More accurate study of seismicity effect on Sumatra-Fault for liquefaction potential in Banda Aceh by using cyclic loading mobility data

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Abstract. Banda Aceh is a prone city, predictions from earthquake experts with a potential for a tsunami in the return period of 500 years there will still be a large earthquake that threatens development in Aceh, especially Banda Aceh. A great earthquake has occurred in Aceh on December 26, 2004, which destroyed government infrastructures and property and human life in Banda Aceh. The high number of casualties during the natural disaster occurred due to low government preparedness and public understanding of earthquake disasters caused by several earthquake sources surrounding the city of Banda Aceh, such as; Aceh-Sumatra great fault, the subduction of the Indo-Australian plate with the Euro Asia plate which move side by side along the side of Aceh province - Andaman Island. This research will provide important information regarding the orientation of the depth of the strong layer and the distribution (horizon) of the subsoil of the city surface in several densely populated zones and surrounding areas. The study method was carried out by using a cross-section of the sub-surface of the earth's plate from the coast - transition - land using Surfer software. Quantitative and qualitative analysis results obtained 3D image surface sand shading relief; soft layers, moderately layers and hard layers, each of which the thickness and depth of the soil was used to perform an analysis of the phenomenon of liquefaction potential; soft layers less than 10 kg/cm² thickness 0.2 - 3.6 m depth, moderately layers 10 - 50 kg/cm² thick 1.0 - 7.0 m depth 1.2 - 10.6 m, hard layers > 120 kg/cm² thickness 2.0-18.6 m depth 5.0-46.8 m, respectively

1. Introduction
In earthquake-prone areas, including Aceh Province, are areas prone to the threat of earthquakes and tsunamis. From combination data of the NEIC-USGS and BMKG catalogues for the period 1963-2013, showing the distribution of seismicity points from shallow to medium depths was already so tightly covering almost the entire land and ocean area of Aceh. A great earthquake measuring 9.3 MW that triggered tsunami waves up to an altitude of 24 M, it occurred on December 26, 2004.

Munirwansyah et al. [1] stated that the effect of the earthquake that was felt in the city of Banda Aceh in the earthquake was so great that it caused many monumental buildings and multi-story buildings built from reinforced concrete structures to collapse due to the shock of the earthquake. Since then, studies on geotechnical aspects, seismic load effects [2], and sub-surface investigations on the distribution of bearing layers for substructure building planning purposes such as deep foundations have been increasingly focused and have become the focus of attention of researchers at Universitas Syiah Kuala, Banda Aceh. in detailed engineering design planning
Muniwarsyah et al. [1] have data on earthquake distribution that resembles a saw blade as shown in Figure 1, that the magnitude of the earthquake appears to vary and fluctuate in a function of time and return period. Munirwansyah et al. [2] found a layer of appearance bearing stratum between soil profile of bearing layers in the form of a layer of sand in the depth under the saturated surface of the groundwater which is vulnerable in soil character change will occur liquefaction under Banda Aceh. This layer has the potential to experience liquefaction when receiving vibration loads such as cyclic loading mobility. This article shows the distribution of soil layers under the city of Banda Aceh which is still limited. More accurate data were obtained with more accurate measurement results using the GP3D (3D Global Positioning System) measuring instrument, which was compared again using the 3D Globe GIS.

Figure 1. Earthquake magnitude variation (Mw) from 1990-2016 recorded at BMKG in Aceh Province

Google Earth used to make it easier to find out the location of development planning, bring up the geographical conditions of a location, show the locations of remote areas, see coordinates and surface elevations, and can make survey trajectories from a planning location. Fajrianto [3] suggests a device used as a satellite signal receiver in general use is called a GPS Tracker or GPS Tracking. This GPS uses a tool that allows a user to track the position of the place and the location of the point planning. Moreover, Fajrianto [3] explains that google earth is a program to map the earth from the superimposition of images collected from satellite mapping, aerial photography, and 3D GIS globe. Fajrianto [3] also explains that Global Positioning System (GPS) is a navigation system using satellites designed to provide instant position, speed, and time information in almost any place on earth, any time and in any weather conditions.

Cone Penetration Test (CPT) data was used to determine the profile of soil or rock at a certain depth in the site locations. CPT data can be used to plan the foundation and the location of the hard soil layer. Surfer is an application or device that can be used in making contour maps and the contour can be made into three dimensions by basing it on the data grid. Aprilyawan [4] explains that this software plots irregular XYZ tabular data into a regular grid of rectangular dots. Detailed contour analysis by surfer software allows the creation of three-dimensional maps of tabular data compiled using a worksheet. The
surfer also facilitates the formation of contours involving topography with the help of google earth and shows the results of the soil profile in the zone under study.

Munirwan et al. [5] suggests that in determining the bearing stratum, for simple buildings, soil layers with a soil cone resistance value \( q_c = 0-10 \) kg/cm\(^2\) (soft soils) can be used for buildings with moderate loads up to three-story building can use a layer of soil with a hardness of \( q_c = 10-50 \) kg/cm\(^2\) (medium soil), for buildings with heavy loads a High-Rise-Building can use a layer of soil with a hardness of \( q_c = 50-120 \) kg/cm\(^2\) (hard soil) and for Super-Tall-Buildings can be piled in a layer of soil with \( q_c \) hardness \( \geq 120 \) kg/cm\(^2\) (stiff soil).

2. Methodology

Over the past period, several significant changes have been made to the assessment framework for interpreting the hazards, structural responses, damage, and losses. This research is not based on the analytical method, the initial implementation for searching data coordinate (XYZ) and topographic surface analysis mapping was carried out using Google Earth sand continued with re-measurement using a more accurate GPS-3D tool that able to show the height of the position of the point on the earth's surface on above sea level, which is then converted to \( q_c \)-CPT data to obtain the depth and thickness of each type of soil layer at the measurement location. The data obtained from measurement methods then combined with the GPS coordinate grid system and the SURFER-3D software to process and digitize the distribution of layers and thicknesses in each zone studied, namely the coastal zone which is a zone coastal city and inner land zone of Banda Aceh. The distribution of CPT-GPS measurement points in this study, as shown in Figure 2.

![Figure 2. Distribution of measurement points and the accuracy of the Pole Measurement Device within the zone observed locations in Banda Aceh City](image-url)

The coordinate measurement method is carried out by placing the GPS at the prepared point in a more stable position and using the principle of the benchmarking measurement pole device (BM-MPD) point mapping system as shown in Figure 3. The measurement data is finally processed into each map contour layer, which spreads below the location of the research area or zone with the Surface Mapping...
System (Surfer) application. The number of data collection points in the coastal area of Banda Aceh City consists of 22 points. These points are scattered along the coast of Banda Aceh, including 5 points in Meuraxa District, 3 points in Kuta Raja District, 5 points in Kuta Alam District, and 9 points in Syiah Kuala District.

![Pole Measurement Device and GPS positioning](image)

**Figure 3.** Pole Measurement Device and GPS positioning to calculate coordinate (x,y,z) by Google Earth and Global Positioning System for 3D-Surfer analysis

Primary and secondary data that have been obtained are then processed using Surfer Software. Surfer has a working principle of spreading X-Y-Z tabular data. The irregular X-Y-Z data is spread out into a sheet of regular rectangular dots called a grid. Before the map was formed, the data from the contour height measurements in the field were entered into a part of the surfer called a worksheet. Keckler [6] said that surfer software can function as an exact interpolator or as a data smoother, depending on the parameters used so that the data is more detailed.

3. Results and discussion

Parameters that were used for data analysis are Google Earth coordinates, Global Positioning System (GPS) coordinates, depth of CPT data, and q_c values in CPT data. The analysis results are presented in the form of maps, tables, 3D images obtained by using calculations using surfer software. The research results obtained from data processing in the form of a research map points and a bearing layer contour analysis model that can be used for infrastructure planning as earthquake mitigation and liquefaction.

The distribution of research location points is needed for the accuracy of the data plotted into the Surfer worksheet so that the accuracy of the results obtained can be used to mitigate liquefaction disasters, earthquakes, and an initial view of the construction site conditions [7]. The map of the distribution of research points is described based on the coordinate data obtained from Google Earth.

Based on data analysis and processing of primary and secondary data at the research location, a table is obtained that can be used as complete information and helps to create a 3D-mapping layer distribution map. The table is presented in detail, including the coordinates, the depth of each layer, and the strength of the soil layers at the research location. The contours of the bearing layer in the X-Y and Z directions of the Cross-section in the map illustrate the distribution of location points whose coordinates are...
measured, while the Z direction represents the soil profile of the soil layer depth and strength, respectively. The resulting contours of each soil layer can be seen as shown in Figure 4.

The contours of the surface layer of soil surface are as shown in Figure 4(a). From the results of the analysis of each area, the data is obtained that; Meuraxa District is at an altitude of +2.0-3.0 M above sea level, Kuta Raja District is +2.0 M, Kuta Alam District is +2.0-4.0 M, while the height of Syiah Kuala District is +2.0-5.0 M above sea level. It can be seen that the soft soil layer qc value is at 0-10 kg/cm² obtained at an altitude of 0.2 m to 2.0 M above sea level. The contour distribution of the soft layer can be seen in Figure 4(b).

![Figure 4. Distribution of layer under Banda Aceh. (a) surface layer, (b) soft layer, (c) moderate layer, (d) compact layer, and (e) stiff layer](image)

Based on the value of qc = 10-50 kg/cm², the distribution of the moderate layer ranges from 1.2 m to 7.0 m above sea level, as shown in Figure 4(c). For medium dense layers, the qc value is at 50-120 kg/cm². Based on this category, it can be determined that the depth of the soft soil layer is spread in a...
thickness ranging from 2.0 - 17.6 m. This layer can be seen in Figure 4(d). Furthermore, for soil layers, the value of $q_c > 120$ kg/cm$^2$ is illustrated by the distribution and thicknesses ranging from 3.4 to 18.6 M. This layer can be seen in Figure 4(e). In brief, Figure 5 shows the cross-section distribution of the 3D Surface Sand Shading Relief profile, which is a very useful result in geotechnical aspects in planning the substructure as a foundation and other civil engineering structures.

![Figure 5. Cross-section of distribution of layer under Banda Aceh](image)

4. Conclusions
Based on research data, it can be concluded that the distribution of soil layers under the city of Banda Aceh in the coastal zone is as follows:
- Soft soil layers with a value of $q_c = 0$-10 kg/cm$^2$ obtained a thickness from 0.2 M to 3.6 M
- Medium density soil layer with a value $q_c = 10$-50 kg/cm$^2$ thickness from 1.2 to 7.0 M.
- Solid soil layer with a value of $q_c = 50$-120 kg/cm$^2$ thickness 2.0 to 17.6 M.
- Hard soil layer with a value of $q_c = 50$-120 kg/cm$^2$ thickness 3.4 to 18.6 M

In the coastal zone, almost all areas have a layer of saturated sand with apparent strength that is susceptible to the phenomenon of liquefaction. Districts that have the liquefaction potential include Meuraxa, Kuta Alam, and Syiah Kuala Districts.

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