NEW METHOD FOR LIQUEFACTION ASSESSMENT BASED ON SOIL GRADATION AND RELATIVE DENSITY

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ABSTRACT

The liquefaction potential assessment in a soil deposit is an important aspect of earthquake engineering practice since its contribution to the safety of construction. The physical properties of sand soil that include grain size and density had known give effects to the liquefaction resistance. Those physical properties of sand soil associated to liquefaction resistance have been studied in laboratory. The new method as a results of that study is demonstrated here to assess the liquefaction potential. The example case is a real construction design of reclamation shore in order to develop a new port in Medan, Indonesia. Since the limitation of reclamation source material, it founds that the gradation of the ready use materials are suspect to liquefaction. Then, using the new methods, the solution to treat those material as part of the construction requirement. The treatment to be accomplished is compaction efforts to reach a certain relative density in order to avoid the possibility of liquefaction on site.

Keywords: Liquefaction, Earthquake, Grain size, Relative density, Reclamation

I. INTRODUCTION

Liquefaction and related construction failures are commonly associated with earthquakes. Liquefaction usually refers to the loss of strength in saturated cohesionless soils due to the build-up of pore water pressures during dynamic loading. The propagation of shear waves during seismic loading causes the soil to loose internal contract and increases the water pore pressure in soil mass. The seismic shaking usually occurs in relative short time that resulting the soil performs an undrained material. In the liquefaction condition, the effective stress in soil mass is rapidly decreased and thus the shear strength of the soil dropped off to essentially zero. In this condition, the individual soil particles are released from any confinement [1].

The liquefaction potential assessment in a soil deposit is an important aspect of geotechnical earthquake engineering practice since its correspondence to the construction stability and safety. A very famous method named "simplified method" was proposedin the past to assess the liquefaction potential of a natural soil deposit in certain site (Figure 1). That method was developed based on the liquefaction experience related to the field test data [2]. The use 'simplified method' has been presented to demonstrate the liquefaction potential assessment at the coast of Padang due to the M 7.6 West Sumatra earthquake in 2009 [3] [4] (Figure 2). However in practice the application of this method actually is not as simple as its name since it involves many parameter that rarely used in civil engineering such as earthquake magnitude and depth factor. To improve the procedure, many later researches based on a number of liquefaction histories around the world were conducted

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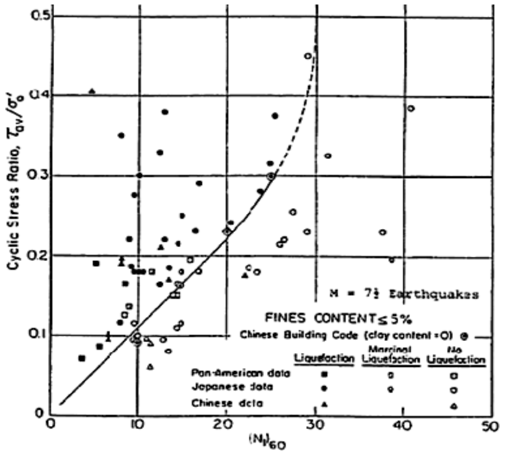
continuously [5]. The application guidance by means of penetration-based methods has been discussed [6].

It has been recognized that the newly deposited loose sands under the shallow ground water are susceptible to liquefaction [7]. It has also been summarized a number factor of soil that effect the liquefaction potential such as liquefaction histories, geological processes, soil typesand sizes, relative density and effective stress. Besides the earthquake properties such as applied peak acceleration, a_{max} and duration of the motion, the soil properties that are needed to be evaluated related to the liquefaction potential are [8] [9]:

- Relative density, D_r
- Initial stress of the soil, σ_i
- Mean grain size of the soil, D_{50}
- Over consolidation ratio, OCR
- Initial pore pressure, u_i

In spite of sands were historically considered to be the only type of soil that susceptible to liquefaction, but later observation showed that clayey soil also experienceto liquefaction. The clayey soils may have a tendency to liquefy under a vibration load if they satisfy at least the first three of the Chinese criteria [10] that are:

- Fraction finer than 0.005 mm less than 15%
- Liquid Limit, LL less than 35%
- Natural water content more than 0.9 LL
- Liquidity Index less than 0.75



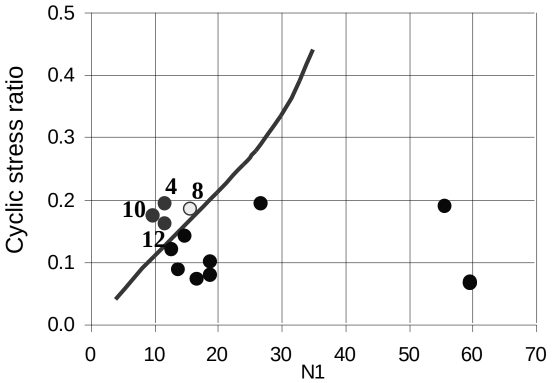


Fig. 1 The ‘Simplified Method’ chart [2]. Fig. 2 Liquefaction Using ‘Simplified Method’ [3].

The distribution of liquefied soil particle in the past indicates that the liquefaction in soil has relation to their size distribution. Based on the Kocaeli earthquake 1999 in Turkey, the results of sieve analysis tests of soil from several location has been plotted in Figure 3 [11]. Then due to Padang earthquake 2009 [3] it also has been also reported the particle distribution of liquefied soil samples as shown in the same figure (shadowed). The distribution of liquefied soils in Padang compose fine sand more than 60% with the fine content less than 20%.

Based on the liquefaction histories around the world, 78% of the mean grain size of liquefied soils happened for size of 0.1125 to 0.3375 [12]. For Padangliquefaction, the mean grain size D_{50} is about 0.15 to 0.35mm. This grain size value then become a parameter to be consider on this liquefaction study.

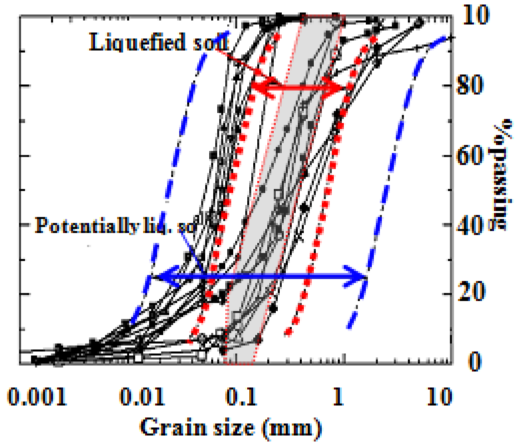


Fig. 3Grain Size Limit for Liquefaction [11]

II. NEW ASSESSMENT METHOD

To have a good estimation of the liquefaction problem in practice, a simple liquefaction potential assessment becomes essential. In this paper, a straightforward liquefaction potential assessment based on laboratory experiments and its application are presented. A series of laboratory testing has been done by placing soil samples in the round container. The considered factors in the laboratory experiments to develop the new method are:

- Relative density, D_r
- Mean grain size of the soil, D_{50}
- Applied peak acceleration, a_{max}
- Duration of the motion, t

these tests the relative density D_r and the mean grain size D_{50} became variables. The reach the state of liquefaction, the soil samples are placed on the shaking table and vibrated for 0.3g and 0.6g accelerations. During the testing the acceleration and the settlement of the indicator bar that are place on the samples are recorded.

The new criterion used in laboratory is the rate of settlement during shaking. The settlement rateof about 0.1 cm/sec is taken as the separation criterion to distinguish between liquefied and non-liquefied soils in laboratory. The rate settlement more than 0.1 cm/sec indicated that liquefaction has happened in this saturated soil samples. The general results of the testsare the presented as a new chart as shown in Figure 4. The linear boundary line are made up for each acceleration 0.3g and 0.6g.This chart then is used to assess the liquefaction potential in later study case.

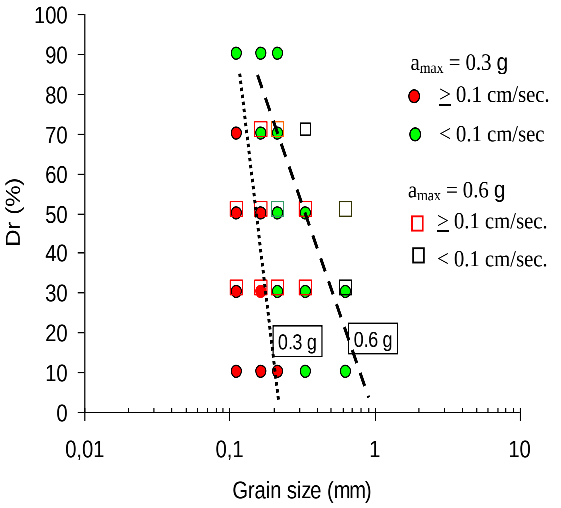


Fig.4 Liquefaction Chart Based on D_r– D_{50}.

An important variable of the samples in this experiment is the relative density D_r of the soil that essentially used in practice. Relative density of the sample is defined as the ratio of densities of sand in dry condition using the following equation:

$$D_r = \left(\frac{\frac{1}{\gamma_{d,min}} - \frac{1}{\gamma_d}}{\frac{1}{\gamma_{d,min}} - \frac{1}{\gamma_{d,max}}} \right)$$

Where γ_d, $\gamma_{d,\,min}$ and $\gamma_{d,\,max}$ respectively are current, minimum and maximum dry unit weight of soil. The relative density is expected to describe the relationship between the initial densities with liquefaction potential using Figure 4.In general practice, a soil mass can be grouped according to its relative density value is shown in the Table 1:

Table 1. Designation of Soil Based on Relative Density

Relative density, Dr:	Description
10%	very loose
30%	loose
50%	medium dense
70%	dense
90%	very dense

III.LIQUEFACTION ASSESSMENT

Medan Marine Port in North Sumatra Province of Indonesia, is under development to build the capacity for container transportation services in around Sumatra region. This development needs are clamation work to construct the container yardas well as ship dock. The material resources for reclamation work is required from the local area.

3.1 Reclamation Material Requirements

It was found that the available material has a very limited amount. The material also must meet several criteria that are included the volumetric unit and the gradation range as shown in Figure 5. In fact the available materials are fine sands that are have grain sizes about in the lowest requirement. Those granular materials are included in the category of fine sand. Since the reclaimed sands will be always below sea level then the saturated conditions will always be experienced on them. Then liquefaction potential assessment of the reclamation work become essential.

In order to complete that aim, the sieve analysis of reclamation sands has been conducted. This analysis is purpose to investigate soil distribution as presented in Figure 5. To see whether the material is susceptible to liquefaction, in the same figure are plotted boundary area based on events Earthquake liquefaction ground Sumatra 2009 [3] and also boundary made up from Turkey liquefaction [11]. It is clearly seen that reclamation sands from available sources are susceptible to liquefaction since it is in exactly those boundaries. The D_{50} of those reclamation sands are between 0.12 to 0.30 mm in diameter.

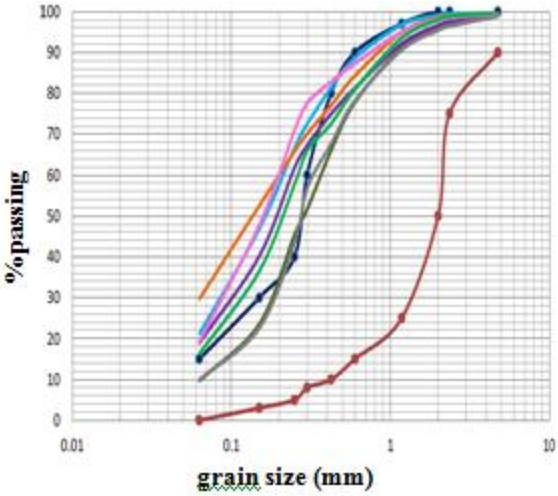


Fig.5 Particle Distribution of Reclamation Sand

3.2 Indonesian Seismic Map

To perform the analysis of liquefaction potential, the maximum required acceleration caused by the future earthquake that may occurat the site of the port must be estimated. The maximum acceleration values are taken from the Indonesian seismic map for the area around the planed port that is a $_{max}$=0.3g(Figure 6).

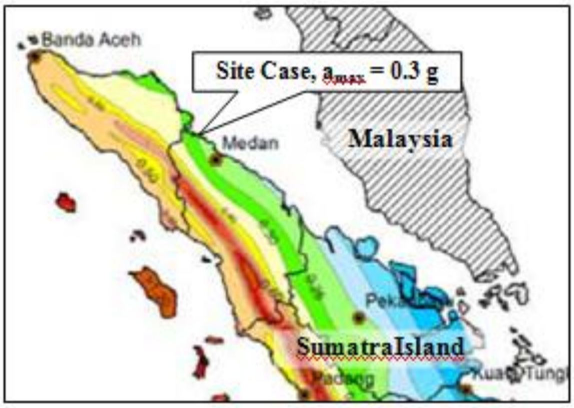


Fig. 6 Seismic Map for Medan Area.

3.3 Relative Density Requirement

The test results ofunit weight of the original source reclamation material and the values of the maximum and minimum unit weight from compaction tests of the same material are shown in Table 2.

Table 2. Relative Density of Sands

Parameter	value (kN/m^3)	D_r (%)
$\square_{d,natural}$	12.0	30
$\square_{d,min}$	10.7	0
$\square_{d,max}$	16.8	100

Both value Relative density, D_r and Mean grain size, D_{50} as well as maximum acceleration a_{max} are the plotted in the 'Liquefaction Chart' as shown in Figure 7. It shows that point initial points pair D_r and $D_{0.5}$ of original material still under the line 0.3g which indicated that the material prone to liquefaction in case of earthquake.
In Figure 7 then also plotted the required point in order to avoid liquefaction potential on chart. The required points have minimum relative density of 60%. In the real practice, the additional requirement make use of compaction effort must be done to have Relative density of 60% in the field.

IV. CONCLUSIONS

In this paper, a new method for liquefaction potential assessment of a soil deposit based on the relative density and the mean particle size has been presented. It shows that the method is practically essential to determine the liquefaction potential using physical properties of soil. Both relative density and mean particle size give unique relationship for the liquefaction resistance of soil against possible earthquake.
Based on the analysis of the study case of reclamation work, the specification of relative density is required to prevent liquefaction in the future. The additional requirement should be included in the process of reclamation work in order to achieve relative density as prescribed.

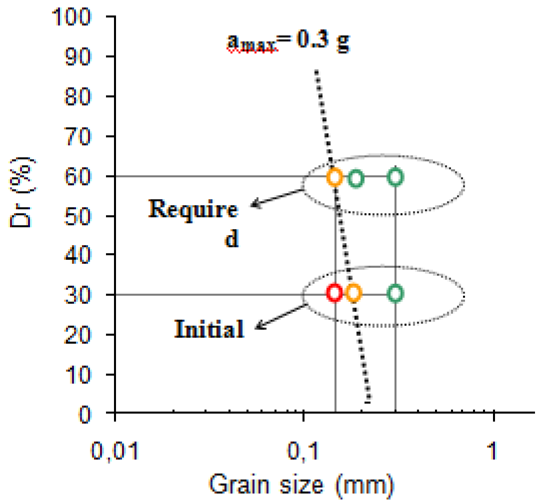


Fig. 7 Liquefaction Assessment for Medanport.

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