Liquefaction Potential based on Earthquake History in Sanana Region, Sula Island Regency, North Maluku, Indonesia

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ABSTRACT

Sula Islands is a region in Maluku Province that is very vulnerable to earthquakes because it is located on an active seismic line. One of the disasters that often accompanies earthquakes is liquefaction. Sandy soil in a saturated condition will lose its strength when an earthquake occurs, thus endangering the building above it. The aim of the study was to determine seismicity and estimate the liquefaction potential of the earthquake history and CPT test in the Sanana region and its surroundings. The method in this study uses a "simplified procedure" method for evaluating liquefaction resistance of soils. 2 main parameters were sought in this study, CSR obtained based on tectonic conditions and a history of seismicity and CRR obtained from the results of CPT testing. The results showed that seismicity in the Sanana region was sourced from Sula-Sorong active fault activity with a history of the greatest magnitude of 8.1 and 7.7. As for the calculation results from CPT data, the Sanana area has the potential for liquefaction of sand medium material at a depth of 5-12 m for earthquakes with magnitude 7.5 and 4 -12 m in magnitude 7.7 and 8.1. The potential for liquefaction in this area is caused by the type of saturated medium sand material and this location which is close to the active fault activity of Sula-Sorong. Therefore, it is necessary to evaluate the potential for liquefaction in planning, building and developing infrastructure in earthquake-prone areas so that disasters of liquefaction can be prevented.

Keyword: Liquefaction, Earthquake, CPT, Active Fault Sula-Sorong, Sula Islands

INTRODUCTION

Liquefaction is an event where the soil experiences effective shear loss due to increased pore water stress as a result of very fast cyclic loads and in a momentary period (Idriss and Boulanger, 2008). When earthquake loads work on the ground in an undrained condition while sand-type soil is in a saturated condition, the pore water pressure will rise, so that the soil will lose its strength or the shear strength will be zero (Ikhsan, 2011).

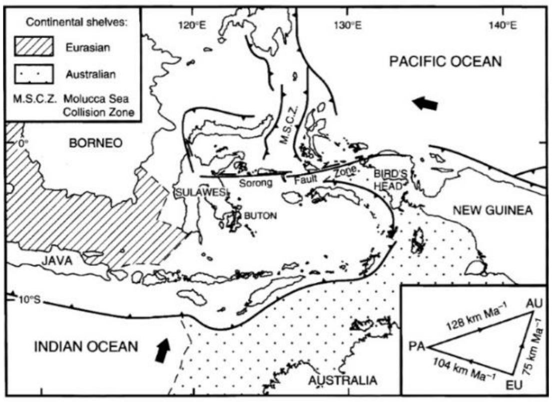

Figure 1. Regional tectonic setting the Sorong fault zone (Charlton, 1996)

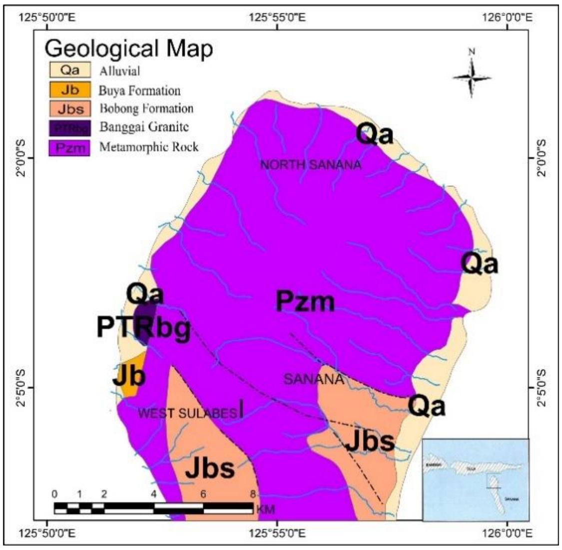

Figure 2. Geological map of the research area (Surono and Sukarna, 1993)

Sula Islands is one of the regions in Maluku Province which is very vulnerable to earthquakes because it is in an active seismic pathway, so it has a vulnerability for the occurrence of liquefaction phenomena. Along the coast of Sula Island specifically, the Sanana region, composed of Holocene

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alluvium (Surono and Sukarna, 1993), where the dominant soil conditions are composed of sand so that the vulnerability of liquefaction is increasing. Therefore it is necessary to study and analyze the Sanana coastal area potential liquidation of this area.

This paper aims to determine seismicity and estimate the potential of liquefaction from earthquake history and CPT test in Sanana area and its surroundings. The evaluation of the potential for liquefaction has a huge influence in planning the establishment of buildings or infrastructure. This was done to prevent the occurrence of disasters due to liquefaction so that in the establishment and planning of civil buildings, this research could be used as a material consideration as well as references in building planning that reviews the potential for liquefaction.

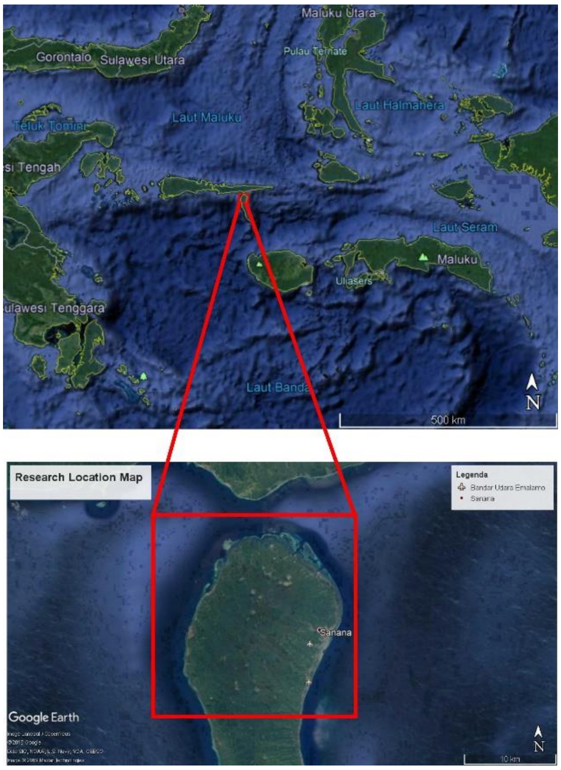

Figure 2. Location of research sites in Sanana Region

Administratively, the research area is in Sanana, Sula Islands Regency, North Maluku.

RESEARCH METHOD

The method used in this study uses a "simplified procedure" method developed by Seed and Idriss in 1971. In this method, two main parameters are sought: Cyclic Stress Ratio (CSR) or earthquake load parameters and Cyclic Resistance Ratio (CRR) which is the resistance of the soil to withstand liquefaction. CSR or seismic load parameters were obtained based on tectonic conditions and the history of seismic location analyzed, while CRR parameters or soil resistance parameters can be obtained from the results of field and laboratory tests, where in this study data from CPT results were used.

The relationship between duration and magnitude of earthquake magnitude is not always certain, there are other factors that influence the duration of the earthquake. The duration generally increases with distance from seismic sources and can vary with tectonic provinces, site conditions, and bedrock topography (basin effects).

The earthquake data was obtained from USGS (United State Geological Service) with M ≥ 5.0 SR where the data presented is earthquake data from 1919 - 2019. The earthquake data obtained is earthquake data in the Sulu and surrounding islands. This analysis aims to predict the return period of the earthquake and the time of the earthquake and is expected to get an overview of the earthquake activity in the study area.

Cyclic Resistance Ratio (CRR)

CPT field testing was carried out in 4 test sites, where the field data obtained from the CPT test was conus tip resistance (qc) (Figure 3). From the value of the end resistance then corrected to get a corrected resistance (qc1N) which then this value can be calculated CRR value which represents the value of soil resistance to the cyclic load caused by the earthquake.

Calculation of corrected resistance value qc1N, formulated by Seed and Idriss (1971) in Youd and Idriss (2002) as follows:

$$(q_{c1N})cs = K_c \times q_{c1N} \quad \text{.........................} \ (1)$$

$$q_{c1N} = C_N \times q_c = C_Q . \frac{q_c}{P_a} \quad \text{.........................} \ (2)$$

Where,

$$C_Q = (\frac{Pa}{\sigma'_v})^n \quad \text{.........................} \ (3)$$

Where, the Pa value = 1atm ≈ 1 kpa.

To estimate soil types, Robertson and Wride (1998) in Youd and Idriss (2002) graph the soil type limits that can be used to calculate the effect of soil characteristics on qc1N and CRR. The result of this graph is the soil behavior type index Ic that counts with the following equation:

$$I_c = [(3{,}47 - \log Q)^2 - (1{,}22 + \log F)^2]^{0{,}5} \text{.......} \ (4)$$

$$Q = \left[\frac{(q_c - \sigma_v)}{Pa}\right]\left[\frac{Pa}{\sigma' v}\right]^n \quad \text{.........................} \ (5)$$

$$F = \frac{f_s}{q_c - \sigma_v} \times 100\% \quad \text{.........................} (6)$$

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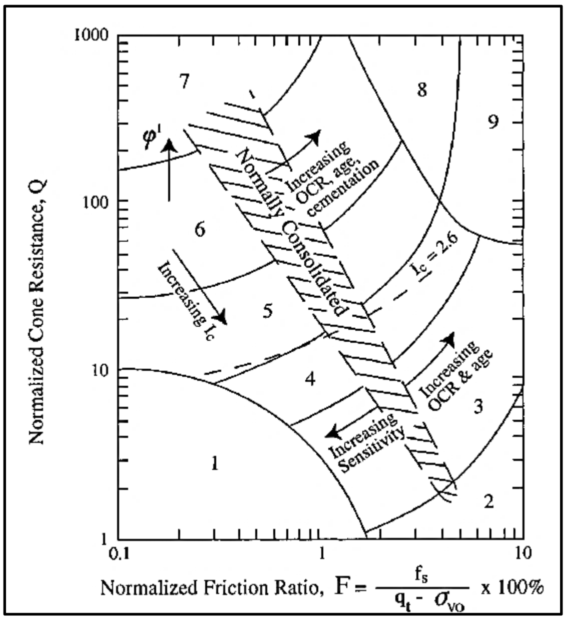

Figure 3. Graph of soil classification based on qc and Fr (Robertson, 1990; Youd and Idriss, 2002)

Calculation of the normalized value of CPT (qc1N) cs can be determined by the equation:

$$(q_{c1N})_{cs} = K_c \times q_{c1N} \quad ....(7)$$

Where Kc, the correction factor for grain characteristics, is defined from the following equation (Robertson and Wride, 1998; Youd and Idriss, 2002):

for Ic ≤ 1,64 , then Kc = 1,0

for Ic > 1,64 , then

$$Kc = -0{,}403\ Ic^4 + 5{,}581\ Ic^3 - 21{,}63\ Ic^2 + 33{,}75\ Ic - 17{,}88 \quad ....(8)$$

Robertson and Wride (2011) provide the equation below so that it can be calculated empirically the value of CRR 7,5:

If the value (qc1N) cs <50, then

$$CRR_{7,5} = 0{,}833 \times \left[\frac{(q_{c1N})_{cs}}{1000}\right] + 0{,}05 \quad ....(9)$$

If the value 50 < (qc1N)cs < 160, then

$$CRR_{7,5} = 93 \times \left[\frac{(q_{c1N})_{cs}}{1000}\right]^3 + 0{,}08 \quad ....(10)$$

Table 1. Geotechnical Parameters of Sondir Data

Point	Depth (m)	qc, (kg/cm²)	Soil Type	Unit Weight (kN/m³)	Cohesi (Cu,kPa)
S-01	0,00 ~ 2,40	5	Organic Clays and Mixed Soils	15	25
	2,40 ~ 6,00	12	Clayey Sands and Silts	16	
	6,00 ~ 14,20	41	Medium Sand	16	
	14,20 ~ 20,00	82	Very Shell Sands, Limerock	20	
S-02	0,00 ~ 7,00	6	Organic Clays and Mixed Soils	15	30
	7,00 ~ 11,40	28	Medium Sand	15	
	11,40 ~ 20,00	78	Very Shell Sands, Limerock	20	
S-03	0,00 ~ 5,20	6	Organic Clays or Mixed Soils	14	30
	5,20 ~ 7,60	12	Clayey Sands and Silts	16	
	7,60 ~ 14,40	40	Medium Sand	16	
	14,40 ~ 20,00	90	Very Shell Sands, Limerock	20	
S-04	0,00 ~ 7,20	6	Organic Clays or Mixed Soils	14	30
	7,20 ~ 9,00	13	Clayey Sands and Silts	16	
	9,00 ~ 14,40	40	Medium Sand	16	
	14,40 ~ 20,00	90	Very Shell Sands, Limerock	20	

Cyclic Stress Ratio (CSR)

Cyclic stress ratio is the cyclic stress that occurs due to an earthquake divided by the effective voltage. Seed and Idriss (1971) in Youd and Idriss (2002) formulate equations for cyclic stress ratios (CSR):

$$CSR = \frac{\tau_{av}}{\sigma' v} = 0{,}65 \left(\frac{a_{max}}{g}\right)\left(\frac{\sigma_v}{\sigma_v'}\right) rd \quad ....(11)$$

rd can calculate with the equation made by Seed and Idriss (1971) in Youd and Idriss (2002) the relationship of z depth and analytical rd value can be approximated by functions like the following:

E-ISSN : 2579 – 3136

$$rd = 1 - 0{,}00765z \quad ; z < 9{,}15\ m \quad \ldots\ldots\ldots\ldots (12)$$

$$rd = 1{,}174 - 0{,}0267z \quad ; 9{,}15 < z < 23\ m$$

$$rd = 0{,}744 - 0{,}008z \quad ; 23 < z < 30\ m$$

$$rd = 0{,}5 \quad ; z > 30\ m$$

Magnitude Scaling Factors (MSF)

The value of MSF for magnitude is smaller or greater than 7.5 based on the results of re-evaluation by Seed and Idriss (1976) in Youd and Idriss (2002)as follows:

$$M_w < 7{,}5\ then,\ MSF = \left(\frac{10^{2,24}}{M_{w\cdot}\ 10^{2,56}}\right) \quad \ldots\ldots\ldots\ldots (13)$$

Safety Factor (FS)

Calculation of FS value with SPT and CPT data is to use the following equation:

$$FS = \left(\frac{CRR_{7,5}}{CSR}\right) MSF \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (14)$$

RESULT AND DISCUSSION

Based on the results of the technical geological analysis, the research area belongs to the Alluvium (Qa) unit. This area is formed by alluvium deposits. The results of drilling and CPT show that the study area is composed of types of sandy clay, sand silt, sand, clay sand, and silt, with dominant sand which has very loose-dense strength.

Seismic Analysis

The source of the trigger for the earthquake in this area came from the Sula-Sorong active fault. The earthquake caused by this fault was marked by the presence of several shallow earthquakes. The location of the earthquake point far from the subduction zone shows that the shallow earthquakes are not related to the subduction zone, but rather an earthquake triggered by active fault activity.

The largest earthquake occurred on January 24, 1965, with M 8.1 at a depth of 20.0 km on the Sula archipelago, then in the Banda Sea, occurred November 29, 1998 with a magnitude of 7.7 and the closest earthquake to the study area occurred in the East of the research area, in the Sula archipelago which occurred on October 19, 1936 with a magnitude of 6.6. The earthquake occurred along the Sorong-Sula fault located north of the study area. The earthquake average magnitude> 5, is 6.0 and the smallest is 5.5.

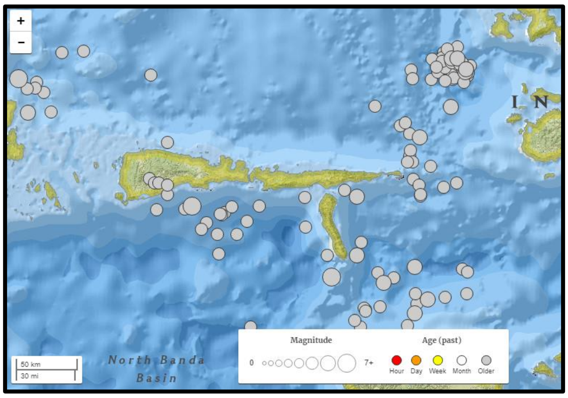

Figure 4. Tectonic Earthquake of Research Areas in 1919-2019 (USGS, n.d.)

Analysis of Potential Liquefaction

Based on the calculation of the safety factor on earthquake magnitude 7.5, the FS graph is obtained at the four points of CPT. The calculation results show that in an earthquake with magnitude 7.5, the Sanana area has the potential for liquefaction. On the graph, it is known that the liquefaction potential is at a depth of 5 to 12 m.

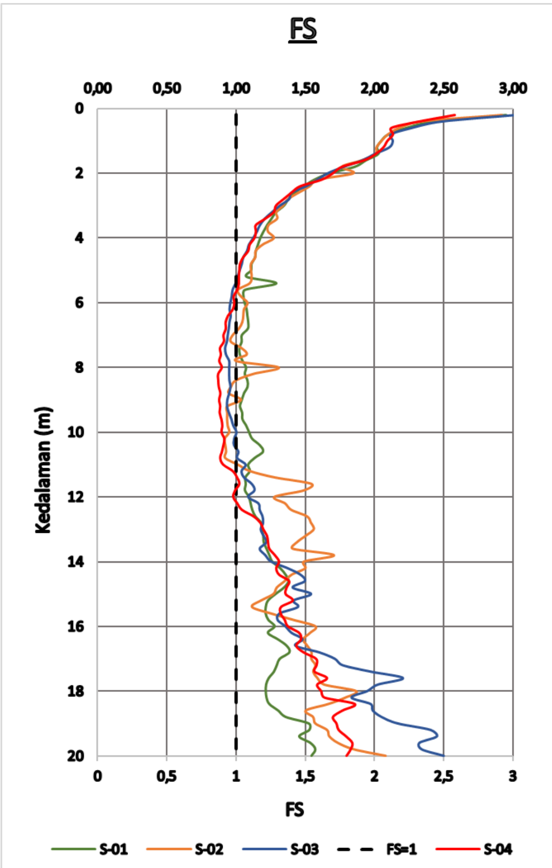

Figure 5. Safety Factor graph of CPT sites

At the earthquake load from the history of the earthquake, the Sula archipelago with magnitude 8.1 and 7.7 showed insignificant

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depth changes, namely at depths of 4 - 12 m which is the same type of material that is the medium sand.

On FS charts that show FS values <1 indicate at that depth the soil has potential liquefaction. The soil resistance properties of earthquake loads are shown in intersecting CSR & CRR graphs. This graph shows that this depth of soil has a low seismic resistance, the value of the cyclic resistance ratio is greater than that of the cyclic stress ratio caused by earthquakes.

The level of consistency of subsurface sediment layer density reflects the level of material density. The greater the value of QC will have an even greater CRR value so that by increasing the CRR value and decreasing the value of CSR, the value of the potential safety factor of liquefaction will be even greater.

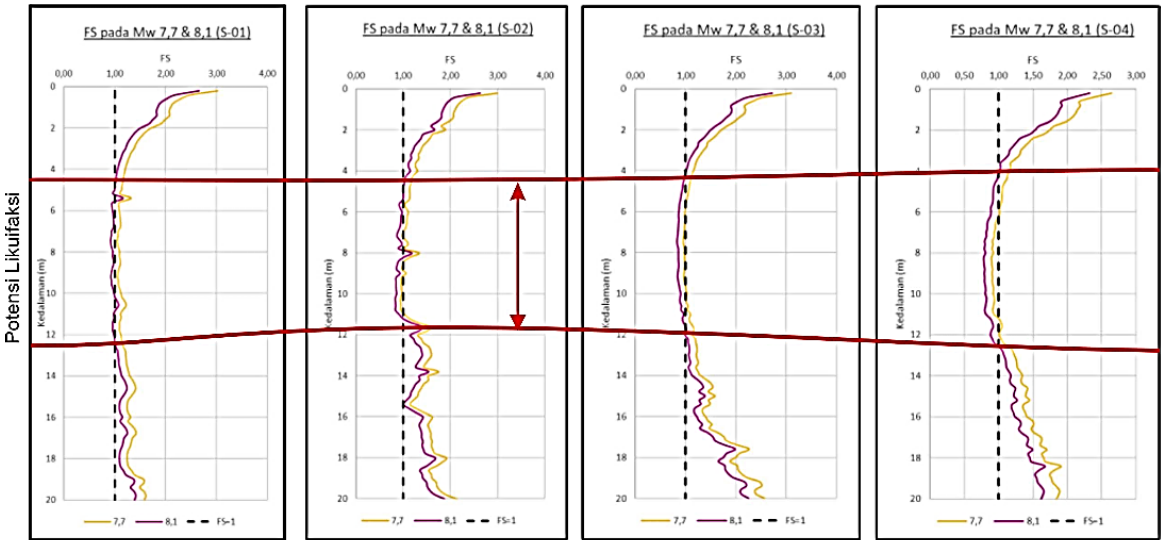

Figure 6. The depth of the layer that has liquefaction potential from the CPT graph

CONCLUSION

Based on the analysis of seismic history and calculations made from CPT data at 4 test sites, it can be concluded that the seismicity and potential liquefaction of the Sanana region and its surroundings. The seismic activity in the Sanana region originates from the Sula-Sorong active fault activity where the largest earthquake occurred on January 24, 1965, with magnitude 8.1 at a depth of 20.0 km on the Sula archipelago and on November 29, 1998, in the Banda Sea with magnitude 7.7. The earthquake occurred along the Sorong-Sula fault located north of the study area.

Based on the calculation results from CPT data, the Sanana area has the potential for liquefaction. Soils that have the potential for liquefaction in magnitude 7.5 earthquakes are at depths of 5-12 m which are types of medium sand material and in earthquakes with magnitude 7.7 and 8.1 soil which have the potential for liquefaction at depths of 4 to 12 m.

The potential for liquefaction in this area is caused by saturated medium sand material and the Sanana region which has high seismicity with a large history of earthquakes.

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