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Short Review on Liquefaction Susceptibility

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ABSTRACT
This paper reviews the previous related research on liquefaction susceptibility to provide critical literature recommendations on liquefaction susceptibility assessment. The developments of liquecation susceptibility evaluation in last 40 decades are included. Modified Chinese Criteria is the best known indicator which globally recognized. Due to the existing literature gaps of liquefaction susceptibility of fine soils and the deviation of actual liquefaction cases in past earthquake, reexamination and modification is essential to ensure the usability of Modified Chinese Criteria. The controversy and confusion of the fine grained soils behavior after being disturbed by cyclic load is complex. The use of clay fraction as a controlling parameter is the main contribution of inaccurate in the evaluation. Plasticity index is the most suitable controlling parameter to replace the clay fraction in Modified Chinese Criteria. Plasticity index can confidently distinguish the fine grained soils behavior for the ease of assessment. Fine grained soil could be either "clay-like" which expected to be cyclic softening or "sand-like" that susceptible to liquefaction phenomena. With this the cyclic behavior of fine grained soils are well understood and this lead to a more precise and confident output. Thus, Chinese Criteria should replace fine percentage with plasticity index in the assessment.

Keywords **– Liquefaction susceptibility, Chinese Criteria, fine grained soil, clay fraction, plasticity index**

I. INTRODUCTION

Liquefaction had been studied extensively by researchers all around the world right after two main significant earthquakes in 1964. Since that lots of terminologies, conceptual understanding, procedures and analyze methods have been proposed as a modern engineering branch.

The evaluation of soil liquefaction phenomena and related ground failures associated with earthquake are one of the important aspects in geotechnical engineering practice. It will not only cause the failure on superstructure, but also the substructure instability and both lead to catastrophic impact and severe casualties.

Development of liquefaction evaluation started when Seed and Idriss (1971) [1] published a methodology based on empirical work termed as "simplified procedure". It is a globally recognized standard which has been modified and improved through Seed (1979) [2], Seed and Idriss (1982) [3], Seed et al. (1985) [4], National Research Council (1985) [5], Youd and Idriss (1997) [6], Youd et al. (2001) [7]; Idriss and Boulanger (2006) [8].

Although researchers had made efforts on identification of the susceptible soil type on liquefaction based on both empirical and theoretical conduct, there is still no qualitative and quantitative parameter in geotechnical field could be used as an evaluation tool on liquefaction susceptibility.

It is worth mentioning that the effect of fines grains soils on liquefaction potential, particularly the susceptibility are inconsistent and confusing. The focus of this paper was to review the previous related research on liquefaction susceptibility and hence provides critical literature recommendations on liquefaction susceptibility assessment procedure.

II. LIQUEFACTION SUSCEPTIBILITY

Liquefaction is a transformation of granular material from solid state into liquefied state with a significant increasing of pore water pressure until effective stress reach to zero. The most susceptible soil type is loose to moderately dense granular soils while cohesive soil is non-liquefiable. Fine grained soils (silts, clayey and silty soils) were classified as non-liquefiable soil under controversy circumstances.

Chinese Criteria is the best known liquefaction susceptibility identification founded by Wang (1979) [9] following the 1975 Haichang Earthquake and 1976 Tangshan Earthquake. However, Wang did not include the observation data of low plasticity soil (ML). Most of the tested soils had clay contents less than 15%. Hence, the insight is discriminating and less significant.

Based on reevaluation of Wang's work, Seed and Idriss (1982) [3] stated that soil which susceptible to liquefaction behavior must fulfill three basic criteria. It had become the state of practice in evaluation of liquefaction susceptibility. The criteria as shown in Figure 1 including (1) contains less than 15% clay fraction (finer than 0.005 mm); (2) liquid limit (LL) less than 35%; (3) water content (WC) higher than 90% LL

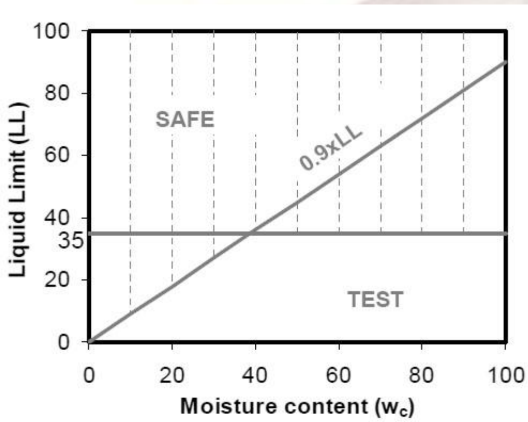

Figure 1 Chinese Criteria after Wang (Seed and Idriss (1982)

However, this procedure is too conservative and less reliable. The main reason is that the practice on determination of soil index such as liquid limit is different from ASTM International's procedure. Extensive attempts had been made by other researchers to ascertain an accurate susceptibility assessment.

Finn (1991) [10] suggested the following adjustments for in accordance of US standard: (1) decrease fines content by 5%; (2) increase LL by 1% and (3) increase water content by 2.

Andrews and Martin (2000) [11] refined empirical data and produced a new assessment index as shown in Table 1. It is a transformation of Chinese Criteria in accordance to US standard. The major differences of Modified Chinese Criteria with original Chinese Criteria are that 0.0002 mm was used as limit between clay and silt particles and liquid limit should be obtained using Casagrande type equipment.

Table 1: Modified Chinese Criteria (Andrews and Martin, 2000)

Clay Content	**Liquid Limit < 32%**	**Liquid Limit ≥ 32%**
< 10%	Susceptible	Further studies required (considering plastic non clay sized grain - mica)
>10%	Further studies required (considering non plastic clay sized grain – mine and quarry tailings)	Not susceptible

Chinese Criteria method was globally used as indicator until 1990s. Researchers start to question and debate on the use of clay fraction as means to indicate the liquefiable of soil when some field observation of past earthquake especially 1989 Loma Prieta Earthquake, 1994 Northridge Earthquake, 1999 Kocaeli Earthquake and 1999 Chi-Chi Earthquake show that silty and clayey sands exhibits liquefaction behavior.

Past earthquake observations show that percentage of "clay-size" particle in determination is misled; the "clay mineral" percentage is more relevant. Hence, with a combination with LL, plasticity index (PI) is a better indicator than by using clay content. Researchers using different approach had reach similarity in distinguish behavior of silts on liquefaction susceptibility will be discuss briefly in the followings paragraphs.

Guo and Prakash (2000) [12] carried out test on silt-clay mixtures and found a threshold value of PI at around 4-5 which silt-clay mixtures have highest susceptibility of liquefaction. At lower plasticity range, PI is inversely proportional to liquefaction resistant while PI is directly proportional to liquefaction resistant at higher plasticity range; which illustrated in Figure 2 Therefore, more details and comprehensive study is warranted to prove that the lowest level of liquefaction resistance is at PI = 4.They recommend that more research to understand seismic behavior of fined grained soils is essential.

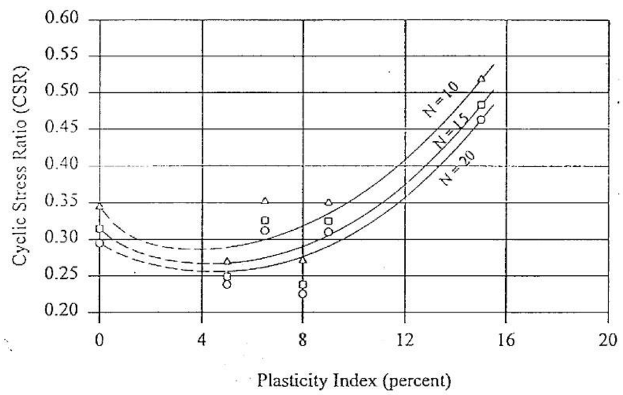

Figure 2 Normalised cyclic ratio vs plasticity index on indisturbed samples (Guo and Prakash, 2000)

Seed et al. (2001) [13] indicate that PI of 10 is the hallmark of soil had the tendency to liquefy while soils with 10 < PI < 12 fall into an "uncertain range". Seed et al. (2003) recommended an assessment chart to incorporate Modified Chinese Criteria with influences of fines contents in the assessment as shown in Figure 3. In other words, it acts as a summary of current findings. The soils laid in Zone A are prone to liquefaction while soils within Zone B is potentially susceptible to liquefaction. The soils which not out of the Zone A and Zone B are considered as non-liquefiable.

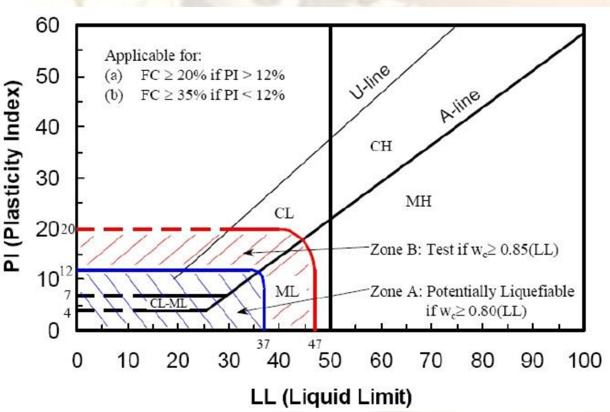

Figure 3 Recommendations Assessment of Liquefiable Soil Types (Seed et al., 2003)

Bray and Sancio (2006) [14] agree that PI is a good index of liquefaction susceptibility together with WC / LL criterion. Based on field observation and cyclic tests result, they conclude that liquefaction start to occur on loose dense soils of PI < 12 (low plasticity) at WC / LL > 0.85 while soils between PI of 12 to 18 were less liquefaction potential. PI > 18 is a hallmark where soils are not susceptible to liquefaction. However, this proposed criterion should be use with caution and based on own engineering judgment. Although PI is a good screening tool for liquefaction susceptibility, factors such as soil mineralogy, void ratio and etc. should be implicitly taken into consideration.

Boulanger and Idriss (2006) [15] give a less conservative statement; sand-like fine grained soil with PI < 7 is liquefiable and any PI beyond that value will exhibit clay-like fine grained soils behavior. Figure 4 illustrate the transition behavior of fine grained soils.

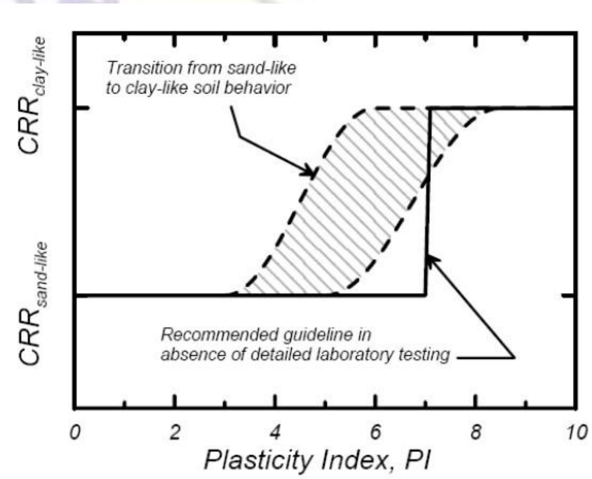

Figure 4 Transition of sand-like to clay-like behavior of fine grained soils (Boulanger and Idriss, 2006)

Gratchev et al. (2006) [16] examined the validity of using PI as screening parameter based on literature. Based on the results of undrained cyclic stress-controlled ring-shear tests, liquefaction potential of soil decreasing when PI value is increasing and liquefaction will not happen to soil with PI > 15.

Prakash and Puri (2010) [17] had extended their previous work. They stated that the use of fine percentages for liquefaction susceptibility determination should be discontinued. Plasticity index gives more quality review and more research on this is needed to fill the literature gaps.

III. FINES INFLUENCE ON LIQUEFACTION

Basically, the evaluation of liquefaction of cohesionless soils is well defined with remarkable developments. The analysis of clean sand with few fines had obtained a general agreement globally either in form of laboratory testing or in-situ investigation. On the other hands, soils containing fines fraction (silty or clayey soils) are not well defined. This is because the physical process of how the fines undergoes cyclic loading is complex and a lots of literature gaps on that.

Comprehensive site investigation on ground failure in Adapazali caused by 1999 Kocaeli Earthquake was studied by Sancio et al. (2004) [18]. Results of tests on undisturbed soil samples from the sites show that the liquefaction phenomenon of Adapazali soil contains a significant amount of clay-size particles which is supposed to be non-liquefiable. Besides, the soil properties of liquefaction cases in 1999 Chi-Chi Earthquake are deviated from the expected on Modified Chinese Criteria.

Youd et al. (2001) [19] in NCEER Workshop highlighted this confusion and agreed that Modified Chinese Criteria is inadequate to define vulnerability of fine grained soil toward liquefaction. Hence, more consensus research is a must for this critical state to improve the usability and ensure the accurate results being evaluated.

Thus, susceptibility of silts is unclear because it falls between high susceptibility soil (sand) and non-susceptible (clay). Silts could be grouped as liquefiable very fine sand as its particle size; or act as plastic fines to infill sand grains and then reduced the void ratio. Hence Boulanger and Idriss (2006) [15] recommended that fine grained soil should be divided into two sub categories for reliable results. The two sub categories are “sand-like” and “clay-like” fine grained soils.

IV. CONCLUSION AND RECOMMENDATION

This paper had outlined the developments of liquefaction susceptibility in last 40 decades. Due to the disagreements in soil index test procedure, original Chinese Criteria had been changed to the Modified Chinese Criteria to fits globally use standard, in accordance of ASTM International.

Although Modified Chinese Criteria is well known, the usability of the Chinese Criteria had been in doubt when it is deviated from the actual field observation of past earthquake. The controversy and confusion of the fines grained soils behavior after disturbed by cyclic load is complex. Hence, review on fine grained soils which vulnerable to liquefaction must be study and more related research on this was warranted.

Researchers found similarity and questioning on the use of clay fraction as screening criteria in Chinese Criteria. More recent, researchers tentatively consider the plasticity index as controlling variable in their study on liquefaction susceptibility. Given the current literature reviews, it is believed that clay fraction could lead to inaccurate results.

Plasticity index can confidently distinguish the fine grained soils behavior either “clay-like” which expected to be cyclic softening or “sand-like” that liquefiable. With this information, the cyclic behavior of fine grained soils are well understood and this lead to a more precise and confident output. Thus, Chinese Criteria should replace fine percentage with plasticity index in the criterion.

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