Mapping of the depth of hard/dense layer at Banda Aceh-Indonesia and the surrounding areas

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Abstract. The 26 December 2004 disaster caused enormous casualties and damages in affected regions. Indonesia suffered a loss of 42.7 trillion Rupiah. On the other hand, this disaster has raised awareness among some people to carry out construction following engineering principles, so that the newly constructed buildings have an adequate level of safety. A hard/dense soil layer has a close relationship with the safety level of a building. This paper proposes a map of the depth of hard/dense (stable) layer at one of the worst affected cities, i.e., Banda Aceh (Indonesia) of the boxing day 2004 disaster. A static cone penetration test (CPT) was employed to determine the depth of stable soil. The data from the 35 cone penetration tests were used to develop the zoning map of the depth of the stable soil in the study location. The dominant hard/dense soil depth in the study location is > 10 meters below the existing ground level. In certain places, such as the areas around Lambung, Neusu Aceh, Lambaro Skep, Jeulingke, Doi, Kopelma Darussalam, and Lamjame, the depth of stable soil is from 5 to 10 meters.

1. Introduction
The earthquake and tsunami disaster of 26 December 2004 resulted in a large number of casualties and structural damages [1, 2]. It was reported 127,054 missing and 78,395 deaths in the Provinces of Aceh and Nias Island, North Sumatra. Economically, Indonesia suffered a loss of 42.7 Trillion Rupiah in which 78% destroyed non-public assets. As a result of this disaster, it was estimated that the loss of 2.7% of the Indonesian National Gross Regional Domestic Product (GRDP) or more than 97% of the GRDP of Aceh Province. There was another psychological impact that cannot be measured in real terms [3].

The positive side impact that arises from this disaster is the emergence of public awareness in some parts of the community to carry out construction in accordance with engineering principles [1, 2]. Thus, the newly constructed house/building that they live in has to be built at an adequate level of safety in the event of a disaster. This awareness arises because, during the 2004 tragedy, there were a lot of structural and non-structural failures in their house/building.

An adequate soil bearing capacity is closely related to the subsurface conditions of an area. In a simple way, sufficient bearing capacity will be found on hard/dense soil. The foundation on which a building is based will be placed on a layer of soil that is quite hard or stable [4]. Therefore, mapping the depth of hard/dense soil is very important to do [5].
2. Testing programme

2.1 Quasi-static CPT test

A soil investigation was carried out to map the depth of the hard/dense soil layer. The cone penetration test (CPT), called a quasi-static cone penetrometer, was used in this study. The CPT that was widely used in Indonesia was only the penetration of a static cone (sondir) (Dutch Penetrometer/Dutch Deep Sounding Apparatus/Quasi-Static Penetration Test). This sondir is a static device originating from the Netherlands, where the tip is pressed directly into the ground so that no drill holes are needed [4]. The tip is conical (cone) connected to a series of the internal handlebar, and the outer sleeve (static cone penetration pipe) is pressed into the ground with the help of a frame and a jack anchored to the ground (Figure 1a). There are two types of penetrometer tips that are commonly used, namely the standard type (single cone) and the cone with additional friction sleeve or adhesion jacket type (double-cones). In this study, we used the static cone penetration tool of double-cones type, as shown in Figure 1b [6].

The cone tip of this quasi-static CPT device is a $60^\circ$ cone with a cross-sectional area of 10 cm$^2$ [6], [7, 8]. In the measurement, the cone tip is pressed downwards with a series of the inner handlebar and outer blanket. The forces required to push the cone without- and with- the sleeve down for 20 cm are measured by a gauge placed on the jack frame at ground level. After the measurement has been taken, the cone, handlebar, and outer blanket are advanced to the point (depth) where the next measurement is made by pressing the outer pipe-casing only. This pressing will automatically return the whole cone to a position ready for the subsequent measurement [6].

![Figure 1](image)

**Figure 1.** (a) Installation of the quasi-static CPT for the measurement, and (b) the cone with additional friction sleeve or adhesion jacket type (double-cones) [6-8].

2.2 Spatial testing distribution

The primary target location of this study is in the city of Banda Aceh (Indonesia), which was severely affected by the boxing day 2004 disaster [1]. This city has a total area of 61.36 km$^2$. The object of the present study is the subsurface soil of Banda Aceh and the surrounding areas. The spatial testing
distribution overlaid in Banda Aceh city map can be seen in Figure 2. A total of 35 points of quasi-static CPT was used in this study. Field testing activities are demonstrated in Figure 3.

![Figure 2. Static cone penetration test points at the research location](image)

![Figure 3. CPT field testing activities](image)

2.3 Hard/dense layer criteria

Based on the results of the cone penetration test, i.e., cone resistance data, the relative density/consistency of the soil layer can be interpreted. In the case of granular soil, the interpretation of
the relative density can be from very loose to very dense, as shown in Table 1 [7]. For cohesive soil, the classification by [9] can be applied. The justification of cohesive soil consistency is shown in Figure 4.

In the Indonesian common practice [4, 6], the quasi-static CPT is terminated if three successive cone resistance readings reached 150 kg/cm². This 150 kg/cm² cone resistance can be interpreted as a hard/dense layer [10]. Therefore, this 150 kg/cm² is adopted in this study to justify the depth of the hard/dense layer.

| Granular soil [7] | Low plastic cohesive soil [11] |
|-----------------|-------------------------------|
| Cone resistance/CR (kg/cm²) | Relative density class | Net cone resistance (KPa) | Consistency |
| 1 | 0 – 16 | Very loose | <275 | Very soft |
| 2 | 16 – 40 | Loose | 275 – 500 | Soft |
| 3 | 40 – 120 | Medium | 500 – 930 | Medium stiff |
| 4 | 120 – 200 | Dense | 930 – 1800 | Stiff |
| 5 | >200 | Very dense | >1800 | Very stiff/hard |

Figure 4. Classification of cohesive soil consistency [9,11]

3. Testing results and discussion

3.1 Results
Data from the reading of the manometer on the CPT tool are cone resistance (CR) and total resistance (TR), which are expressed in units of kg/cm². From the two reading values, the sleeve friction (SF) is calculated. Using the hard/dense layer criteria, as mentioned above, the depth of the hard/dense level in each tested location is justified. The depth of the hard/dense soil layer at the study site is tabulated in Table 2.
### Table 2. Depth of hard/dense layer of the present study

| No | Location name                  | Depth of hard/dense layer (m) |
|----|--------------------------------|-------------------------------|
| 1  | SDN 1 Lamjame                  | 3.2                           |
| 2  | SDN Asoe Nanggroe              | >10                           |
| 3  | Jembatan Bitai                 | >10                           |
| 4  | SMP 5 Banda Aceh               | 5.2                           |
| 5  | SDN 95                         | >10                           |
| 6  | SMP Percontohan                | >10                           |
| 7  | SDN 96 Banda Aceh              | 3.6                           |
| 8  | Kejaksan Tinggi Banda Aceh     | 6.6                           |
| 9  | SD Muhamadiyah Banda Aceh      | >10                           |
| 10 | Kantor Pos at Merduati         | >10                           |
| 11 | SDN 17 Banda Aceh              | >10                           |
| 12 | Kantor Pemkot Banda Aceh       | >10                           |
| 13 | Ruko di Moh. Jam               | >10                           |
| 14 | SDN 6 Banda Aceh               | >10                           |
| 15 | SDN 64 Banda Aceh              | >10                           |
| 16 | Jembatan Ateuk Jawo            | >10                           |
| 17 | SDN 30 Banda Aceh              | 7.0                           |
| 18 | Bappeda NAD                    | 5.0                           |
| 19 | Museum Tsunami                 | >10                           |
| 20 | Perluasan Gedung Kantor Imigrasi| >10                         |
| 21 | Jamsostek                      | >10                           |
| 22 | SMP 2 Banda Aceh               | >10                           |
| 23 | SDN 45                         | 7.0                           |
| 24 | Asrama Mahasiswa               | 5.0                           |
| 25 | SDN 76                         | 5.2                           |
| 26 | Perumahan DPRA                 | >10                           |
| 27 | Kanwil HAM                     | 7.8                           |
| 28 | Rumah Dinas POLDA              | 6.4                           |
| 29 | Klinik Putro Phang             | >10                           |
| 30 | Ruko at Rukoh                  | 5.6                           |
| 31 | Asrama Mahasiswa               | >10                           |
| 32 | SDN 83 Banda Aceh              | >10                           |
| 33 | Hyugo Perfecuture Building     | >10                           |
| 34 | Gedung Kuliah Pasca Sarjana    | 6.0                           |
| 35 | Ruko at Penyeurat              | >10                           |

The hard/dense soil depth data can also be plotted in a base map, which is useful for knowing the position of each test point and the depth of stable soil at each location. Then an interpolation is made to determine the zoning of hard/dense depth, as shown in Figure 5. The zoning map shows that most of the tested locations have a stable soil depth of 10 meters below the existing ground surface. In certain places such as the area around Lambung, around Lamjame, around Neusu Aceh, around Lambaro Skep, around Jeulinge, around Doi, and around Kopelma Darussalam exhibited stable depth from 5 to 10 meters. The shallowest hard/dense soil depth is only found around Lamjame of Jaya Baru District.

#### 3.2 Discussion

The depth of stable soil at the study site varies from 3.2 meters to more than 10 meters below the existing ground level. Simple statistical analysis shows that the depth of stable soil is very much dominated by a depth of > 10 meters below the existing ground surface (62.86%). At the study site, no stable soil layer is found at depths from the ground to 2.5 meters. The depth of stable soil ranging from 2.5 to 5 meters.
has a percentage of 11.43% of the total 35 test points, while for depths of 5 to 7.5 meters, it has a percentage of 22.86%. Stable soil at a depth between 7.5 and 10 meters only has a percentage of 2.86%. A more detailed description can be seen in Table 3 below. This result can be used for the site response analysis to re-estimate the site amplification of the study site [2, 12].

Table 3. Depth of hard/dense layer of the present study

| No | Depth of hard/dense layer of qc>150kg/cm² (m) | Frequency | Percentage |
|----|---------------------------------------------|-----------|------------|
| 1  | 0.00 – 2.50                                 | 0         | 0.00       |
| 2  | 2.51 – 5.00                                 | 4         | 11.43      |
| 3  | 5.01 – 7.50                                 | 8         | 22.86      |
| 4  | 7.51 – 10.00                                | 1         | 2.86       |
| 5  | >10                                         | 22        | 62.86      |
|    | TOTAL                                       | 25        | 100        |

Figure 5. Zoning of the depth of the hard/dense layer at the study area
4. Conclusion
Based on the 35 CPT data, mapping of the depth of the hard/dense layer at Banda Aceh (Indonesia) and the surrounding areas has been carried out. Zoning for stable soil depth at the study site is dominated by more than 10 meters below the existing ground surface. The shallowest hard/dense soil depth is only found around Lamjame-Jaya Baru. This study is still far from perfect considering the very complex conditions of the underground surface at the study site [13-15] so that a couple of suggestion is given, as follows: a) Adding more CPT testing points are suggested. This additional CPT tests will increase the resolution of the map.
b) For more detailed results in future research, it is necessary to obtain soil samples through hand/machine drilling or other tools or other methods, i.e., passive seismic data analysis [16, 17].

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