Analysis of Liquefaction Potential Based on SPT and CPT Data in the Yogyakarta International Airport Area

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Abstract

The occurrence of earthquakes will cause damage to building structures as well as damage to soil structures. One of the impacts is Liquefaction, which is a process or event of changing the state of the soil from a solid state to a liquid state caused by a cyclic load at the time of the earthquake so that there is a change in the voltage in the soil. Analysis method of potential liquefaction using simplified method, based on SPT and CPT data. From the data, cyclic stress ratio (CSR), Cyclic Resistant Ratio (CRR) and security factors were obtained. Based on the calculation analysis, it is known that there is a potential liquefaction in YIA area with different depth variations according to the location of data retrieval with an earthquake magnitude of 7.5 SR.

Keywords: Standar Penentration Test (SPT), Cone Penetration Test (CPT), Cyclic Resistance Ratio (CRR), Cyclic Stress Ratio (CSR), Liquefaction

I. PRELIMINARY

Earthquakes can cause damage to the soil structure. The risks caused by an earthquake are not only the risk of failure of the building structure, but also the risk of failure that occurs in the soil structure that supports the building above it. Damages to the soil structure include settlement, rock fall, landslides and damage related to slope balance (land slide and slope stability) and liquefaction (liquefaction) (Kongar et al., 2017).

Laia (2014) explains that liquefaction is a process or event of changing soil properties from a solid state to a liquid state caused by cyclic loads during an earthquake so that the pore water pressure (powerwater) increases near or exceeds the vertical stress and causes the flow of underground water to be pushed. to the surface. As liquefaction progresses, the strength of the soil decreases and the ability of the soil deposit to withstand loads also decreases.

The southern coast of Kulon Progo has the potential for large earthquakes, earthquakes being one of the main causes of liquefaction (Amelia & I Gede Budi Indrawan, 2017; Idriss & Boulanger, 2008). The phenomenon of liquefaction usually also occurs in areas that have high groundwater levels, this causes liquefaction to often occur in low areas such as riverbanks, lakes and beaches which generally have high groundwater levels. Liquefaction that occurs in infrastructure buildings will have an impact on the loss of a person's life, loss of livelihood, loss of energy, disrupting the economy and reducing transportation connectivity (Kongar et al., 2017). Observing this, it is necessary to analyze the interpretation of the Cone Penetretation Test (CPT) and Standard Penetration Test (SPT) data at that location to determine the potential for liquefaction at the study site.

II. RESEARCH PLOT

Several experiments and field data analysis have been carried out regarding the potential for liquefaction (Iswanto et al., 2017). An example is asuch as practical method where this analysis method is carried out using field test data such as Cone Penetration Test (CPT), Standard Penetration Test (SPT), and boring test. In addition, the potential for liquefaction can also be carried out based on laboratory tests such as grain analysis. Of these several methods, the analytical method using SPT and CPT data is the most frequently used method considering the ease of implementation. The method to evaluate the liquefaction potential uses a simplified method developed (Youd T et al., 2001) by obtaining the value of the safety factor from the comparison of the Cyclic Resistance Ratio (CRR) value, which is a value that reflects the strength of the cyclic load caused by an earthquake with value of Cyclic Stress Ratio (CSR) and Safety Factor. Check whether the value of the safety factor is >1 which means it is safe from liquefaction, <1 has the potential for liquefaction. The research steps can be seen in the flow chart in Figure 1

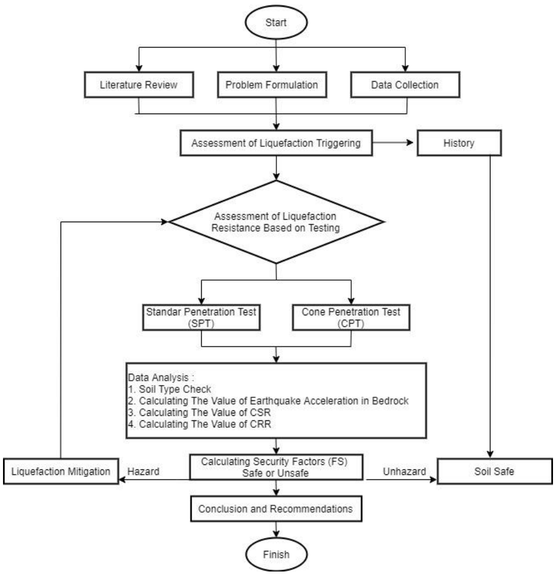

Figure 1. Flow Chart

III. RESULT AND DISCUSSION

A. Type and Soil Properties

Data soil obtained from PT. PP (Tbk) KSO and Yogyakarta International Airport (YIA) New Airport Project can be seen in table 1, table 2, and table 3 as follows

Table 1 The nature and layer of soil at the point R-25

Layer	Layer Thickness	Soil Types	Depth (m)	Gs	Km3	n	Fines Content (%)
I	5,55	SP	1-5 m	3,27	14,06	0,58	8,25
II	4	SP	6-9 m	3,43	16,1	0,54	30,30
III	0,45	SP	1 m	2,94	12,88	0,57	30,30

Table 2 The nature and layer of soil at the point R-*26*

Layer	Layer Thickness	Soil Types	Depth (m)	Gs	Km^3	n	Fines Content (%)
I	4	SP	1-3 m	3,09	11,49	0,64	29,55
II	2	SP	4-6 m	3,05	13,35	0,57	29,55
III	4	SP	7-10 m	2,54	13,41	0,48	40,30

Table 2 The nature and layer of soil at the point R-27

Layer		*Layer Thickness*	*Soil Types*	*Depth (m)*	*Gs*	*Km3*	*n*	*Fines Content (%)*
I		*4,5*	*SP*	*1-4,50 m*	*3,47*	*14,01*	*0,6*	*40,00*
II		*1,5*	*SP*	*4,60-6 m*	*3,16*	*14,75*	*0,54*	*40,00*
III		*4*	*SP*	*7-10 m*	*2,83*	*15,51*	*0,46*	*40,00*

Based on the data in table 1 and table 2 at location R-25 and location, it can be concluded that the soil in layers I, II, and III has the potential to liquefy because it is a non-cohesive soil (SP).

Liquefaction Potential Analysis using SPT data.

The SPT was originally developed to investigate the status of incohesive soil deposits for pile installations. (Bolton, 1983). Functions of using Standard Penetration Test for Cyclic Resistance Ratio (CRR) and Cyclic Stress Ratio (CSR):
1. Determine from the parameters of earthquake strength (MW), PGA, FC and effective stress (SV').
2. Determine the CRR of the value (N1)60
3. Another correction factor.
4. Determine the Magnitude Scaling Factor (MSFs)
5. Determine the Safety Factor

Cyclic Stress Ratio (CSR) values on the graph (Bolton, 1983) are available only for 7.5 SR mermagnetic earthquakes. There are several data needed to calculate CSR, including the total vertical stress and the effective vertical stress. The value of Cyclic Stress Ratio (CSR) at drill point 1 is as shown in table 4

Table 4. Calculation of CSR value at point R-25

Depth (m)	σv/σ'v	**a_{max}**	**g**	**rd**	**CSR**
1	3,308	1	9,81	0,992	0,218
2	3,308	1	9,81	0,985	0,216
3	3,308	1	9,81	0,977	0,214
4	3,308	1	9,81	0,969	0,212
5	3,308	1	9,81	0,962	0,211
6	1,895	1	9,81	0,954	0,120
7	2,560	1	9,81	0,946	0,161
8	2,560	1	9,81	0,939	0,159
9	2,560	1	9,81	0,931	0,158
10	4,195	1	9,81	0,907	0,252

Calculation of the CSR value at point 1 depth 2 m

$$\text{CRS} = 0,65\left(\frac{\alpha\text{max}}{g}\right)\left(\frac{\sigma vo}{\sigma' vo}\right)rd$$
$$= \left(\frac{1}{9,81}\right)(3,308)0,985$$
$$= 0,216$$

Liquefaction potential analysis was carried out by connecting the CRR 7.5 value for each case in each soil layer with the CRR value in that soil layer. The calculation of the values Δ(N1)60, (N1)60CS, and CRR7.5 at point R-25 as follows.

Calculation of (N1)60 at a depth of 1 m

$$\Delta(N_1)_{60} = 1,63\,\frac{9,7}{FC+0,01} - \left(\frac{15,7}{FC+0,01}\right)^2$$
$$= 1,63\,\frac{9,7}{8,25+0,01} - \left(\frac{15,7}{8,25+0,01}\right)^2$$
$$= -\ 1,727$$

Calculation $(N_1)_{60CS}$ depth 1 m.

$$(N_1)_{60CS} = (N_1)_{60} + \Delta(N_1)_{60}$$
$$= 0,129 + -\ 1,727$$
$$= -1,598$$

Calculation $CRR_{7.5}$ at depth 1 m.

$$CRR_{7.5} = \frac{1}{34-(N1)60\,Cs} + \frac{(N1)60\,Cs}{135} + \frac{50}{[(10(N1)60Cs)]^2} - \frac{1}{200} = \frac{1}{34-(-1,598)} + \frac{(-1,598)}{135} + \frac{50}{[(10\,x\,(-1,598)]^2} - \frac{1}{200}$$
$$= 1,670$$

Table 5. CRR value in earthquake Mw 7,5

Depth (m)	**%FC**	**$(N_1)_{60}$**	**Δ(N1)60**	**$(N_1)_{60CS}$**	**$CRR_{7.5}$**
1	8,25	0,129	-1,727	-1,598	1,670
2	8,25	0,109	-1,727	-1,618	1,691
3	8,25	0,076	-1,727	-1,651	1,725
4	8,25	0,053	-1,727	-1,674	1,748

Depth (m)	%FC	$(N_1)_{60}$	Δ(N1)60	$(N_1)_{60CS}$	$CRR_{7.5}$
5	8,25	0,043	-1,727	-1,684	1,759
6	30,30	0,017	0,259	0,276	-0,228
7	30,30	0,025	0,259	0,284	-0,236
8	30,30	0,035	0,259	0,294	-0,246
9	30,30	0,031	0,259	0,290	-0,242
10	30,30	0,080	0,259	0,339	-0,291

Calculation safety factor value at depth 6 m. magnitude 7,5 SR point 1.

$$SF = \frac{CRRMW}{CSR} = -1{,}9$$

Due to the value of SF < 1, it can be concluded that the layer has the potential to experience liquefaction, the details can be seen in Figure 2.

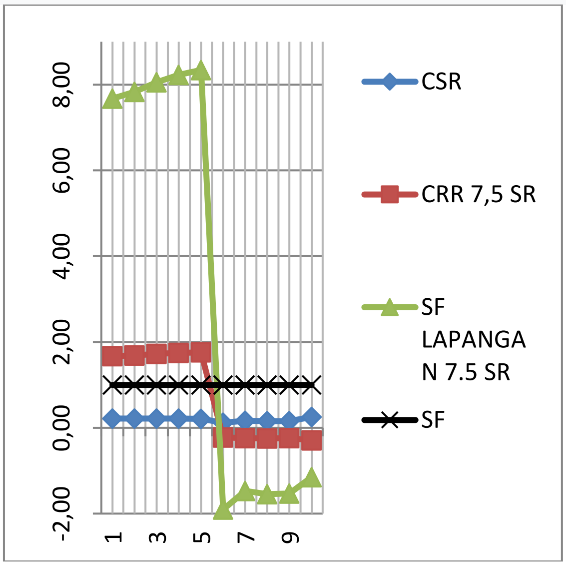

Figure 2. Graph of relationship between CRR, CSR and factor of safety (SF) for SPT data

Liquefaction Potential Analysis using CPT data

The main advantage of the CPT is that the penetration resistance of the profile can continuously be developed for statigraphic interpretation. The data produced by CPT is generally more consistent and has good repeatability so that the data obtained are relatively close to each other. Statigraphy obtained from CPT has more ability in interpreting liquefaction resistance data than SPT (Ikhsan, 2011).

Based on several fault case histories from the 1989 Loma Prieta Earthquake, I.M. Idriss suggests that the clean sand curve in Figure 3 below should shift to the right by 10-15%.

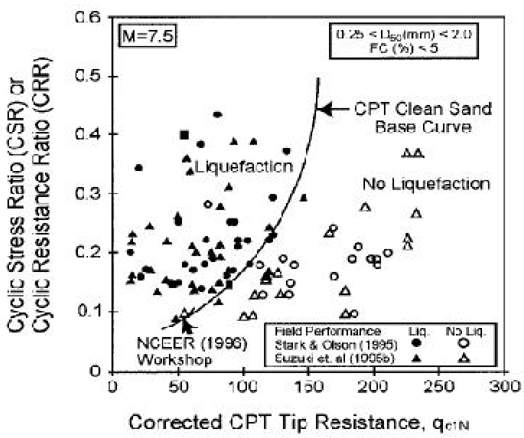

Figure 3 Kurva yang direkomendasikan untuk perhitungan CRR dari data CPT sepanjang data empiris likuifaksi dari gabungan sejarah kasus Sumber : Soil Liquefaction During Earthquakes (Idriss & Boulanger, 2008)

The normalization of the cone penetration resistance is obtained as follows:

$q_{c1N} = C_N (q_c / P_a)$

$C_N = (P_a / a'_{vo})^n$

(Idriss & Boulanger, 2008) stated that CRR7,5 value is as folows :

If $(q_{c1N})_{cs} < 211$

$CRR_{7,5} = \exp [((q_{c1N})_{cs}/540) + ((q_{c1N})_{cs}/67)^2 - ((q_{c1N})_{cs}/80)^3 + ((q_{c1N})_{cs}/114)^4 – 3)$

If $(q_{c1N})_{cs} > 211$, maka $CRR_{7,5} = 2$

Where:

C_Q is the normalizing factor for the CPT resistance;

Pa = 1 atm the same pressure used by σ'_{vo} ;

n = exponent depending on soil type;

q_c = end resistance of cone

Then the $CRR_{7,5}$ value is obtained at 14,49 depth 2 meters.

At shallow depths CQ becomes very large due to low overburden pressure, how ever values more than 1,7 should not be applied. As previously explained, the value of n varies from 0.5-1.0 depending on the grain characteristics of the soil (Olsen 1997).

The CPT friction ratio (fs) generally increases with increasing fines content and soil plasticity properties, which allows a rough estimate of the soil type and its finest content which can be determined from CPT data which is usually defined as the soil behavior type index Ic calculated using the following equation

$Ic = [(3.47 - \log Q)^2 - (1.22 + \log F)^2]^{0.5}$

Where:

$Q = [(q_c - \sigma_{vo})/P_a][(P_a / \sigma'_{vo})^n]$

$F = [f_s /(q_c - \sigma_{vo})] \times 100\%$

If Ic is calculated with an exponential value of 1.0 and a value of >2.6 is obtained, the soil will be classified as clay. However, soil samples should be taken and tested to confirm soil type and liquefaction resistance. Soil criteria can be applied to confirm that the soil is non-liquefable. They so-called "Chinese criteria" as defined by (Bolton, 1983), liquefaction can only occur if all of the following conditions are met:

1. Clay content (particles smaller than 5) is 15% less than
2. the weight.
3. Liquid limit less than 35%
4. Its natural moisture content is greater than the 0.9 liquid limit.

Calculation of the equivalent value of normalized CPT (qc1N)cs can be determined from the following equation

$(q_{c1N})_{cs} = K_c q_{c1N}$

Where:

Kc: correction factor for grain characteristics, defined from (Robertson dan Wride, 1988) :

for Ic ≤ 1.64 Kc = 1.0

for Ic > 1.64 Kc = -0.403 Ic4 + 5.581 Ic3 – 21.63 Ic2 + 33.75 Ic –17.88

Kc curve defined by the above equation is plotted in Figure 4. For Ic > 2.6, the curve will be shown as a dotted line indicating that the soil has a range of Ic that is most likely to experience liquefaction. From the calculation, value of Ic = 1.88 at 2 meters depth

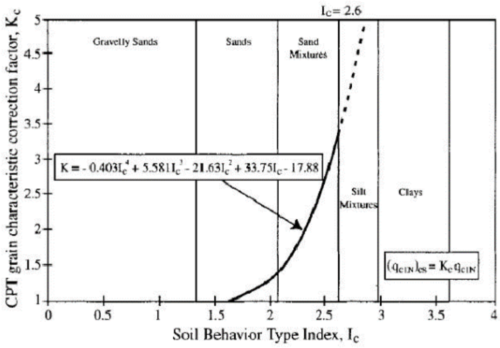

Figure 4. Grain-Characteristic Correction Factor Kc for Determination of Clean-Sand Equivalent CPT Resistance Sumber: (Robertson & Campanella, 1985)

Theoretically and laboratory studies show that the CPT cone resistance (qc) is influenced by the soft soil layer above or below the cone. As a result, the CPT tip resistance measurement is small value in a thin layer of granular soil sandwiched between the soft layers. Using a simple elastic solution, Vreugdenhil et al (1994) in (Ikhsan, 2011) developed a procedure for estimating the equivalent CPT resistance in a rigid thin layer located in a soft layer. This correction applies only to a thin rigid layer embedded within a thick soft layer. Robertson and Fear (1995) recommend a conservative correction of qcA/qcB = 2.

Figure 5 describes the relationship between Safety Factor (SF) and depth. Soil layers that have the potential to experience liquefaction based on analysis data are found in all soil layers at the sampling points of the soil with an earthquake magnitude (Mw) of 7.5. For example, at a depth of 2 meters for the location of CPT1 with Mw=7.5, the SF value of 0.17 is obtained. The low SF value can be caused by the low qc value. A low qc value reflects that the soil material is loose which is one of the factors causing liquefaction (Iswanto et al., 2017)

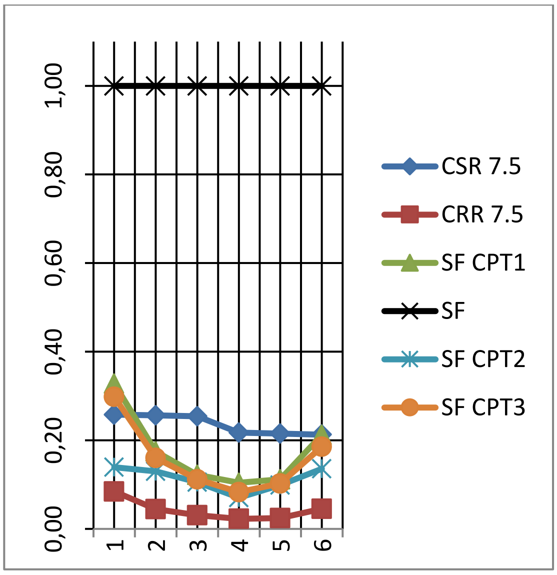

Figure 5. Graph of relationship between CRR, CSR and the factor of safety (SF) for CPT . data

IV. CONCLUSION

SF value is an indicator where a study area has liquefaction potential or does not have liquefaction potential. From the two data used, namely SPT and CPT, in general the location or area of the Yogyakarta International Airport has the potential to experience liquefaction. Therefore, appropriate mitigation and handling measures are needed to reduce the risk or impact of liquefaction.

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