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Analysis of Soil Liquefaction Potential in Puger Coastal Area, Jember Regency, East Java Using CPT Data

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Abstract. The existence of which is traversed by world plate meeting brings Indonesia in earthquake prone area. One of the dangers that occur in earthquake is soil liquefaction. At the time of the earthquake occurs, the soil changes the nature of solid into liquid due to the received cyclic load. As a result, the non-cohesive soil will lose its power. The consequence of soil liquefaction is the decline of the building. Measurement of soil strength and identification of soil type can be done by using the Cone Penetration Test (CPT). In this study, CPT measurement was used to evaluate the liquefaction potential of Puger coastal area, Jember Regency. The potential of liquefaction is determined by obtaining the value of Cyclic Resistance Ratio (CRR), Cyclic Stress Ratio (CSR), Safe Factor (SF) and subsequently calculating ground settlement due to soil liquefaction. As for the results of measurements on 13 points, 7 points of them have the potential for soil liquefaction. From those points, the largest ground settlement is up to 3.24 cm, hence based on the degree of damage to buildings developed by Ishihara and Yosimine [1], the category is included as minor damage.

INTRODUCTION

Indonesia is a meeting point of three major tectonic plates, namely the Indo-Australian plate, the Eurasian plate and the Pacific plate. The Indo-Australian plate collides with the Eurasian plate off the coast of Sumatra, Java and Nusa Tenggara, while it collides with the Pacific plate in the northern Irian and Maluku. Around the location of this meeting point, a collision of energy is accumulated to a point where the earth layer is no longer able to hold the pile up of the energy, thus it is released in the form of earthquakes.

The seismotectonic map of Java Bali [2] is shown in Figure (1). In 2006 to 2017, there were 1032 seismic events with magnitude of 3.3-7.7 SR were recorded. Meanwhile, in the south of Jember, 146 earthquakes were also recorded with magnitude of 3.3-5.9 SR, from 2006 to 2017. One of the impacts of the earthquake is soil liquefaction. The result of this soil liquefaction is the soil will lose its strength and the building will decrease. Through a measurement of soil strength with the Cone Penetration Test (CPT), the potential of soil liquefaction in the Puger coastal area can be revealed.

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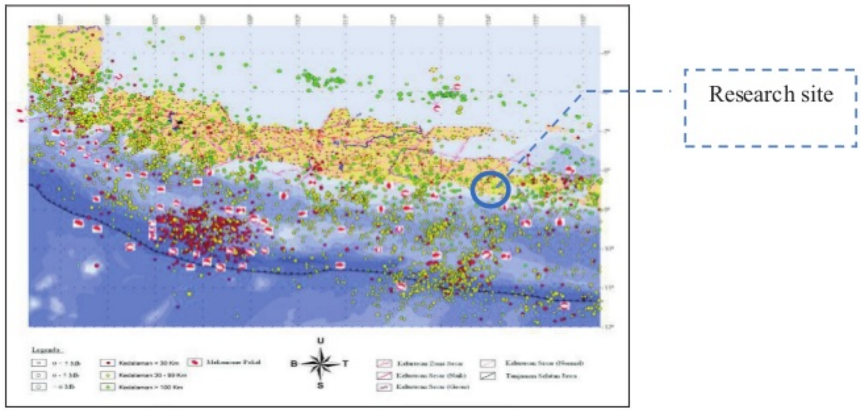

FIGURE 1. Seismotectonic Map of Java and Bali [2].

SOIL LIQUEFACTION POTENTIAL ANALYSIS

The soil liquefaction is the loss of soil strength due to the increase in pore water stress and the decrease in effective pressure of the soil layer caused by dynamic load. The soil liquefaction caused by the earthquake potentially occurs on non-cohesive soils. In the event of soil liquefaction, soil strength decreases thus the soil is unable to carry the weight of the building. The effective tension received by the soil due to the cyclic load with the characteristics of grained, water saturated and moderate to loose density, where the property of soil is changing from solid to liquid and the ground tension becomes zero.

Liquefaction may lead to soil degradation, collapse, ground cracking, crumbling, and damage to public facilities. Some examples of the earthquake followed by liquefaction are the Niigata earthquake of 1964, Kobe earthquake of 1995, Turkey earthquake of 2002, Taiwan earthquake 1999, India earthquake of 2001, Maumere earthquake on December 1th, 1992, Aceh and Nias earthquake on December 26 th, 2004, Bengkulu earthquake of 2000, and Yogjakarta earthquake on May 27 th, 2006. Because of the dangers of soil liquefaction, the investigation of its potential on a region is required.

Robertson and Wride [3] used CPT data to determine the potential of soil liquefaction, specifically in determining the criteria of sedimentary soils affected by two parameters, namely: the equivalent clean sand normalized penetration resistance $(q_{c1N})_{cs}$ and the cyclic stress ratio (CSR). The penetration equation according to Robertson and Wride [3] is:

$$(q_{c1N})_{cs} = K_c\, q_{c1N} \tag{1}$$

where the conversion factor Kc (Figure 2) for grain characteristics is calculated from the soil behavior type index Ic as follows:

$$\begin{aligned} K_c &= 1 \quad \text{for} \quad I_c > 1.64 \\ &= -0.403\, Ic^4 + 5.581\, Ic^3 - 21.63\, Ic^2 + 33.75\, Ic - 17.88 \quad \text{for} \quad I_c < 1.64 \end{aligned} \tag{2}$$

The soil behavior type index, Ic, is defined by Robertson and Wride [3] as:

$$I_c = \{(3.47-\log Q)^2 + (\log F + 1.22)^2\}^{0.5} \tag{3}$$

and q_{c1N} is the normalized cone penetration resistance calculated as:

$$\begin{aligned} q_{c1N} &= (qc/P_{a2})(P_a/\sigma_{vo})^{0.5} && \text{if } I_c < 2.64 \\ &= Q && \text{if } I_c > 2.64 \end{aligned} \tag{4}$$

where P_a= 100 Kpa if σ_{vo}' is in Kpa, P_{a2}=0,1 Mpa if σ_{vo} is in MPa. Subsequently, Q and F are the normalized tip resistance and friction ratio, respectively as follows:

$$Q = (q_c - \sigma_{vo}) / \sigma_{vo}' \tag{5}$$

$$F = f_s/(q_c-\sigma_{vo})\ 100\% \quad (6)$$

Where fs = friction ratio, qc = cone penetration, $\sigma_{vo'}$ = Effective overburden stress of soil, and σ_{vo}= Total overburden stress of soil

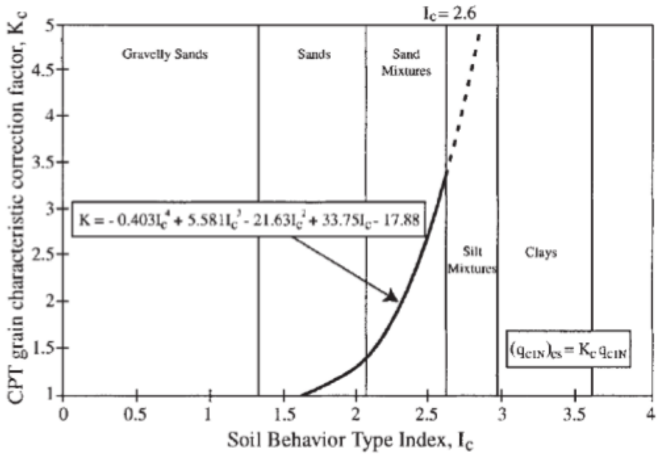

FIGURE 2. Graph of K_c and I_c relationship of Soil Behavior Type [3].

Soil lliquefaction potential analysis also requires a variable as interpreted in an equation that defines the soil capacity as a liquefaction resistance (CRR). [3] developed a graph of CRR relationship with correlated Qc_1 values (Figure 3) on fine sand with FC (fine content) of ≤ 5% and a magnitude of earthquake at 7.5 SR. The equations used to estimate the value of CRR on the ground are:

$$\text{if, } 50 < (q_{c1n})_{cs} < 160 \quad CRR_{7,5}=93\ \{(q_{c1n})_{cs}/1000\}+0.05 \quad (7)$$
$$\text{if, } (q_{c1n})_{cs} < 50 \quad CRR_{7,5}=0{,}833\ \{(q_{c1n})_{cs}/1000\}+0.05 \quad (8)$$

The flow chart for CRR is presented in Figure 5. Furthermore, CRR values are used to determine the safety factor of the soil characteristics that can be obtained by comparing the values of CSR and CRR through equation (4) as follows:

$$FSL = (CSR/CRR)MSF \quad (9)$$

Where the value of MSF (Magnitude Scaling Factor) is calculated using the equation given by from Youd [4] namely:

$$MSF = 10^{2,24}/M^{2,56} \quad (10)$$

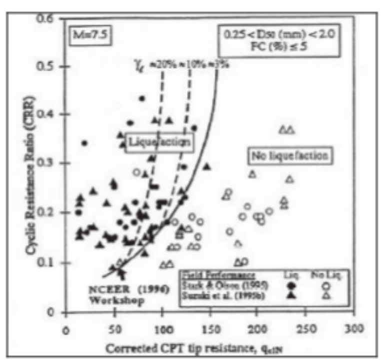

FIGURE 3. Graph of q_{c1N} and CRR relationship to the potential of soil liquefaction [3].

The second parameter is CSR (cyclic stress ratio), which is a parameter used to define seismic symptoms that occur in the soil layer. The calculation of CSR values is formulated by Seed and Idriss [5] as follows:

$$CSR = 0,65\ x \left\{ \frac{a_{max}\ x\ \sigma_{vo}}{g\ x\ \sigma_{vo}'} \right\} x\ r_d \qquad (11)$$

Where g = acceleration of gravity (mm/s), a_{max} = maximum ground acceleration (gal), and r_d = stress-reduction factor.

The value of r_d is a stress reduction at a depth which is used to estimate the magnitude of the reduction coefficient of the magnitude of CSR. Liao and Whitman [6] proposed a formulation to estimate the stress reduction coefficient using the following equations:

$$r_d = 1,0 - 0,00765\ z,\ if\ z \le 9,15\ m \qquad (12)$$

$$r_d = 1,174 - 0,00267\ z\ ,\ if\ \ 9,15\ m < z < 23\ m \qquad (13)$$

It is assumed that soil liquefaction will cause a decrease in soil. Furthermore, [7] developed a graph of the relationship between volumetric strain (ε_v), safety factor for liquefaction (SF) and equivalent sand normalized penetration resistance $(q_{c1N})_{cs}$ through the experiments in the laboratory as presented in Figure 4. The mean of the decrease is determined by the equation below:

$$S = \int_0^z \varepsilon_v dz = \sum_{i=1}^{j} \varepsilon_{v,i} \Delta z_i \qquad (14)$$

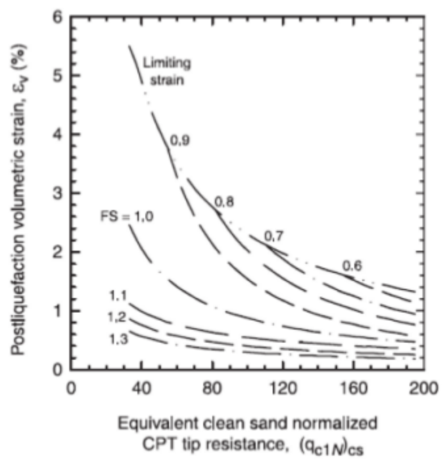

FIGURE 4. Relation of seismic end resistance, and volumetric strain for various safety factors [7]

RESEARCH METHODOLOGY

The research was done through field data collection in the form of CPT measurement. Measurements using the Cone Penetration Test (CPT) were used to determine the ground resistance to the liquefaction or Cyclic Resistance Ratio. Meanwhile, in calculating the value of Cyclic Stress Ratio, the earthquake acceleration on the ground of a_{max} was based on earthquake regulation in 2002, where Puger sub-district is classified in Zone 4. Furthermore, after the liquefaction potential was obtained, the calculation of decrease due to the potential of soil liquefaction and the classification of soil liquefaction potential was determined based on the Ground settlement. The classification is presented in Table 1.

TABLE 1. Relationship between the ground settlement and the degree of damage to buildings [8,1]

Degree of damage to buildings	Ground settlement (cm)	The phenomenon at ground level
Minor damage	0-10	Minor cracks
Moderate damage	10-30	Small cracks, fine sand out of the ground
Heavy damage	30-70	Large cracks, fine sand gush, lateral deformation

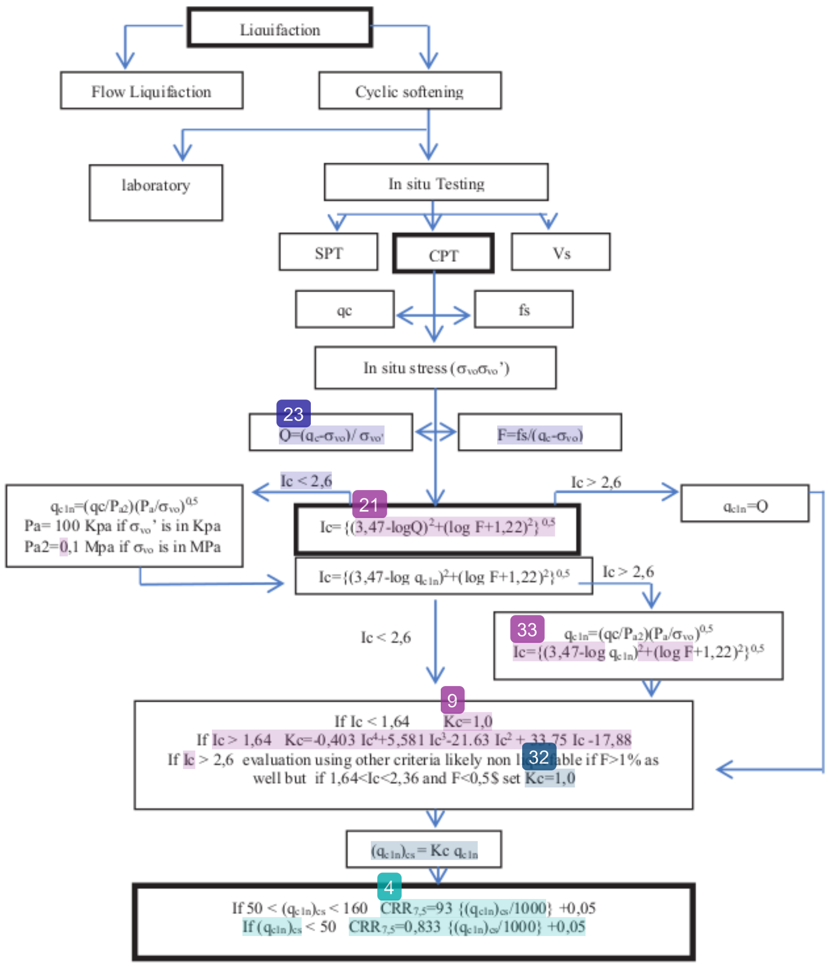

FIGURE 5. Flow chart of the application of an integrated CPT method to evaluate the ratio of cyclic resistance (CRR) in sandy soils [9].

SOIL LIQUEFACTION POTENTIAL ANALYSIS

Analysis of soil liquefaction potential was conducted on 13 CPT measurement points. Further analysis was done by using LIQIT software. In this paper, the calculation results for the CPT Point 2 are explicated. At the CPT Point 2, the depth of water is 1.5 m, while the peak of earthquake acceleration (PGA) surface based on the 2002

Earthquake Regulation is 0.34g. Subsequently, the magnitude of earthquake is Mw = 7.5. The results of the analysis with liqit are presented in Fig. 6 and Fig. 8. Fig. 6 demonstrates CPT Graph, Stress Ratio Graph, Pore Pressure Graph, Graph of SBT Index, and Soil Behavior Type Graph of CPT Point 2. Fig. 8 presents the CPT Graph, Stress Ratio Graph, Safety factor Chart, Ground Settlement Chart of Liquefaction of CPT Point 2. In CPT Point 2, the ground settlement caused by liquefaction is about 3.24 cm.

The ground settlement due to liquefaction on all CPT points can be seen in Fig. 7 and Fig. 9. Of the 13 points, 7 points have the potential soil liquefaction with the maximum ground settlement occurs at Point 2, which is approximately 3.24 cm. Based on the classification, ground settlement at the coastal area of Puger is categorized into the level of minor damage.

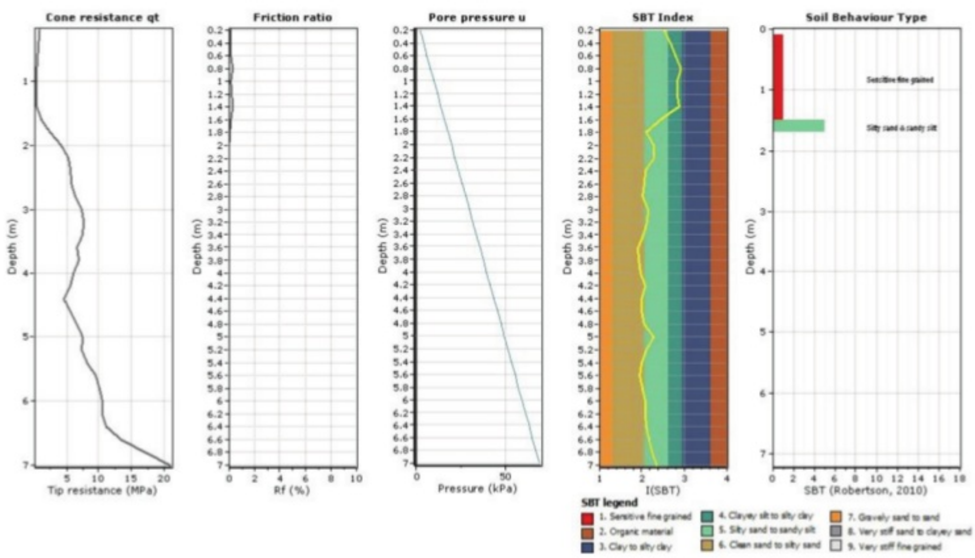

FIGURE 6. CPT Graph, Stress Ratio Graph, Pore Pressure Graph, Graph of SBT Index, and Soil Behavior Type Graph of CPT Point 2.

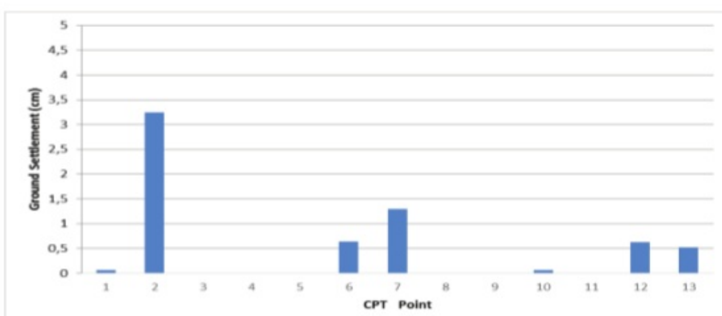

FIGURE 7. Barchart of Ground settlement due to liquefaction on 13 Points of CPT Test.

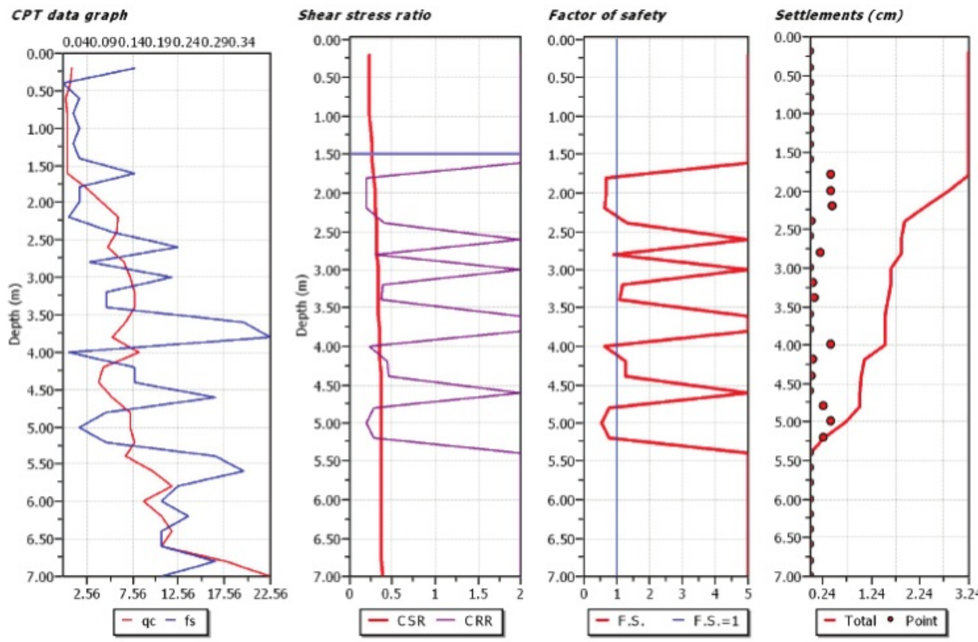

FIGURE 8. CPT Graph, Stress Ratio Graph, Safety factor Chart, Ground Settlement Chart of Liquefaction of CPT Point 2.

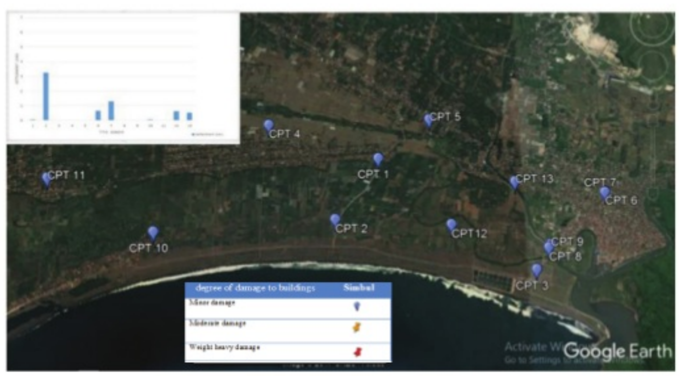

FIGURE 9. Map of Potential Distribution of Liquefaction in Puger Coastal Area, Jember Regency.

CONCLUSION

The conclusions obtained from the research entitled Analysis Of Soil Liquefaction Potential in Puger Coastal Area, Jember Regency, East Java Using CPT Data are as follows:

- From the 13 CPT measurement points, there are 7 (seven) points classified into liquefaction potential points with the minor damage category (The phenomenon at ground level is a minor crack).
- Potential ground settlement due to the liquefaction is obtained at the maximum ground settlement of 3.25 cm and occurs at the CPT measurement of Point 2 at coordinates of 8.22.489° S and 113.26.908° E.

SUGGESTION

Suggestions proposed to be developed in further researches are as follows:

- Determination of soil liquefaction potential is strongly influenced by the determination of the selected earthquake acceleration in this research. In this study, earthquake acceleration was based on the 2002 Earthquake Map. Based on its development, it has been revised into the 2010 Earthquake Map. Therefore this research needs to be developed with the use of the newest earthquake map.
- In addition to the earthquake acceleration, it is also influenced by the condition of the groundwater surface, which is in the shallow or deep water surface area. In this study, the groundwater level was measured at the time of CPT measurement, so it still did not consider the change of water level for one year, therefore in the next study it is necessary to evaluate this issue.
- Anticipation of damage to the existing infrastructure in the study area is still required. The improvement of soil that can be done is by increasing the density of the soil or by using stone column installation.

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