Liquefaction Potential Based on Geology and Geotechnical Data on Sanana Region, Sula Island Regency, North Maluku, Indonesia

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Abstract. Soil liquefaction is one of a major problem in infrastructure development. This disaster can occur on sandy soil and high seismicity region. Soil with liquefaction potential will affect as a liquid during earthquakes and has high potential to collapse after the earthquake. The purpose of this study is to identify liquefaction potential in Sanana, Sula Island, North Maluku where many infrastructure developments being carried out. The method used in this research is “simplified procedure” for evaluating liquefaction resistance of soils. This method considers geological and geotechnical characteristics based on Standard Penetration Test. The geological characteristics of Sanana region show that this region has liquefaction potential because it is composed of Holocene alluvium and located in high seismicity region. Furthermore, based on the geotechnical data from the SPT test, this region has liquefaction potential in the sand, silty sand and sandy silt with loose-medium density. The loose-medium properties affect a low seismic resistance to cyclic loads. This will lead to high liquefaction potential in this research area. Therefore, in order to prevent possible disaster caused by liquefaction, this problem needs to be considered in future infrastructure planning and development.

Keywords: Liquefaction, earthquake, SPT, sandy soil

1. Introduction

Liquefaction is one of the seismic hazards caused by earthquakes. During an earthquake, Soil with liquefaction potential will affect as a liquid during earthquakes and resulting in loss of the soil ability to support the building which could lead to building failure. The Sanana region located in Maluku, where this region is at the convergence of three main plates, causing this region to have very high tectonic and seismic complexity. This condition makes this region frequent earthquakes were the source of the earthquake trigger in this area came from the Sula-Sorong active fault activity with the largest history of the earthquake at magnitude 8.1 (depth of 20.0 km) on Sula Island on January 24, 1965 (Figure 1).
Sulabesi Island is the result of collision with a subduction system along the eastern boundary of the Sundanese Exposure which produces a tectonic setting of Eastern Indonesia [2,3]. The Sorong Fault in the Sula Islands region is separated into two fault systems, each is the North Sula Fault and the South Sula Fault. Tilted movements the Sorong fault to the west along with the Indo-Australian plate movement.

The composition of the regional research is guided by the P.Tabuabu geological map and its surroundings [4,5]. In the Geological Map the Sanana Sheet, Maluku consists of 10 rock formations and 1 surface deposit, ranging from Carbon to Holocene [5].

In addition, In the Sanana Geological Map by [6] (Figure 3), along the coast of the island, the Sanana region consists of alluvium (Qa) which consists of sand, gravel, clusters, and clays where the age of material is Quaternary. The condition of the region which is composed of alluvium deposits such as sand and silt which is susceptible to liquefaction increases the possibility of liquefaction which causes soil failure.
2. Research Methods

Contains research approach, research method, sampling, survey method, etc. The method used in this research is “simplified procedure” for evaluating liquefaction resistance of soils. This method considers geological and geotechnical characteristics based on Standard Penetration Test. The data needed in evaluating liquefaction potential in this study uses geological setting data and is correlated with evaluation of liquefaction resistance.

2.1. Liquefaction Potential Evaluation based on Geological Criteria

Preliminary studies of potential liquefaction were carried out by analyzing the geological conditions of the study area. Factors that cause ground failure susceptibility include sedimentation, sedimentation process, age of deposition, geological history, depth of water table, grain size distribution, density state, depth of burial, ground slope, and nearness of a free face [7]. The geological process will make a region have material with uniform grain distribution and make the material loose so that the soil layer has a high susceptibility to liquefaction. The presence and depth of the water table are one of the important parameters for liquefaction because this event will occur if the material is saturated with water. In addition, the age of the deposit also has an important effect, this is due to the process of lithification in the rock or soil.

Information on geomorphology units can be used as a database for potential liquefaction analysis. This geomorphology unit is categorized into 3, including likely, possible, and not likely of liquefaction (Table 1).

| Rank | Geomorphological Units | Liquefaction potential |
|------|------------------------|------------------------|
| A    | Present riverbed, old riverbed, swamp, reclaimed land, and interdune low | Liquefaction likely |
| B    | Fan, natural levee, sand dune, flood plain, beach, and other plains | Liquefaction possible |
| C    | Terrace, hill, and mountain | Liquefaction not likely |

Table 1. Liquefaction Susceptibility of Various Geomorphological Units [8,9]
Table 2. Liquefaction Susceptibility of Various Geomorphological Units [9,10]

| Age of Deposit          | Depth of Water Table |
|-------------------------|----------------------|
|                         | 0-3 m    | 3-10 m   | 10 m    |
| Latest Holocene         | High     | Low      | Nil     |
| Earlier Holocene        | Moderate  | Low      | Nil     |
| Late Pleistocene        | Low      | Nil      | Nil     |

2.2. Evaluation of Liquefaction Potential Based on Geotechnical Data

In evaluating liquefaction potential, Seed and Idriss developed a "simplified procedure" method in 1972 based on earthquakes that occurred in Alaska and Nigiita in 1964. The criteria for evaluating liquefaction resistance using the N-SPT value are the most commonly used and powerful methods for years.

Basically, analysis of liquefaction potential is looking for 2 variables: Cyclic Stress Ratio (CSR) which is cyclic stress that occurs due to an earthquake divided by effective vertical overburden stresses and Cyclic Resistance Ratio (CRR) is the soil resistance to resist liquefaction. The CRR value obtained from the field test results is one of them is the SPT. The method for evaluating liquefaction potential is by obtaining a safety factor value from the comparison of the CRR value which reflects the strength of the soil against the cyclic load which is usually caused by the earthquake load with CSR. The safety factor used should not be less than one, because if there is less than one liquefaction will occur [11,12].

\[
CSR = \frac{\tau}{\sigma_v} = 0.65 \left(\frac{\sigma_v}{g}\right) rd
\]

Relationship between depth \( z \) and \( rd \) value according to [11,12]

\[
rd = 1 - 0.00765z \quad ; z < 9.15\text{ m}
\]
\[
rd = 1.174 - 0.0267z \quad ; 9.15 < z < 23\text{ m}
\]
\[
rd = 0.744 - 0.008z \quad ; 23 < z < 30\text{ m}
\]
\[
rd = 0.5 \quad ; z > 30\text{ m}
\]

In evaluating the CRR value, this value can be calculated by the formula \( CRR_{7.5} \) from Rauch (1998) in [11] with the equation (3):

\[
CRR_{7.5} = \left(\frac{1}{34 - (N1)_{60}}\right) + \left(\frac{(N1)_{60}}{135}\right) + \left(\frac{50}{[(N1)_{60} + 45]^2}\right) - \left(\frac{1}{200}\right)
\]

Where the value \( (N1)_{60} \) can be calculated by the equation Robertson (1998) in [11] provide a correction to get the value \( (N1)_{60} \):

\[
(N1)_{60} = N_M \cdot C_N \cdot C_E \cdot C_B \cdot C_R \cdot C_S
\]

This equation will be valid if \( (N1)_{60} < 30 \), because if \( (N1)_{60} \geq 30 \) then the material does not need to be evaluated, and it will be strong to withstand seismic loads because the soil is too dense to experience liquefaction.

To calculate the CRR with an earthquake magnitude other than 7.5, a correction factor called Magnitude Scale Factor (MSF) is needed. Seed (1983) in [11] gives an equation:

\[
CRR_{MW} = CRR_{7.5} \cdot MSF \cdot K_\sigma \cdot K_\alpha
\]

Where \( K_\alpha = 1 \) (assuming a flat surface) and \( K_\sigma \) must be \( \leq 1 \), Pa value = 1atm \( \approx 1kpa \).
Based on the results of re-evaluation by [11] for the value of MSF for magnitude smaller than 7.5 and magnitude greater than 7.5, as follows:

\[
MSF = \frac{10^{2.24}}{M_{W}^{0.56}}
\]  

(6)

Then the calculation of the FS value with the SPT data from the corrected CRR is to use the following equation:

\[
FS = \frac{CRR_{MW}}{CSR}
\]

(7)

3. Results and Discussion

3.1. Contains findings of the study and research discussion. Liquefaction Potential based on geological criteria

Based on the criteria of geological characteristics, the research area has the potential for liquefaction. The research area is composed of sandy clay, sandy silt, sand, clay sand, and silt, with the dominantly very loose-dense sand. The results of drilling techniques show that the subsurface stratigraphic conditions are Holocene alluvium, which is characterized by the repetition of a sand unit that is dominantly very fine to coarse sand grains, and there are clay and silt mixed with sand and gravel (Figure 4).

The repetition of layers of clay, silt, and sand shows that this area has been carried out repeatedly in the process of sedimentation, either caused by tectonic processes, tides or sedimentation processes during past deposition in this basin. This process is characterized by a fine to coarse sand deposition sequence with the continuity of silt and clay layers that interfinger in several drilling sites. In this study, the distribution of ground water levels was obtained during drilling. Hydrogeological conditions of the Holocene alluvium deposits show shallow depths of MAT from 1.5 to 2 m from the surface. Area research which is generally composed of alluvium deposits consisting of material a layer of fine-coarse sand, silt, and gravel functions as a layer of aquifer due to it permeable while silt-clay layers are
layers semipermeable. The distribution of layers of loose sand and shallow groundwater can cause liquefaction phenomena. (Figure 5)

![Figure 5. Morphographic map (elevation) of the study area](image)

The results of the geomorphological analysis show that the study area is included in the lowland unit (altitude 0-50 meters above sea level) so that based on Table 1, the study area also has the potential for liquefaction.

3.2. Liquefaction Potential based on geological criteria Geotechnical data
Based on an evaluation of liquefaction potential evaluation from Seed and Idriss (1972) in [11], all SPT sites have liquefaction potential at depths of 3 to 13 m which consisted of silt and very fine-medium sand grains very loose-dense density. This layer has very loose density so that when there is a large earthquake shake, the acceleration of vibration will also be higher (Figure 6 and Figure 7).
Figure 6. FS graph of BH-01, BH-02, and BH-03

Figure 7. CRR7.5 vs. CSR graph from BH-02

On FK graph (Figure 6) showing FK values <1 indicate that at that depth the soil has the potential for liquefaction because it has a CSR value smaller than the CRR value. The CRR value is large, due to the value of small N-SPT with loose-medium density. The resistance to cyclic stress is shown in the CSR & CRR graph, where at the depth of liquefaction, the soil has a low seismic resistance to stress from the earthquake. FK> 1, indicating that at that depth the soil has a large cyclic resistance ratio compared to the cyclic stress ratio caused by earthquakes.

The results of this study indicate that the area based on the geological characteristics of several geological parameters, has the potential for liquefaction. The position of the sanana region which is in the active fault region of Sorong increases the potential for liquefaction, where in this region frequent earthquakes occur. In addition to that quantitatively using geotechnical data (SPT) with the simplified procedure method, the calculation results show that the area of sanana also has the potential for liquefaction.

Evaluation of liquefaction potential based on geological and geotechnical characteristics shows the consistency of the results. The results of qualitative analysis based on geological characteristics are preliminary studies in evaluating liquefaction potential, then further studies are conducted with quantitative analysis both through soil strength and seismicity that occur so that better and more accurate evaluations are obtained.

4. Conclusion

From the method described above, the results of the analysis of geological conditions, geotechnical conditions and laboratory results to estimate potential liquefaction, it can be concluded that the Sanana region has the potential for liquefaction. Geologically, the Holocene alluvium with low water table
depth conditions and the location of the Sanana region in the South Sula-Sorong active fault causes this region to have potential liquefaction. Whereas in the technical geology of the SPT results, the depth of the subsurface layer that has liquefaction potential at depths of 3 to 13 m. Therefore, in order to prevent possible disaster caused by liquefaction, this problem needs to be considered in future infrastructure planning and development.

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