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LIQUEFACTION MAPPING PROCEDURE DEVELOPMENT: DENSITY AND MEAN GRAIN SIZE FORMULATIONS

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ABSTRACT: The assessment of liquefaction potential is very important and is the main step in making a map of liquefaction hazard in a certain area. The assessment methods of liquefaction potential have been proposed by researchers since last eight decades. Each method is based on the purposes and completeness of the data obtained by the developer. In this study, these methods then were modified to propose the new method that is easier and technically cheaper. Furthermore, the method will be applied in making liquefaction hazard maps. The method as a result of this study is a new procedure that is more practical to be applied. This method is associated with soil parameters that are commonly and easy obtained in general soil investigation. The soil parameters used to assess the potential of liquefaction in this procedure are the density and mean size of soil particles. Soil density and particle mean size needed for analysis of liquefaction potential can be obtained from laboratory tests or the correlation results from the value of field tests, namely the standard penetration test or cone penetration test. This new procedure is expected to be more applicable and reliable in making liquefaction hazard maps.

Keywords: Liquefaction, Assessment method, Grain size, Density, Field tests

1. INTRODUCTION

An evaluation procedure of soil liquefaction potential using the simplified method [1] based on both a liquefaction resistance factor (FL) and a liquefaction potential factor, (PL) has been proposed in 1981 [2]. The procedure tried to introduce the factor FL and PL which are is the liquefaction potential at a calculated depth and at the surface respectively. The factor PL then used with the famous name as liquefaction potential index (LPI) by researchers in Korea, India and Bangladesh [3] - [5]. The LPI becomes interesting since it indicates the damage level at the surface at the site of interest related to the factors of safety of liquefaction potential at the deeper point underneath.

The first LPI is introduced for only 20m of depth with the formula of:

$$\text{LPI} = \int_0^{20} \text{F(z) W(z) dz} \quad (1)$$

where F(z) = 1 - FS with the minimum 0.0, W(z) = 10 - $^1/_2$ z with the minimum 0.0, z and dz are the depth the incremental depth respectively. The modified term of severity level of LPI has also been introduced by the other researcher [Luna 1995] as:

$$\text{LPI} = \sum_{i=1}^{n} \text{F}i\ \text{W}i\ \text{H}i \quad (2)$$

where n denotes the number of discretized layers, Hi denotes the thickness of the discretized layer, Wi weighting function and Fi is the liquefaction severity for layer i. The liquefaction severity assessed based on the liquefaction potential index (LPI) is shown in Table 1.

Table 1 The liquefaction severity - potential index

LPI	Iwasaki [2]	Luna-Forest [6]	Chung et al [7]
0	Very Low	Little to None	None
0-5	Low	Minor	Little to None
5-15	High	Moderate	Moderate
. 16	Very High	Major	Severe

In order to show the severity liquefaction from the liquefaction potential index (LPI), the typical illustrations based on field observations in the New Zealand are presented in Fig. 1 [8].

2. LIQUEFACTION ASSESSMENT

The liquefaction potential assessment is an important aspect for mapping the earthquake related hazard for certain area. Since Niigata earthquake in 1964 the simplified method [1] has been widely used. However this continuously improved method became complex since it involves many parameters that rarely used in geotechnical engineering and not as simple as it was named [9] [10]. The method also has been modified for assessing liquefaction potential based on Cone Penetration Test results [11].

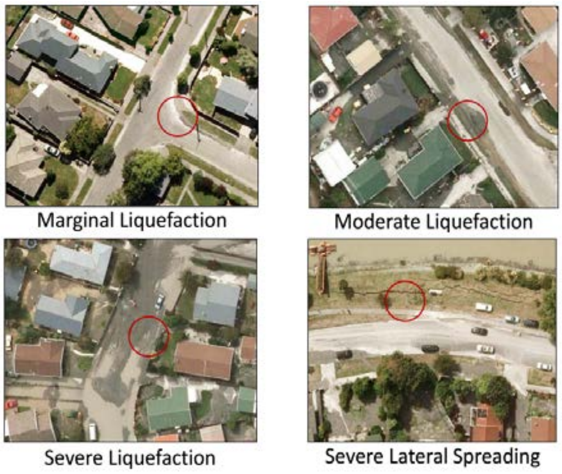

Fig. 1 Bird-eye observed liquefaction [8]

The liquefaction potential in the soil layer can be assessed based on the mean grain size (D_{50}) and its relative density (Dr) [12]. This method has been applied to real cases in the field and gave satisfactory results [13]. The liquefaction potential at certain point in the soil layer can be determined by plotting the value of the relative density and the average grain size (Fig. 2).

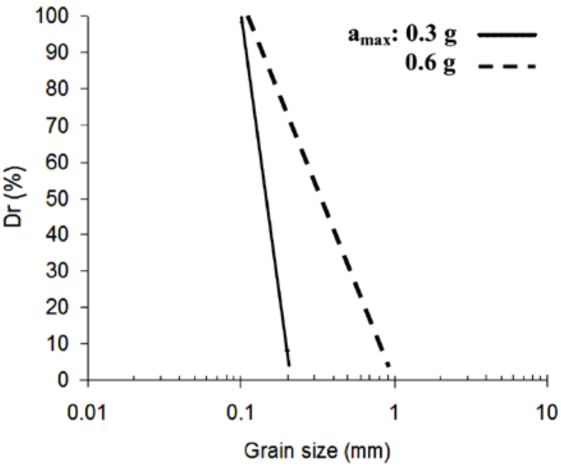

Fig. 2 Dr – D_{50} for liquefaction assessment

Based on the authors' experience so far, the most popular direct in field tests used in Indonesia for civil works are the Standard Penetration Test (SPT) and Cone Penetration Test (CPT). The Standard Penetration Test provides a soil parameter value in the form of N or Nspt. The Standard Penetration Test usually follows the drilling works that include soil samples that can involve sieve analysis in advanced. While the Cone Penetration Test often produces cone tip resistance parameters (qc) and friction ratio (Fr). Both of these filed tests have no relative density value involved in. In order to develop a general method for using Dr and D_{50} Liquefaction assessment, it will be written the simple procedure to obtain the relative density estimation based on the correlation of those filed tests. In addition it is also given an estimated mean of grain size based on those filed tests' results.

3. FIELD TEST CORRELATION

Obtaining of soil parameter generally require laboratory tests that take time and cost. Fortunately past engineers and researchers have done a number of precious works to obtain soil parameters from soil field test report. This approach is taken in this study to correlate soil parameters with based on the results of the most commonly used soil field investigation CPT and SPT. The correlation of CPT and SPT test results also has been proposed by many researcher as recently it is done [14]. However, each test has its own advantageous and restriction in engineering practices.

3.1 Dr from SPT

In a laboratory, relative density can be calculated as a relationship result of maximum density, γ_{max} minimum density γ_{min} and at present state of soil density γ_d, as follows:

$$Dr = \frac{\gamma_d - \gamma_{min}}{\gamma_{max} - \gamma_{min}} \times \frac{\gamma_{max}}{\gamma_d} \times 100\% \quad (3)$$

However, in the absence of relative density test of soil samples in laboratory test as it is usually, the value of Dr can be taken from the N correlation. In the past, the researchers then made relationship between the laboratory test values of Dr with the number of blows from SPT (N).

The first relative density and penetration resistant correlation was revealed in 1948 [15]. Later on a researcher [16] has conducted the sophisticated laboratory investigation on N and Dr relationship using a 1.2 m high heavy steel tank with the diameter of 1 m. The important feature of this test is it had two different soil grain sizes that are the coarse sand with D_{50} of 1.5mm and fine sand with D_{50} of 0.3mm as shown in Fig. 3.

General result of that study is given in graphs of relationship between penetration resistant, N and relative density, Dr for cohesionless sands as shown in Fig. 4. It seems that for air dry sand, the grain size of sand has no significant effect to the penetration resistant and relative density relationship. However, for saturated sands, the gain size of the sand contributed very important effect to the penetration resistant and relative density relationship. It indicates that the grain size of sand is a very important parameter to effect on the behavior of the soil. So, it must be considered in soil mechanic analysis. Then, for liquefaction potential analysis based on Standard Penetration Test results, it must include the sieve analysis of soil samples that taken from the same drilling hole to obtain the grain size of the soil.

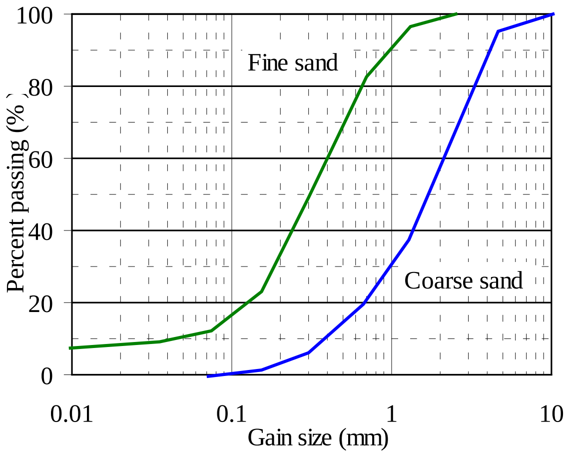

Fig. 3 Gradation of sand used in the Dr-N tests, reconstructed from [16]

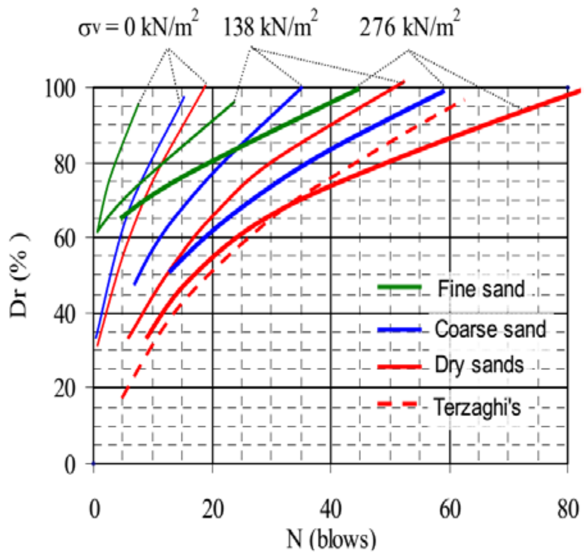

Fig. 4 Relative density and penetration resistance relationship for fine and coarse sands, reconstructed from [16]

3.2 Dr from CPT

Different from the Standard Penetration Test, the Cone Penetration Test give two soil parameter; cone tip resistance (qc) and skin resistance (qs). The ration of those two values is named a friction ratio (Fr). This ratio is very important value that can be used to estimate the type of soil.

The first relative density, Dr correlation from CPT cone resistance, qc was published in 1975 [17]. The Dr - qc correlation then was updated and published in 1978 [18]. Both correlations take into account the effect of vertical effective stress, σv' as they are shown in Fig. 5.

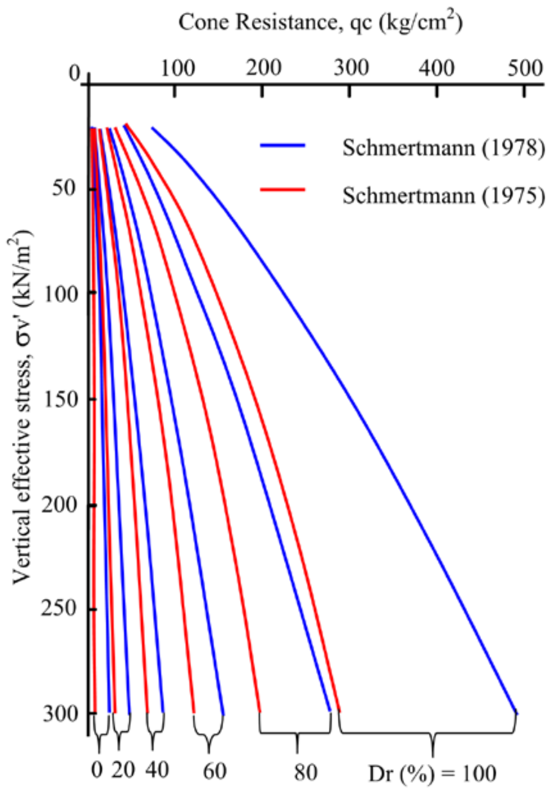

Fig. 5 Relative density – qc relationships for sandy soil, reconstructed from [18]

In Indonesia, the Cone Penetration Test is very famous in engineering practice, then Dr - qc relationship become very important for liquefaction potential analysis. It has been known that the qc is effected by sand density, in-situ effective stress and sand compressibility. Sand compressibility depends on grain size, grain shape and mineralogy. For the liquefaction potential analysis purpose, the relative density of the soil can be taken from the cone resistant correlation in the equation as follows [19]:

$$Dr = C_2^{(-1)} \ln Q/C_0 \quad (4)$$

Where C_0=15.7, C_2=2.41 and $Q=(qc/p_a)/(\sigma v'/p_a)^{-0.5}$. Here p_a is reference pressure taken as 100kPa, in the same unit as qc and σv'.

Using the above equation, the liquefaction assessment of sand deposit in Pasir Jambak due to Padang earthquake 2009 has been demonstrated [13]. This formulation is practically simple and gave good estimation of the liquefaction potential in sand deposits.

3.3 D50 from CPT

Although it is widely used for soil investigation works, unfortunately CPT is usually not followed by drilling for soil sampling. So the test of the grain size of the soil is not possible. But fortunately CPT also provides information on the skin resistance of qs, where in the terms of the comparison with the qc resulting in the value of Fr.

The CPT test result generally can be used to form soil profiling as well as soil type. The cone resistance, (qc) is generally higher in sands and lower in clays. Then, the friction ratio, Fr consequently is lower in sands and higher in clays. The Fr value can not to provide exact estimation of grain size but it may provide a guide to soil type which has particular characteristic and behavior.

Many researcher had observed soil grain size using CPT and confirmed that sandy soils tend have high cone resistance, qc where consequently gave low friction ratio Fr, and the reverse for soft clay soils [21] [22]. Fig. 6 presents the D50 and Rf correlation, the CPT data were taken from mechanical and electrical cones.

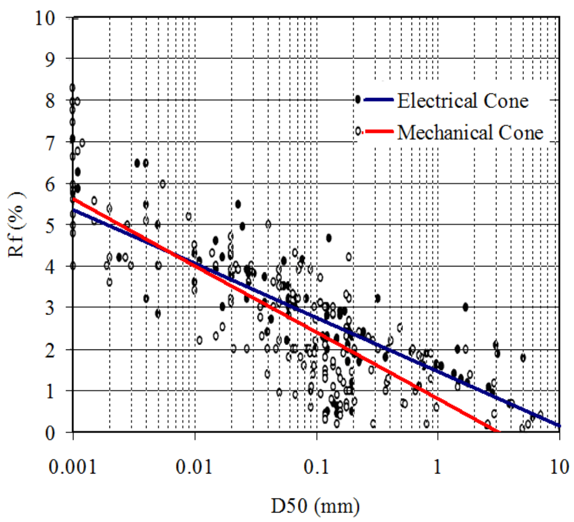

Fig. 6 Dr-Rf correlation [20]

The best fit equation for the Dr-Rf correlation of [21] is:

Rf=1.45-1.3 log(D50) for electrical cone (5)

and,

Rf=0.78-1.61 log(D50) for mechanical cone (6)

For estimating D50 from Rf, the Eq. (5) and Eq. (6) turn into Eq. (7) and Eq. (8) as follows:

D50= 3.056 $e^{-1.4302\ Rf}$ for electrical cone (7)

and respectively,

D50= 3.043 $e^{-1.7712\ Rf}$ for mechanical cone (8)

In addition, the past studies on soil grain size distribution had been conducted using SPT and CPT resistances [21] and [22]. The SPT data is presented in the terms of N60 values which is corresponding to the energy ratio of about 60%. They concluded that the qc-N ratio is strongly related to the soil grain size and expressed by the mean grain size (D50) as shown in Fig.7. It is very useful in practice if both CPT and SPT are performed in soil investigation.

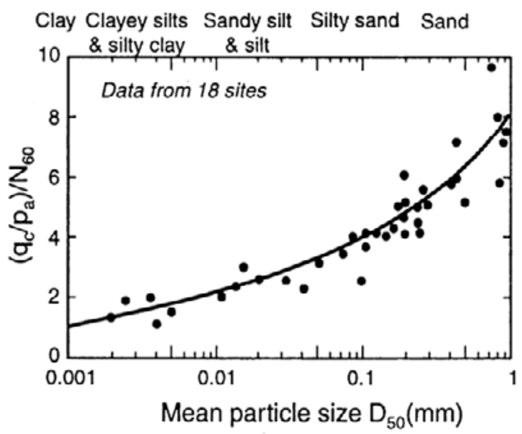

Fig. 7 CPT-SPT correlation with D50 [22]

4. ASSESSMENT FORMULATION

Based on the previous description, the procedure for liquefaction potential assessment of soil layers then can be developed based on the Dr-D50 parameters obtained from the correlation of the test results of soil investigation in the field using CPT and SPT. Each penetration test procedure can be made in the form of a flow chart as shown in Fig. 8 for CPT and Fig. 9 for SPT respectively. Specifically for SPT testing, soil samples from the soil layer must be taken to determine the grain size of the soil, or there must be a companion CPT test to determine the correlation of soil grains.

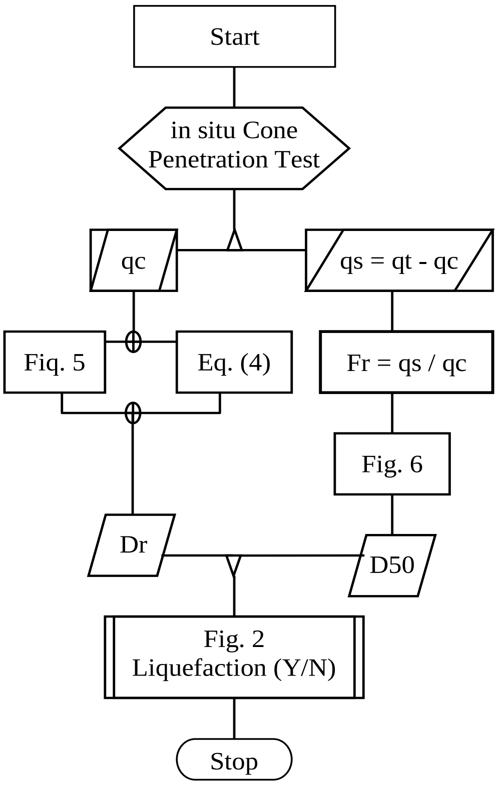

Fig. 8 Dr-D50 Procedure for CPT test results

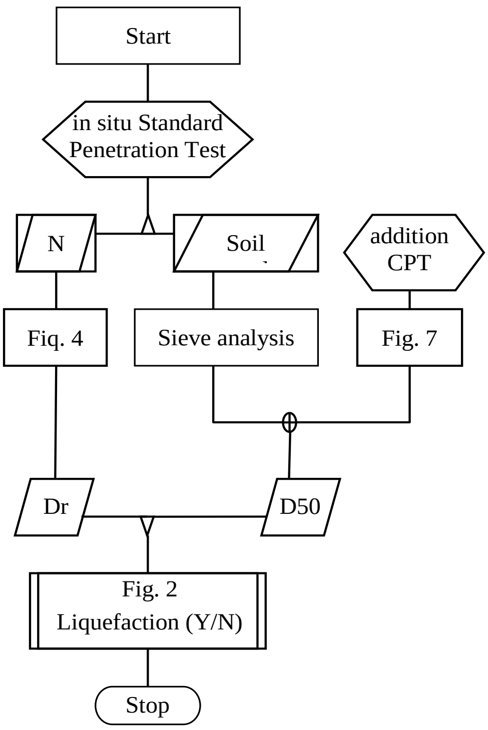

Fig. 9 Dr-D50 Procedure for SPT test results

Table 2 The liquefaction assessment results

Depth m	q_c kg/cm^2	Dr (%)	D50 mm
0.00	0	80	3.0781
0.20	2	80	0.0000
0.40	10	80	0.1753
0.60	17	80	0.2456
0.80	20	80	0.7346
1.00	45	100	0.3314
1.20	25	70	0.0557
1.40	5	30	0.1753
1.60	20	60	0.0418
1.80	14	50	0.3976
2.00	5	40	0.0100
2.20	4	30	0.0024
2.40	4	30	0.0024
2.60	4	30	0.0024
2.80	2	20	0.0000
3.00	2	20	0.0000
3.20	3	20	0.0002
3.40	3	20	0.0002
3.60	2	20	0.0000
3.80	2	20	0.0000
4.00	6	20	0.0260
4.20	20	20	0.7346
4.40	25	40	0.0557
4.60	25	50	0.0557
4.80	30	60	0.1088
5.00	30	60	0.1088
5.20	30	60	0.1088
5.40	55	80	0.2275
5.60	20	40	0.7346
5.80	30	50	1.1843
6.00	30	50	0.2827
6.20	55	70	0.2275
6.40	70	80	0.3976
6.60	45	60	0.6265
6.80	55	50	0.2275
7.00	55	50	0.2275
7.20	80	80	0.5135
7.40	90	90	0.6265
7.60	100	90	0.7346
7.80	105	100	0.3976
8.00	125	100	0.5516
8.20	130	100	0.3396
8.40	140	100	0.3976
8.60	150	100	1.1843
8.80	150	100	1.1843

5. ASSESSMENT RESULTS

The liquefaction assessment based on the procedure of a soil deposit in Padang is then conducted and described here. The soil parameters are evaluate based on the Dr and D50 correlation of the CPT test results in the field. The CPT tesst was conducted in the Air Tawar - Padang where experience the liquefaction during Padang earthquake in 2009 [23]. The results of analysis are then presented in the Table 2. The Dr - D50 values then are plotted in the diagram as shown in Fig.10. It can be seen that there is liquefaction potential at that site which confirmed the experience in 2009.

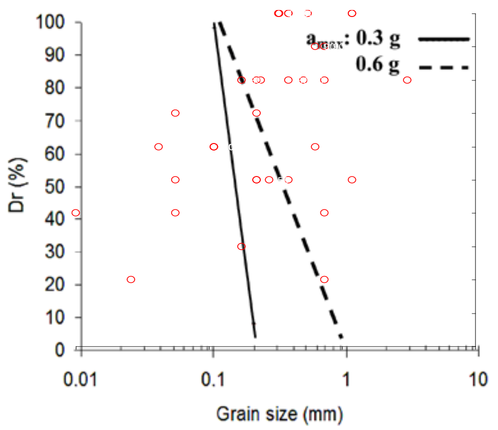

Fig. 10 Dr-D50 diagram for Air Tawar - Padang

6. CONCLUSIONS

In order to produce a liquefaction hazard map of a specific area, the assessment of liquefaction potential is very important and become the main step. Some liquefaction potential assessment methods have been proposed by researchers since the last century. Every method is developed based on the purposes and the completeness of available data. The modified method in here is based on soil relative density and mean grain size which are obtained from laboratory tests.

In this paper a modified new method that is easier and technically cheaper is proposed. The method is developed based on the penetration resistance data of the standard penetration test, SPT and/or cone penetration test, CPT. The method is a new procedure that is more practical to be applied for general soil investigation test results.

This method is associated with soil parameters that are obtained from the available correlation from soil investigation test results that turned into the relative density and mean grain size of the soil layer. This new procedure is expected to be more applicable and reliable in making liquefaction hazard maps. The application of the purposed procedure has been demonstrated in terms of liquefaction potential of Air Tawar-Padang City which give a good result.

7. ACKNOWLEDGMENTS

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