The bearing capacity based on standard penetration test

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Abstract. The stability of building construction or series is not only determined by the upper circuit but the stability of the lower series in this case the foundation plays an equally important role in maintaining the stability of the structure. In planning the foundation, the bearing capacity of the soil is an important issue. This research is focused on knowing the bearing capacity value of the allowable bearing capacity formula developed by Meyerhof. This research was conducted in the Tambakharjo area and its surroundings, Semarang City, Central Java. Field data collection includes the results of the standard penetration test (SPT) and undisturbed soil samples (UDS). The N-SPT data was later used to determine the bearing capacity of the soil. The results show a positive linear relationship between N-SPT and carrying capacity, which means the higher the N-SPT, the higher the carrying capacity value. The distribution of bearing capacity at several soil depths is indicated by a zoning map of the bearing capacity of the soil. N-SPT correlation with soil physical properties (clay fraction percentage, plasticity index percentage, and activity value) was also carried out, but most of the data stations were not in accordance with normal conditions.

1 Introduction

The stability of building construction or series is not only determined by the upper circuit which directly supports the forces acting on the circuit, but the stability of the lower series in this case the foundation plays an equally important role in maintaining the stability of the structure. Foundations have an important role in sustainable development planning in order to anticipate or reduce the impact of settlements that may occurs the bearing capacity of shallow foundations on homogeneous soils by calculating the shear stress of the soil located under the foot of the foundation [1].

Analysis of the calculation of the bearing capacity of the soil there are many factors that affect the bearing capacity, one of which is the distance factor between the foundations [2]. The bearing capacity must be greater than the load on the foundation. To calculate the bearing capacity of layered soil, the approach of the theory of Boundary Equilibrium Method assumes homogeneous layered soil (one layer), although the strength of each soil layer is somewhat different [3].

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Calculation of bearing capacity and settlement requires the existing soil properties (soil properties) obtained through testing in the soil mechanics laboratory. Tests in this laboratory will provide values such as internal shear angle (φ) and cohesion (c) which will be used in the calculation of bearing capacity. In addition to testing in the laboratory, the results of field tests such as the Standard Penetration Test (SPT) can also be used in the calculation of the bearing capacity of the foundation, although only as an initial estimateand must be compared with the results of empirical calculations using the results of laboratory tests. Comparison of the bearing capacity values obtained from various test results can be compared to determine the permissible load capacity value according to the geometry and depth of the existing foundation. These results are used as recommendations regarding the type and depth of foundation that is safe to use in the area.

2 Literature Review Research Area Geology

According to the Regional Geological Map of Sheets Magelang and Semarang, the rock unit that developed in the study area was Alluvium Deposits (Qa) Alluvium deposits (Qa) are alluvium deposits of beaches, rivers, and lakes [4]. Coastal deposits consist of clay, silt, sand, and a mixture of them reaching a thickness of 50 m or more [5]. The discontinuity of the clay, silt, and sand layers indicates a repeated sedimentation process during deposition [6]. River and lake deposits consist of gravel, gravel, sand, and silt with a thickness of 1-3 m. The coastal area of Semarang City is composed of Holocene deposits which are characterized by tidal deposits, river deposits coastal embankment deposits, swamps, and alluvium which are located on the shelf of the Quaternary plains [4]. The physiographical arrangement of the Semarang area and its surroundings is an alluvial plain area in the form of river deposits, delta deposits, and tidal deposits. This zone is a transition zone from the Rembang Zone-Kendeng Zone. The geology of the Semarang exposure area is characterized by the repetition of loam–silt units which are quite dominant with sand insertsranging in size from fine to coarse. East coast alluvium has a higher expansive rate than the west coast [7].

The units are swamp sediment, brownish gray to greenish gray, rock hardness is very soft – soft, low – high plasticity, generally saturated with water, contains plant remains and shell fragments, and thickness ranges from 2.5 – 20 m. The distribution is mainly along the coast, with high compressibility; the depth of the groundwater table is very shallow - shallow. The area is a waterlogged area. Land use is generally in the form of fish ponds, settlements, and warehousing. This unit contains; Silt (40 – 72%), Clay (6 – 42%), and Sand (15– 42%).

2.1 Soil

Soil is composed of liquids, gases, and solids in the form of organic and inorganic materials [8, 9]. Soil is useful as a construction material in various kinds of civil engineering work, besides as a support for the foundation of the building [10]. Weak bonds between soil particles are caused by the influence of carbonates or oxides which are compounds between these particles, or it can also be caused by the presence of organic matter [11]. According to Shower and Shower (1967) in [12], soil is a constituent mineral with or without decaying, structured, and textured organic plant and fauna. In general, soils can be classified as cohesive soils and non-cohesive soils, or as fine-grained or coarse-grained soils [13], but the term is too general to allow for the same identification of soils of similar nature. The system commonlyused is the Unified Soil Classification System or Unified Soil Classification System (USCS).

2.2 Clay Mineral

Clay material is composed of clay minerals and other very fine minerals with a size of 0.002 mm in the form of flat plates [14, 15]. The clay minerals are formed due to the interaction of fluids with rocks which are controlled by the process of dissolving and recrystallization [16]. Clay minerals are chemically divided intotwo types, namely 1:1 clay minerals which are composed of one tetrahedral chip and one octahedral chip, and 2:1 clay minerals composed of two tetrahedral and one octahedral pieces [17]

The presence of clay minerals is often a concern in infrastructure development, some of which are kaolinite, illite, and montmorillonite because these minerals are composed of hydrated aluminosilicate crystals [18]. The property is the swelling properties, especially if there is water, and are easily destroyed when exposed toair or physically weathered in the form of clay crumbling, breaking into pieces, andbreaking down. This last trait is referred to as slacking.

The swelling and shrinkage event in clay minerals is an activity that indicates a change in volume related to water content. The interaction of the material with seawater with a pH of 7.5-8.4 causes the release of SiO2- compounds in clay minerals [19]. This condition causes the addition of K (potassium) molecules to the montmorillonite, causing the montmorillonite to turn into illite [20].

Table 1. Value of clay mineral activity figures [12].

Activity Numbers	Mineral Properties	Activity
0.4 – 0.5	Kaolinitic	Low
0.5 – 1.0	Illitic	Medium
1.0 – 7.0	Monmorilonitic	High

2.3 X-Ray Diffraction

X-Ray Diffraction (XRD) is conducted to analyze the phase or compound composition of the material and also for the characterization of crystals. The analytical method with XRD can be used to identify the type of mineral as long as the mineral has a certain crystal form even though the size is very small. Semi-quantitative XRD analysis was carried out to determine the proportion of montmorillonite, illite, and kaolinite/chlorite clay minerals which were useful for estimating the expansive properties of clay contained in rocks. Semi-quantitative identification of clay minerals is carried out based on the peak area.

Potassium ions can also bond to montmorillonite and can convert montmorillonite into illite [20]. Illite minerals consist of two tetrahedral gibbsite pieces and one octahedral silica chip bonded to each other by bonds between potassium/potassium ions present in each chip. Kaolinite is composed of one tetrahedral gibbsite chip and one octahedral silica chip [10].

Clay is dominating the northern coastal area of Semarang. The eastern coastal area of Semarang has clay with a high degree of expansiveness, dominated by montmorillonite. On the other hand, the western part tends to have a lower level of expansiveness, composed of kaolinite, illite, and, mixed layers between illite and montmorillonite.

2.4 Sea Water Intrusion in Semarang Coast

Seawater intrusion has been going on for a long time in Semarang. This can be known based on the low resistivity value in coastal areas, which can be interpreted as containing saline water. Salinity has increased from 1995 to 2008, and about 55% of groundwater on the coast of Semarang is saline water. This phenomenon is very influential on cities located on the coast, one of which is the city of Semarang, this is indicated by the sea level anomaly which shows an upward trend from 2009 to 2011 of 12.83 mm/year.

Due to technical requirements of OpenType font technology, Microsoft Word's "New Style" Equation Editor works only with fonts specially designed for mathematical typesetting. Unless you have obtained and configured new OpenType math fonts, it is highly likely that your installation of Word will use the Cambria Math font for all mathematics created with the "New Style" editor. Using the Cambria Math font for mathematics and Times Roman for your text will cause a mismatch in the visual appearance of your article, so, for consistency, we prefer authors to use the "Old Style" Equation Editor because it is straightforward to amend the size/style of the fonts it uses.

3 Methodology

The methodology used in this study includes several laboratory works. First is the inspection of water content to get the amount of soil water content. This test standard refersto ASTM D-2216-05. Soil water content (Wn) is the ratio between the weight of the water contained in the soil and the weight of the solid grains in the soil, expressed in percent.

Inspection of volume weight or unit weight of contents is tested to determine volume weight as a comparison between soil weight and soil volume from a soil sample collected in the field. The sample was collected by utilizing drive cylinder to have relatively undisturbed soil by inserting a thin steel cylinder into the ground through a special driving head. This test standard refers to ASTM D-2937-04.

Soil Specific Gravity Examination aims to determine the specific gravity of the soil that has grains through a number 4 sieve with a pycnometer. Specific gravity is the ratio between the weight of the soil grains and the density of distilled water. Meanwhile, the weight of the water content is the ratio between the weight of the water and the water content. For the same water content as the soil grain content, the specific gravity of the soil is the ratio of the weight of the soil grains to the weight of distilled water at a certain temperature. This test standard refers to ASTM D-854-02.

Soil Consistency Limit Inspection is intended to determine the water content of a soil at the state of the plastic limit or plastic limit (PL) and liquid limit or liquid limit (LL). From these values, the plasticity index (PI) LL – PL can be determined. The implementation of the test will refer to the standard ASTM D-4318-06 procedure to obtain the liquid limit and plastic limit.

Inspection of Grain Size and Hydrometer is intended to determine the grain size distribution (gradation) of fine aggregate and coarse aggregate by using a sieve. Then, the hydrometer examination (wet analysis method) is intended to determine the distribution of grain size (gradation) of the soil passing through the number 10 sieve. The soil that is still passing through the number 200 sieve is clay-type soil.

3.1 X-Ray Diffraction Test (XRD)

Analysis of the test sample was carried out by the bulk method, to determine the minerals contained in the sample. After sample preparation, XRD test was performed. The basis of the principle of X-ray diffraction is that X-ray diffraction occurs in the elastic scattering of X-ray photons by atoms in a periodic lattice. The monochromatic scattering of X-rays in this phase provides constructive interference. Based on the Bragg equation, if a beam of X- rays is dropped on a crystal sample, the crystal plane will refract X-rays which have a wavelength equal to the distance between the lattices in the crystal. The refracted light will be captured by the detector and then translated as a diffraction peak. The more crystalplanes contained in the sample, the stronger the intensity of refraction it produces. Each peak that appears in the XRD pattern represents a crystal plane that has a certain orientationin the three-dimensional axis. The peaks obtained from these measurement data are then matched with X-ray diffraction standards for almost all types of minerals.

4 Result and Discussion

4.1 BM 01

At BM 01 drilling location, undisturbed soil samples (UDS) were taken at a depth of 4.5 m, 11 m, 15 m, and 21 m. Then, on each sample, XRD test was conducted to determine the type of mineral and its percentage. It was found that at a depth of 4.5 meters, there are minerals Calcite 0%, Quartz 54.97%, Kaolinite 40.56%, Illite 4.47%, Montmorillonite 0%, at a depth of 11 meters there are minerals Calcite 15.46%, Quartz 48,47%, Kaolinite 29.67%, Illite 6.41%, Montmorillonite 0%, at a depth of 15 meters there are minerals Calcite 8.01%, Quartz 54.92%, Kaolinite 36.38%, Illite 0%, Montmorillonite 0,7%, and at adepth of 21 meters there are minerals Calcite 7.11%, Quartz 39.33%, Kaolinite 45.08%, Illite 8.47%, Montmorillonite 0%.

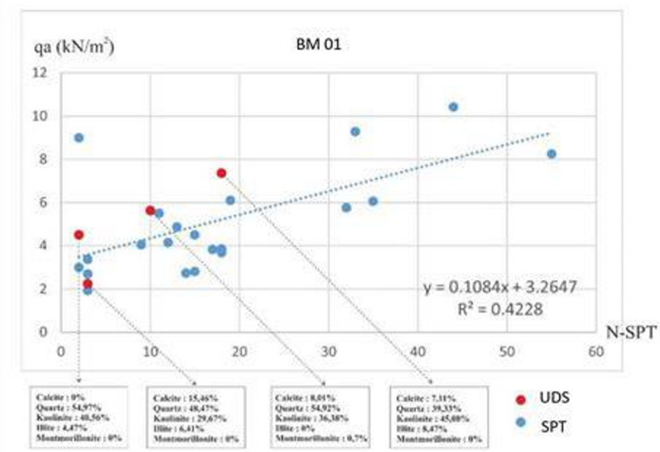

Fig. 1. Relationship between N-SPT and qa on BM 01.

From the relationship between N-SPT and qa graph at BM 01, the R2 value (distribution coefficient) is 0.4228 and the r-value (correlation coefficient) is 0.65. Shows a strong positive linear relationship between x and y, the higher the N-SPT value, the higher the carrying capacity value (Figure 1).

4.2 BM 03

At BM 03 drilling location, UDS were taken at a depth of 5 m, 11 m, and 15 m. Then, XRD was conducted at each sample to determine the type of mineral and its percentage. It was found that at a depth of 5 m there are minerals Calcite 12.11%, Quartz 41.54%, Kaolinite 17.71%, Illite 27.86%, Montmorillonite 0.78%, at a depth of 11 m there are minerals Calcite 9.19%, Quartz 43.92%, Kaolinite 15.81%, Illite 30.14%, Montmorillonite 1.22%.At a depth of 15 meters, there are minerals Calcite 6.84%, Quartz 44.69%, Kaolinite 20.81%, Illite 23.69%, Montmorillonite 1.26% (Figure 2).

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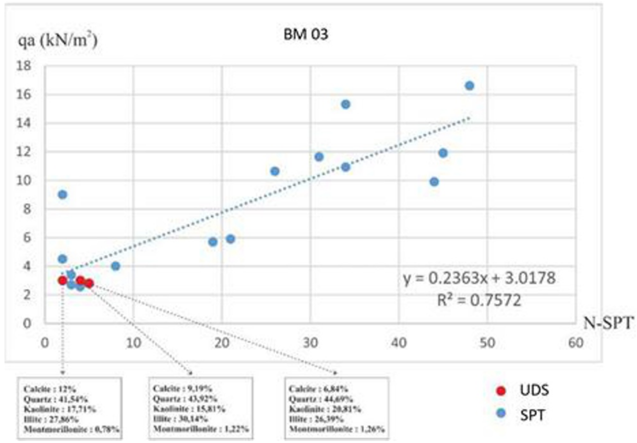

Fig. 2. Relationship between N-SPT and qa on BM 03.

From the graph of the relationship between N-SPT and qa at BM 03, the value of R2 (distribution coefficient) is 0.7572 and the value of r (correlation coefficient) is 0.87. Shows a very strong positive linear relationship between x and y, the higher the N-SPT value, the higher the carrying capacity value.

4.3 BM 04

At BM 04 drilling location, undisturbed soil samples (UDS) were taken at a depth of 5 m, 11 m and 15 m. Then, X-ray diffraction test was conducted on each sample to determine the type of mineral and its percentage.

The relationship between N-SPT and qa in BM 04 is divided into two conditions, the first isthe condition when fill material is included, and the second is the condition of the material or lithology in a natural state, in other words, fill or fill material is not included.

4.3.1 N-SPT relationship with qa at BM 04 (with fill)

At 5 m depth, there are minerals Calcite 16.27%, Quartz 60.8%, Kaolinite 21.87%, Illite 0%, Montmorillonite 1.07%, at a depth of 11 meters there are minerals Calcite 17.16%, Quartz 53 ,67%, Kaolinite 23.9%, Illite 0%, Montmorillonite 5.28%, and at a depth of 15 meters there are minerals Calcite 0%, Quartz 45.72%, Kaolinite 29.01%, Illite 22.06%, Montmorillonite 3.21%.

The relationship between N-SPT and qa on BM 04 (with Fill) shows that the R2 value (distribution coefficient) is 0.057 and the r value (correlation coefficient) is 0.239. A very weak positive linear relationship is identified between x and y (Sarwono, 2006). This is most likely due to two samples that are not adjacent to a linear line, which makes the correlation very weak. The sample has a grain size of sand, silt, and gravel (Fill) which is stockpiled on top of the existing lithology, and has a very high N-SPT value (Figure 3).

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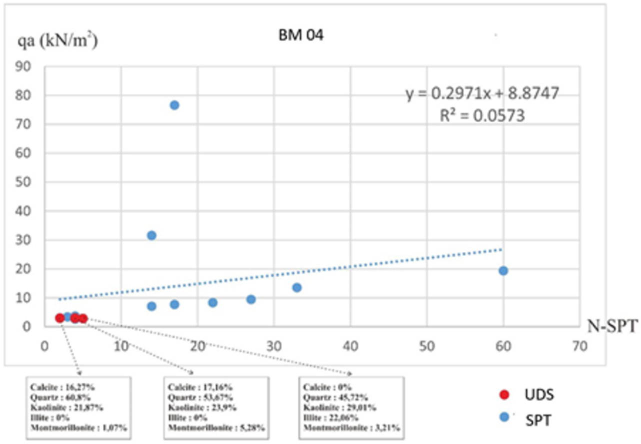

Fig. 3. The relationship between N-SPT and qa at BM 04 (with Fill).

After knowing the results of the correlation between N-SPT and qa at BM 04 by including the fill material, which resulted in a very weak correlation, a graph of therelationship between N-SPT and qa on BM 04 by excluding the fill material is made.

4.3.2 N-SPT relationship with qa at BM 04 (without fill)

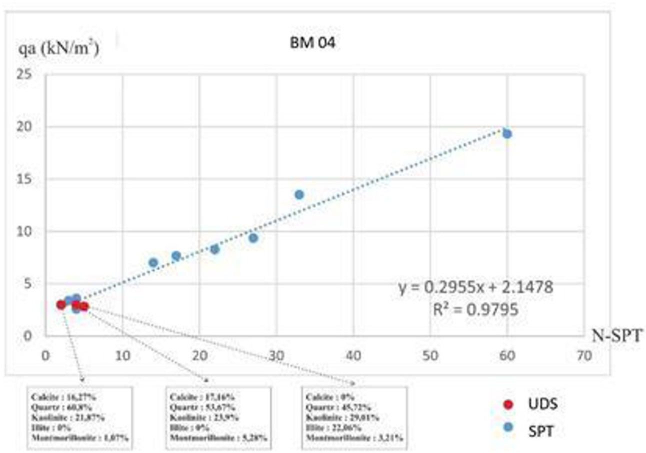

Fig. 4. Relationship of N-SPT with qa at BM 04 (without Fill).

The graph of the relationship between N-SPT and qa at BM 04 (without Fill) shows that the R2 value (distribution coefficient) is 0.9795 and the r value (correlation coefficient) is 0.989. A very strong positive linear relationship between x and y (Sarwono, 2006) is identified. This is because the existing lithology is not backfilled with materials such as sand, gravel, and silt, it will produce a very strong correlation between the N-SPT value andthe carrying capacity value, the higher the N-SPT value, the higher the carrying capacity value (Figure 4).

4.4 BM 05

At BM 05 drilling site, UDS were taken at a depth of 5 m, 11 m, and 15 m. Then on each sample, XRD test was conducted to determine the type of mineral and its percentage. There are two scenarios in evaluating the relationship between N-SPT and qa at BM 05, which are,

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the condition when fill material is included and the condition of the material or lithology in a natural state, in other words, fill material is not included.

4.4.1 The relationship between N-SPT and qa at BM 05 (with fill)

It was found that at a depth of 5 m there are minerals Calcite 12.52%, Quartz 52.53%, Kaolinite 30.09%, Illite 0%, Montmorillonite 4.86%, at a depth of 11 meters there are minerals Calcite 14.04%, Quartz 41.37%, Kaolinite 21.74%, Illite 21.24%, Montmorillonite 1.61%, and at a depth of 15 meters there are minerals Calcite 3.5%, Quartz 80.17%, Kaolinite 11.34%, Illite 0%, Montmorillonite 4.99%. The relationship between N-SPT and qa at BM 05 (with Fill), where the R2 value (distribution coefficient) is 0.0815 and the r value (correlation coefficient) is 0.285 (Figure 5).

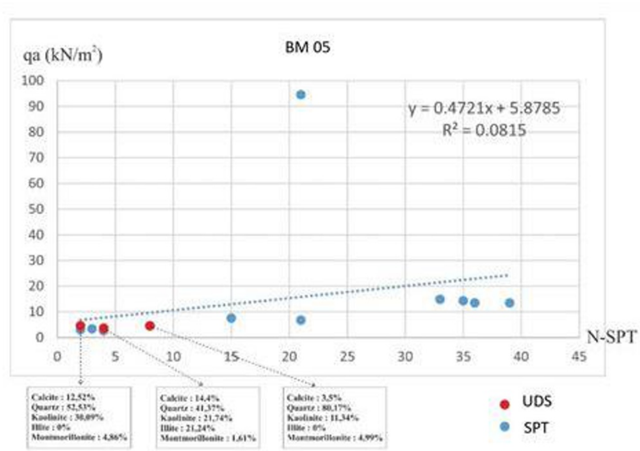

Fig. 5. Relationship of N-SPT with qa at BM 05 (with Fill).

A fairly weak positive linear relationship between x and y (Sarwono, 2006), is most likely caused by one sample that is not close to the linear line. The sample has a grain size of sand, silt, and gravel (Fill) which is stockpiled on top of the existing lithology, and has a very high N-SPT value. After knowing the results of the correlation between N-SPT and qa at BM 05 by including fill material, which resulted in a fairly weak correlation, therelationship between N-SPT and qa at BM 05 by not including fill material was analyzed,in the hope of obtaining a higher correlation than the first scenario.

4.4.2 Relationship of N-SPT with qa at BM 05 (without fill)

The relationship between N-SPT and qa at BM 05 (without Fill) shows that the R2 value (distribution coefficient) is 0.9459 and the r value (correlation coefficient) is 0.972. A very strong positive linear relationship between x and y is detected (Sarwono, 2006). This is due to the existing lithology was not backfilled with materials such as sand, gravel, and silt, which produce a very strong correlation between the N-SPT value and the carrying capacityvalue, the higher the N-SPT value, the higher the carrying capacity value (Figure 6).

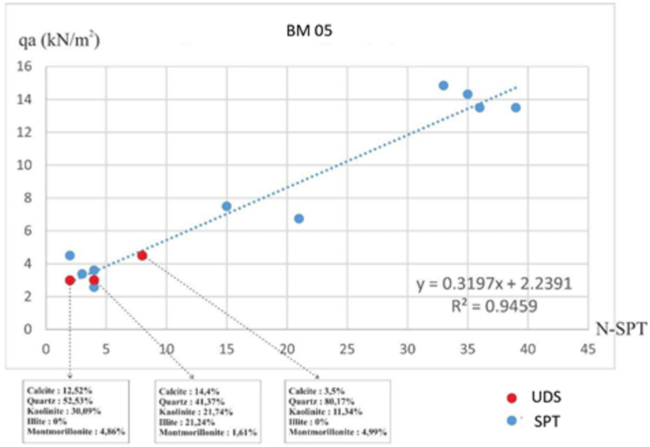

Fig. 6. The relationship between N-SPT and qa at BM 05 (without Fill).

5 Conclusion

Based on the relationship between N-SPT and qa at BM 01, the value of R2 (distribution coefficient) is 0.4228 and the value of r (correlation coefficient) is 0.65. This shows that there is a strong positive linear relationship between x and y. The R2 value at BM 03 is 0.7572 and the r value (correlation coefficient) is 0.87. This condition suggests a very strong positive linear relationship between x and y. The R2 value in BM 04 (with Fill) have 0.057 (distribution coefficient) and the r value (correlation coefficient) is 0.239. Thisindicates a very weak positive linear relationship between x and y.

The R2 value in BM 04 (without Fill) is 0.9795 and the r value (correlation coefficient) is 0.989, which shows a very strong positive linear relationship between x and y. The R2 value at BM 05 (with Fill) is 0.0815 and the r value (correlation coefficient) is 0.285, which indicates a fairly weak positive linear relationship between x and y. The R2 value at BM 05 (without Fill) is 0.9459 and the r value (correlation coefficient) is 0.972. The value suggests a very strong positive linear relationship between x and y. A strong positive linear relationship between x and y indicates the higher the N-SPT value, the higher the carrying capacity value. Where a very weak positive linear relationship between x and y indicates that there is a sample that makes the correlation less strong.

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References

1. G.G. Meyerhof. “Some Recent Research on the Bearing Capacity of Foundations”, Canadian Geotechnical Journal. **1**,16-26 (1963)
2. J. G. Stuart. Interference between foundations with special reference to surfacefootings in sand, Geotechnique, **12**, 15–22 (1962)
3. K. Terzaghi and R. B. Peck. Soil Mechanics in Engineering Practice: Wiley (1948)
4. Thaden, dkk. Peta Geologi Regional Lembar Magelang dan Semarang (1975)
5. D. Sarah, E. Subowo, A. Mulyono, & N.A Satriyo. Model Geologi Teknik Daerah Amblesan Tanah Kota Semarang Bagian Barat. Jurnal Riset Geologi dan Pertambangan. 11–18 (2013)

6. E. Soebowo, D. Sarah, D. Murdohardono, & T. Wirabuana. Geologi Bawah Permukaan Wilayah Amblesan Tanah di Kota Semarang. 57–63 (2014)
7. A. Yuliyanti, D. Sarah, & E. Soebowo. Pengaruh Lempung Ekspansif terhadap Potensi Amblesan Tanah di Daerah Semarang. Jurna Riset Geologi dan Pertambangan. **22**: 91–103 (2012)
8. G. Sposito. The Chemistry of Soils. 2nd ed. (2008)
9. K.H. Tan. Principles of Soil Chemistry. 3rd ed. (1998)
10. B. M. Das. Principal of Geotechnical Engineering (2014)
11. R. F.Craig & B. Susilo S.(Penerjemah). Mekanika Tanah (1989)
12. Z. Zakaria. Daya Dukung Tanah Fondasi Dangkal (2006)
13. J. E Bowles. Physical and Geotechnical Properties of Soils (1979)
14. F.H. Chen. Foundations on Expansive Soil (1975)
15. B.M. Das, N. Endah & Mochtar. Mekanika Tanah (Prinsip-Prinsip Rekayasa Geoteknis) (1995)
16. B. Velde. Origin and Mineralogy of Clays: Clays and the Environment (1995)
17. A. Sanaei, M. Shakiba, A. Varavei, & K. Sepehrnoori. Mechanistic Modeling of Clay Swelling in Hydraulic-Fractures Network. SPE-180372-PA, **21**: 96–108 (2018)
18. J.D. Nelson, & D.J. Miller. Expansive Soil Problems and Practice in Foundation and Pavement Engineering (1992)
19. D. Carroll & H.C. Starkey. Effect of Seawater on Clay Minerals. USGS, 80–101 (2013)
20. S. Aslani, M. Farrokhrouz, A. Dehkar, H. Haghi, & A. Bashari. Study of Montmorillonite to Illite Conversion in Serajeh Gas Storage Field. 46th International October Confernce on Mining and Metallurgy. The 46th International October Conference on Mining and Metallurgy. Serbia: University of Belgrade (2014)