Estimating bearing capacity using static cone penetration test at Banda Aceh area (northern tip of Sumatra)

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Abstract. The static cone penetration test (s-CPT), or better known in Indonesia as the sondir, has been used as a soil investigation procedure since nearly half a century ago in Europe, especially in the Netherlands and Belgium. This s-CPT is one of the standard practices in soil investigation campaigns and can provide many soil engineering parameters, including soil bearing capacity. This study focuses on the soil bearing capacity analysis in the city of Banda Aceh on the data taken from the 35 points of s-CPT. The analysis of the soil bearing capacity at a depth of 1.4 meters and 2.4 meters below the existing ground level (mbgl) was carried out. Dominantly, at a depth of 1.4 mbgl at the research location, it has a low bearing capacity (<2.5 tons/m\textsuperscript{2}) with a percentage of 91.43%. There are 2.86% for bearing capacity ranging from 2.5 to 5 tons/m\textsuperscript{2}, from 5 to 7.5 tons/m\textsuperscript{2}, and from 7.5 to 10 tons/m\textsuperscript{2}. No soil layer had a bearing capacity above 10 tons/m\textsuperscript{2}. At a depth of 2.4 mbgl, the research location has a low bearing capacity (<2.5 tons/m\textsuperscript{2}) with a percentage of 48.57%, for bearing capacity ranging from 2.5 to 5 tons/m\textsuperscript{2} is 17.14%, for bearing capacity of 5 to 7.5 tons/m\textsuperscript{2} is 2.86%, for bearing capacity of 7.5 to 10 tons/m\textsuperscript{2} of 5.71% and bearing capacity above 10 tons/m\textsuperscript{2} is 25.71%.

1. Introduction

The soil bearing capacity and building foundation are closely related to the safety of a building [1]. In the structure, the lower part of a building consists of two main elements, namely the foundation and the soil supporting the foundation. The foundation serves to support all building loads and forward the load of the building into the ground below. A foundation system must be able to guarantee to support the load of the building above it, including external forces such as wind, earthquake, and others (i.e. amplification) [2-4]. For this reason, the foundation must be strong, stable, safe, so that it does not decline, does not break, and does not fail. The occurrence of a break or failure of the foundation system will result in the following things: damage to the walls, cracks, sloping, broken floors, and subsidence of roofs and other building parts [5].

A critical thing closely related to the foundation is soil investigation. The foundation must be placed in a layer of soil with an adequate bearing capacity that is quite hard and dense. It is necessary to conduct
a soil investigation to estimate the soil bearing capacity. One of the tools used for soil investigation is the static cone penetration test (s-CPT) or better known in Indonesia as the sondir [6]. This sondir has been used as a soil investigation procedure since nearly half a century ago in Europe, especially in the Netherlands and Belgium [7-9]. The tip is a cone that is pressed into the ground. The results of the penetration of the soil stress can be automatically read in a connected manometer gauge in a unit of kg/cm². Chandra [10] states that s-CPT is one of the popular geotechnical in-situ tests in Indonesia due to several advantages, including a) Simple use, b) Can provide an overview of the investigated site quickly, and c) Provide a continuous soil strength profile.

2. Testing programme

2.1 Field testing using s-CPT

In this study, we used the double cones apparatus of s-CPT. Wesley [7] explains the use of this double cones s-CPT. In the use of double cones (cone resistance & sleeve friction), the value of both cone resistance and sleeve friction is recorded. This is done by pressing the handlebars. In the beginning, only the cone’s tip is pressed down, and thus only the cone resistance (CR) value is measured. When the cone’s tip has been moved as far as 4 centimeters, then by itself, it will catch the ‘sleeve friction part,’ and the cone along with the friction sleeve is then pressed down. So, the value of the cone’s tip and the sleeve friction (TR) are measured together. The value of the sleeve friction is obtained later by subtracting the CR value from the total (TR) value. Then by pressing only the outer casing, the cone’s tip gear, sleeve friction apparatus, and the handlebars as a whole will be pressed down to a depth where the next reading will be done. Tasks are usually done every 20 centimeters [6]. The s-CPT test was carried out at 35 locations in Banda Aceh and its surroundings. The tabulation of test locations with its village name is presented in Table 1.

| No | Location name       | Village name                        |
|----|---------------------|-------------------------------------|
| 1  | SDN 1 Lamjame       | Lam Jame, Kecamatan Jaya Baru       |
| 2  | SDN Asoe Nanggroe   | Asoe Nanggroe, Kecamatan Meuraxa    |
| 3  | Jembatan Bitai      | Bitai, Kecamatan Jaya Baru          |
| 4  | SMP 5 Banda Aceh    | Lambung, Kecamatan Meuraxa          |
| 5  | SDN 95              | Gampong Baro, Meuraxa               |
| 6  | SMP Percontohan     | Lamlagang, Kecamatan Banda Raya     |
| 7  | SDN 96 Banda Aceh   | Neusu Aceh, Kecamatan Baiturrahman  |
| 8  | Kejaksaan Tinggi Banda Aceh | Kampong Baro-1, Kecamatan Baiturrahman |
| 9  | SD Muhamadiyah Banda Aceh | Merduati-1, Kecamatan Kutaraja     |
| 10 | Kantor Pos at Merduati | Merduati-2, Kecamatan Kutaraja |
| 11 | SDN 17 Banda Aceh   | Peulanggahan, Kecamatan Kutaraja   |
| 12 | Kantor Pemkot Banda Aceh | Kampong Baro-2, Kecamatan Baiturrahman |
| 13 | Ruko di Moh. Jam    | Kampong Baro-3, Kecamatan Baiturrahman |
| 14 | SDN 6 Banda Aceh    | Keudah, Kecamatan Kutaraja          |
| 15 | SDN 64 Banda Aceh   | Ateuk Jawo-1, Kecamatan Baiturrahman |
| 16 | Jembatan Ateuk Jawo | Ateuk Jawo-2, Kecamatan Baiturrahman |
| 17 | SDN 30 Banda Aceh   | Ateuk Pahlawan, Kecamatan Baiturrahman |
| 18 | Bappeda NAD         | Kuta Alam, Kecamak Kuta Alam        |
| 19 | Museum Tsunami      | Lampulo, Kecamatan Kuta Alam        |
| 20 | Perluasan Gedung Kantor Imigrasi | Beurawe-1, Kecamatan Kuta Alam |
| 21 | Jamsostek           | Beurawe-2, Kecamatan Kuta Alam     |
| 22 | SMP 2 Banda Aceh    | Bandar Baru, Kecamatan Kuta Alam   |
| 23 | SDN 45              | Lambaro Skep, Kecamatan Kuta Alam  |
| 24 | Asrama Mahasiswa    | Doi-1, Kecamatan Ulee Kareng        |
| 25 | SDN 76              | Doi-2, Kecamatan Ulee Kareng        |
26 Perumahan DPRA
27 Kanwil HAM
28 Rumah Dinas POLDA
29 Klinik Putro Phang
30 Ruko at Rukoh
31 Asrama Mahasiswa
32 SDN 83 Banda Aceh
33 Hyugo Perfecence Building
34 Gedung Kuliah Pasca Sarjana
35 Ruko at Penyeurat

26.2 Bearing capacity

Chandrawanshi & Kumar [11] stated that soil bearing capacity is the maximum strength of the soil to withstand pressure (due to building loads) well without causing failure. Failure in the soil is an excessive settlement or shear failure (inability) of the soil to resist shear forces. Omar & Sadrkarimi [12] states that if the soil is loaded by any load, i.e., buildings, roads, dams, it will result in shear stress. If the load increases, the shear stress reaches a limit where the soil mass will experience deformation and tend to collapse (failure). The load that results in failure is called the failure load, and the pressure that occurs is called the ultimate soil bearing capacity.

In the bearing capacity analysis using static cone penetration test data, Wesley [7] warns that the cone value obtained by the cone penetration device cannot be equated directly with the bearing capacity of the soil concerned. Thus, an empirical approach is suggested. Schmertmann [8] proposed the bearing capacity of shallow foundation soils using s-CPT data, namely Meyerhof [13] formula, as presented in Equation 1.

\[ qa/qc = B/40 \times (1 + D/B) \]  

(1)

where, \( qa \) = allowable bearing capacity (kg/cm²), B = footing width (m); D = footing depth (m), and \( qc \) = cone resistance (kg/cm²).

The calculation of bearing capacity analysis used in this study is a shallow square footing with a dimension of 1 x 1 meter. Two foundation depth of 1.40 mbgl and 2.40 mbgl are considered. The bearing capacity of footing at all locations in this study is calculated using the formula mentioned above.

3. Testing results and discussion

3.1 Results

As aforementioned, soil bearing capacity analysis is based on the formula from Meyerhof [13], as in Equation 1. In the following section, more emphasis is placed on the results of soil bearing capacity analysis of a 1 square meter footing with a foundation depth of 1.40 mbgl and 2.40 mbgl, as shown in Table 2.

The study area has a very variable bearing capacity at a depth of 1.4 mbgl. The results of bearing capacity analysis at 1.4 mbgl, if plotted on the map and then interpolated, is presented in Figure 1. The zoning map of the bearing capacity of the soil at a depth of 1.4 mbgl shows that the study area is very much dominated with bearing capacity <2.5 ton/m² (red color). The area which has a bearing capacity of between 2.5 to 5 tons/m² only occupies a small part in the Neusu Aceh area, Baiturrahman District and around Lamjame, Jaya Baru District. The bearing capacity of the soil that ranges from 5 to 7.5 tons/m² at a depth of 1.4 mbgl is found in the Neusu Aceh area, Baiturrahman District at 6 tons/m² and in the Lamjame area, Jaya District New with a value of 9 tons/m².

The zoning map of the bearing capacity of the soil at a depth of 2.4 mbgl, as in Figure 2 shows that most of the areas in the study location, also, have a bearing capacity of <2.5 tons/m² (red color). The bearing capacity between 2.5 to 5 tons/m² (orange color) occupies the area around Neusu Aceh, Baiturrahman District, around Gompong Baro, Meuraxa District, around Keudah, Kuta Raja District,
around Doi, Ulee Kareng District, around Lam Gugop, Syiah Kuala District and around Lamjame, Jaya Baru District. The soil bearing capacity from 5 to 7.5 tons/m\(^2\) (yellow color) is found around Neusu Aceh, Baiturrahman District, around Gampong Baro, Meuraxa District, around Keudah, Kuta Raja District, around Rukoh, Syiah Kuala District, around Lam Gugop-Simpang Mesra, Syiah Kuala District and around Lamjame, Jaya Baru District. The bearing capacity of 7.5 to 10 tons/m\(^2\) (blue color) is obtained around Neusu Aceh, Baiturrahman District, around Gampong Baro, Meuraxa District, around Rukoh, Syiah Kuala District, around Lam Gugop-Simpang Mesra, Syiah Kuala District and around Lamjame, Jaya Baru District. The bearing capacity above 10 tons/m\(^2\) (green color) at a depth of 2.4 m bgl is found around Gampong Baro, Meuraxa District (14.17 tons/m\(^2\)), around Neusu Aceh, Baiturrahman District (24.08 tons/m\(^2\)), around Keudah, Kutaraja District (11.33 tons/m\(^2\)), around Lambaro Skep, Kuta Alam District (28.33 tons/m\(^2\)), around Simpang Mesra, Syiah Kuala District (19.83 tons/m\(^2\)), around Kopelma Darussalam, Syiah Kuala District (14.17 tons/m\(^2\)) and around Lamjame (32.58 tons/m\(^2\)).

**Table 2. Bearing capacity of the present study**

| No | Location name                  | Bearing capacity (Ton/m\(^2\)) | At 1.4 m depth | At 2.4 m depth |
|----|--------------------------------|--------------------------------|----------------|---------------|
| 1  | SDN 1 Lamjame                  | 9.00                           | 32.58          |
| 2  | SDN Asoe Nanggreoe             | 0.20                           | 0.57           |
| 3  | Jembatan Bitai                 | 0.20                           | 0.28           |
| 4  | SMP 5 Banda Aceh               | 0.20                           | 1.42           |
| 5  | SDN 95                         | 2.00                           | 14.17          |
| 6  | SMP Percontohan                | 1.60                           | 2.83           |
| 7  | SDN 96 Banda Aceh              | 6.00                           | 24.08          |
| 8  | Kejaksaa Tinggi Banda Aceh     | 0.20                           | 0.57           |
| 9  | SD Muhamadiyah Banda Aceh      | 2.00                           | 4.25           |
| 10 | Kantor Pos at Merduati         | 0.20                           | 2.83           |
| 11 | SDN 17 Banda Aceh              | 1.00                           | 3.40           |
| 12 | Kantor Pemkot Banda Aceh       | 0.20                           | 0.57           |
| 13 | Ruko di Moh. Jam               | 1.60                           | 0.28           |
| 14 | SDN 6 Banda Aceh               | 2.00                           | 11.33          |
| 15 | SDN 64 Banda Aceh              | 1.60                           | 9.92           |
| 16 | Jembatan Ateuk Jawo            | 0.20                           | 0.28           |
| 17 | SDN 30 Banda Aceh              | 2.00                           | 2.83           |
| 18 | Bappeda NAD                    | 0.20                           | 0.28           |
| 19 | Museum Tsunami                 | 0.20                           | 0.57           |
| 20 | Perluasan Gedung Kantor Imigrasi| 0.20                        | 0.28           |
| 21 | Jamsostek                      | 0.20                           | 0.28           |
| 22 | SMP 2 Banda Aceh               | 0.20                           | 0.28           |
| 23 | SDN 45                         | 0.20                           | 28.33          |
| 24 | Asrama Mahasiswa               | 0.20                           | 1.42           |
| 25 | SDN 76                         | 0.40                           | 5.67           |
| 26 | Perumahan DPRA                 | 0.20                           | 1.98           |
| 27 | Kanwil HAM                     | 0.40                           | 1.70           |
| 28 | Rumah Dinas PDLDA              | 1.40                           | 1.13           |
| 29 | Klinik Putro Phang             | 0.20                           | 0.28           |
| 30 | Ruko at Rukoh                  | 0.40                           | 19.83          |
| 31 | Asrama Mahasiswa               | 0.40                           | 14.17          |
| 32 | SDN 83 Banda Aceh              | 2.00                           | 14.17          |
| 33 | Hyugo Perfecture Building      | 2.00                           | 8.50           |
| 34 | Gedung Kuliah Pasca Sarjana    | 3.00                           | 14.17          |
| 35 | Ruko at Penyeurat              | 0.20                           | 2.83           |
3.2 Discussion

Overall, if divided into 5 groups, the bearing capacity obtained in the study area can be clustered, as shown in Table 3. In this table, it can be seen that the very dominant in the study area has a low bearing capacity (<2.5 tons).

Dominantly, at a depth of 1.4 mbgl at the study area, it has a low bearing capacity (<2.5 tons) with a percentage of 91.43%, bearing capacity from 2.5 to 5 tons/m² 2.86%, bearing capacity from 5 to 7.5 tons/m² by 2.86%, bearing capacity from 7.5 to 10 tons/m² by 2.86%. No soil layer had a bearing capacity above 10.00 tons/m².

From Table 3, it can be seen that at a depth of 2.4 mbgl, dominantly, the study area has a low bearing capacity (<2.5 tons/m²) with a percentage of 48.57%. The percentages for bearing capacity ranging from 2.5 to 5 tons/m² and 5 to 7.5 tons/m² are 17.14% and 2.86%, respectively. The bearing capacity of 7.5 to 10 tons/m² is 5.71%. At this 2.4 mbgl depth, a percentage location of a layer of soil with a bearing capacity above 10 ton/m² is 25.71%.

A complex sub-surface conditions of the study area has been recognised by [14, 15]. A further sub-surface investigation using passive seismic approach as suggested by [16], or site response analysis by [17], is interesting topic to explore.
4. Conclusion
A bearing capacity analysis of the soil in the city of Banda Aceh based on the data from the s-CPT shows that the zoning of the soil bearing capacity and the depth of the soil bearing capacity varies. Zoning bearing capacity at a depth of both 1.4 mbgl and 2.4 mbgl shows that the study area is dominated with a bearing capacity of <2.50 tons/m². For the depth of 1.4 mbgl, areas that have a bearing capacity of >2.50 only occupy the Neusu Aceh and Lamjame areas. For the depth of 2.4 mbgl, areas that have a bearing capacity of between 2.5 to 5 tons/m² occupy the Neusu Aceh, Gampong Baro, Keudah, Doi, Lam Gugop, and Lamjame areas. The soil bearing capacity ranging from >5 tons/m² at a depth of 2.4 mbgl, was found around Neusu Aceh, Gampong Baro, Keudah, Lambaro Skep, Simpang Mesra, Rukoh, Lam Gugop Kopelma Darussalam and Lamjame.
Table 3. Tabulation of bearing capacity of the present study

| No | Bearing capacity (Ton/m²) | At 1.4 mbgl depth | At 2.4 mbgl depth |
|----|--------------------------|-------------------|-------------------|
|    |                          | Frequency         | Percentage        | Frequency | Percentage |
| 1  | 0.00 - 2.50              | 32                | 91.43             | 17        | 48.57      |
| 2  | 2.51 - 5.00              | 1                 | 2.86              | 6         | 17.14      |
| 3  | 5.01 - 7.50              | 1                 | 2.86              | 1         | 2.86       |
| 4  | 7.51 - 10.00             | 1                 | 2.86              | 2         | 5.71       |
| 5  | >10                      | 0                 | 0.00              | 9         | 25.71      |
| TOTAL |                       | 35                | 100               | 35        | 100        |

5. Acknowledgement
The authors wish to acknowledge Universitas Syiah Kuala for providing research funding (Contract No. 267/UN11/SPK/PNPB/2020) on the date of March 17 2020. Also, the authors are grateful to the Faculty of Engineering of Universitas Syiah Kuala for their support.

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