_v) ton	Q_{gp} Decourt (ton)	
		Round (D=50)	Round (D=60)
BM-1	349.6	426.115	417.024
BM-2	486.0	533.828	570.969
BM-3	700.4	806.838	817.568
BM-4	700.4	790.234	797.334

Table 9. Bearing capacity of single bored pile based on Poulos

No	Q_{ult} Poulos (ton)		Q_{all} Poulos, (FoS=3), (ton)	
	Round (D=50)	Round (D=60)	Round (D=50)	Round (D=60)
BM-1	296.67	364.48	98.89	121.49
BM-2	198.73	244.13	66.24	81.38
BM-3	600.68	754.73	200.23	251.58
BM-4	604.45	756.99	201.48	252.33

Table 10. Bearing capacity of pile group based on Poulos

No	Load (σ_v) ton	Q_{gp} Poulos (ton)	
		Round t (D=50)	Round (D=60)
BM-1	349.6	451.544	386.429
BM-2	486.0	564.252	532.364
BM-3	700.4	914.272	800.183
BM-4	700.4	920.007	802.579

Table 11. Bearing capacity of a single bored pile based on O'neil & Reese

No	Q_{ult} O'neil & Reese, (ton)		Q_{all} O'neil & Reese, (FoS=3), (ton)	
	Round (D=50)	Round (D=60)	Round (D=50)	Round (D=60)
BM-1	182.69	198.43	60.90	66.14
BM-2	142.11	158.30	47.37	52.77
BM-3	626.77	693.39	208.92	231.13
BM-4	612.47	680.15	204.16	226.72

Table 12. Bearing capacity of pile group based on O'neil & Reese

No	Load (σ_v) ton	Q_{gp} O'neil & Reese	
		Round (D=50)	Round (D=60)
BM-1	349.6	398.390	432.705
BM-2	486.0	525.055	584.855
BM-3	700.4	953.987	735.152
BM-4	700.4	932.220	721.109

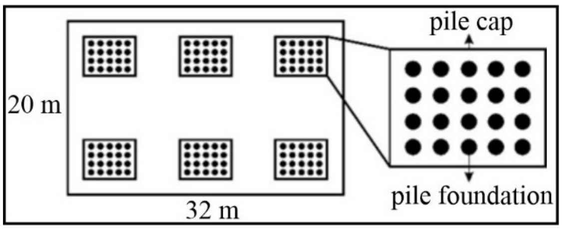

Fig.3 BM-1 group pile foundation.

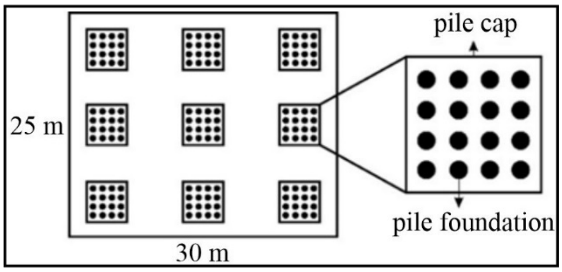

Fig.4 BM-2 group pile foundation.

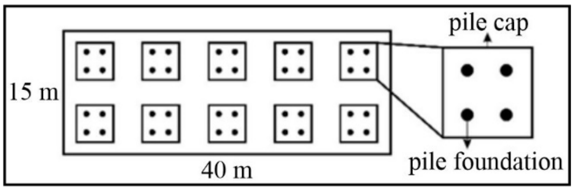

Fig.5 BM-3 group pile foundation.

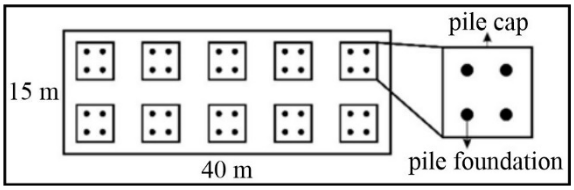

Fig.6 BM-4 group pile foundation.

5.4.4 Bored Pile Foundation on BM-4

Based on the analyses using both driven-piles and bored-piles foundations, the recommended type of foundation for use in buildings at point BM-4 is the bored-pile (D=60 cm) of about 4 piles with a 2x2 pile-group arrangement.

6. CONCLUSION

Geologically, the research location sits on the Alluvial (Qa) deposit of a lagoon depositional environment dominated by silt materials with clay and sand. Geotechnically, the N-SPT value ranges from 2 to more than 60 blows/feet, with the swelling potential categorized as medium to very high. The pile tips of the BM-1 and BM-2 were seated on slightly firm and firm soil materials (20 m depth), and the pile tips of the BM-3 and BM-4 were sitting on a very firm soil material (34 m depth).

The recommended type of foundation at BM-1 is driven piles of 60-cm dia. with 20 piles per a 5x4 arrangement, BM-2 is driven piles of 60-cm dia. with 16 piles per an 4x4 arrangement, BM-3 is bored piles of 60-cm dia. with 4 piles per a 2x2 arrangement, and BM-4 is bored piles of 60-cm dia. with 4 piles per an a 2x2 arrangement. All foundation arrangement provides the factor of safety (FoS) min. 3.

This research shows that recommendations for determining the number of of driven-piles are better using the Meyerhof equation and determining the number of of driven-piles are better using the Poulos equation. This equation will produce more accurate results.

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8. REFERENCES

[1] Thaden R. E., Sumadirdja H., and Richards P. W., Geological Map of Magelang & Semarang Quadrangle, Geological Research & Development Center, 1975, pp. 1.

[2] Abidin, H. Z., Andreas H., Gumilar I., Sidiq, T. P., and Fukuda, Y., Land Subsidence in Coastal City of Semarang (Indonesia): Characteristics, Impacts, and Causes, Geo-matics, Natural Hazards and Risk, Vol. 4, No. 3, Taylor & Francis Group, 2013, pp. 226-240.

[3] Soebowo E., Sarah D., Murdohardono D., and Wirabuana T., Geologi Bawah Permukaan Wilayah Amblesan Tanah di Kota Semarang, Proceeding of Researches 2014, Pusat Penelitian Geoteknologi LIPI, 2014, pp. 57-63.

[4] Wu P. C., Wei M. (M)., and D'Hondt S., Subsidence in Coastal Cities Throughout the World Observed by InSAR, Advancing Earth and Space Science, Vol. 49, Issue 7, 2022.

[5] Frick H., and Setiawan P. L., Ilmu Konstruksi Struktur Bangunan, Kanisius, 2001, pp 1-276

[6] ASTM, ASTM Book of Standards Volume 04.08. Soil and Rock (I): D420- D5779, copyright © ASTM, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959, 2001.

[7] ASTM, ASTM Book of Standards Volume 04.09. Soil and Rock (II): D5780- D6575." copyright © ASTM, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959, 2001.

[8] Samtani N. C. and Nowatzki E. A., Soils and Foundations Reference Manual, Vol. I (NHI Course no. 132012), Federal Highway Administration (FHWA), U.S. Department of Transportation, 2006, pp 1-462.

[9] Wahyudi P. A., Purwanto P., and Putranto T. T., Analysis of Correlation between Bearing Capacity of the Land Against Land Settlement and Duration of Decline in Semarang City, International Journal of GEOMATE, Vol. 19, Issue 73, 2020, pp. 163-169.

[10] Price D. G., Engineering Geology Principles and Practice, Imperial College London, UK, 2010, pp. 1-450.

[11] Whitaker T., The Design of Pile Foundation Second Edition, Hedington Hill Hall, Oxford: Pergamon Press, 1976, pp 1-228.

[12] Mayne P. W., Christopher B. R., and De Jong J., Manual on Subsurface Investigations Geotechnical Site Characterization, Federal Highway Administration (FHWA), National Highway Institute, Washington D.C., 2001, pp 1-332

[13] Skempton A. W., SPT Procedures and the Effects in Sands of Overburden Pressure, Relative Density, Particle Size, Aging, and over consolidation, Geotechnique, Vol. 36, No. 3, 1986, pp. 425-447.

[14] Kulhawy F. H. and Mayne P. W., Manual on Estimating Soil Properties for Foundation Design, Report EPRI-EL 6800, Electric Power Research Institute, Palo Alto, 1990, pp. 1-308.

[15] Mayne P. W., Cone Penetration Testing State-of-Practice. NCHRP Project 20-05, Topic 37-14, The National Cooperative Highway Research Program, 2007, pp 1-137

[16] Chen F. H., Foundation on Expansive Soils, Developments in Geotechnical Engineering 12, Amsterdam: Elsevier Scientific Publishing Company, 1975, pp. 33-60.

[17] Madabhushi G., Knappett J. and Haigh S., Design of Pile Foundation in Liquefiable Soils Chapter 1, Imperial College Press, 2010, pp. 1-232.

[18] Robertson P. K. & Campanella R. G., Interpretation of Cone Penetration Tests – Part I (Sand) and Part II (Clay)”. Canadian Geotechnical Journal, Vol. 20, No. 4,1983, pp 1-83

[19] Brown D. A., Turner J. P., and Castelli, R. J., Loehr, E. J., Drilled-Shaft: Construction Procedures and Design Methods (NHI Course no. 132014), NHI-18-024, Federal Highway Administration (FHWA), U.S. Department of Transportation, 2018, pp 1-747.

[20] Meyerhof G. G., Journal of the Geotechnical Engineering Division, 102(GT3), copyright 1976 ASCE (American Society of Civil Engineering), 1976, pp 197–228.

[21] Tomlinson M. J., Pile Design and Construction Practice, Cement and Concrete Association, 1977, pp 1-587.

[22] Das B. M. & Sivakugan N., Principles of Foundation Engineering Ninth Edition, Cengage, 2017, pp. 461-570.

[23] Decourt L., Prediction of the Bearing Capacity of Piles Based Exclusively on N Values of the SPT, Proceeding of ESOPTZ, Amsterdam 1, 1982, pp. 29-34.

[24] Poulos H. G. & Hull T. S., The Role of Analytical Geomechanics in Foundation Engineering, Proceeding of Foundation Engineering Conference. Illinois: Evanston, 1989, pp. 1578-1606.

[25] O’neil M. W. & Reese L. C., Drilled Shaft: Construction Procedures and Design Method, Report, FHWA-IF-99-025, Federal Highway Administration (FHWA), U.S. Department of Transportation, 1999, pp 1-791.

[26] Kulhawy F. H., Drilled Shaft Foundation, Chapter 14 in Foundation Engineering Handbook, 2nd Edition, Van Nostrand Reinhold, 1991, pp. 537-538.

[27] Meyerhof G. G., Penetration Test and Bearing Capacity of Cohesionless Soils, Journal of the Soil Mechanics and Foundation Division, ASCE, Vol.82, No. SM1, 1956, pp. 1-19.

[28] Reese L. C. & O’neil M. W., Drilled Shaft: Construction Procedures and Design Methods” Federal Highway Administration (FHWA), U. S. Department of Transportation, 1998, pp 1-791.

[29] Widiarso D. A., Haryanto W., Muslim D., Zakaria Z., and Iskandarsyah T. Y., Potential Consolidation Settlement due to Load Stresses of Building Structures, International Journal of GEOMATE, Vol. 17, Issue 60, 2019, pp. 204-210.