

CHAPTER 2

LITERATURE REVIEW

Liquefaction is a natural phenomenon, when partly saturated or fully saturated soil losses some or all of its strength and stiffness. This is due to the increasing of pore water pressure inside the soil and causing reduction of effective strength and stiffness of the soil. Several conditions like undrained soil and increasing of monotonic or cyclic load causing this liquefaction phenomenon to occur. Evaluation of liquefaction potential has become one of the major topics of study for decades. Basically, there are two methods to evaluate liquefaction potential subjected to earthquake.

The first method is to use field performance observation data of soil from previous earthquakes, and combining it with the soil characteristics on site, to analyze the probable similarities or differences between these sites and a new proposed site regarding the liquefaction potential behavior. Field performance method is using field soil performance data and observed soil data, then based on empirical correlation equation to predict the liquefaction potential of soil.

Second method is by evaluating cyclic stress or strain condition of soil that will be developed based on earthquake data that is applied, compared it with strains and stresses data of observed post-liquefaction soil, to cause liquefaction to the soil sample in laboratory that simulate field conditions. This method basically uses laboratory testing procedures to analyze the strain or stress conditions of soil.

In the development of liquefaction potential analysis method, cyclic stress ratio (CSR) became one of the convenient parameters to express the liquefaction of the soil. Cyclic stress ratio (CSR) can be expressed by the ratio between cyclic shear stress that developed on horizontal direction of soil layer after cyclic loading applied to the initial vertical effective stress prior to cyclic loading.

Advantages by using this method is depth of soil layers, depth of water table, intensity of earthquake motion or other cyclic loading phenomena are considered

and taken into account. In order to calculate the cyclic stress ratio, Seed and Idris (1971) develop the following equation:

$$CSR = \frac{\tau_{ave}}{\sigma_{v0}'} = 0.65 \left(\frac{a_{max}}{g} \right) \left(\frac{\sigma_{v0}}{\sigma_{v0}'} \right) r_d$$

where a_{max} = maximum seismic acceleration at the ground surface; g = gravity acceleration of earth; σ_{v0} = total vertical stress; σ_{v0}' = effective vertical stress; r_d = stress reduction coefficient. Value of cyclic stress ratio parameter calculated before, have been correlated, with parameters from actual sites which have and not have liquefied due to the earthquake loading in the past. Lots of parameters can be used for correlation such as relative density of soil obtains from penetration test, blow counts of penetration test, or electrical characteristic of the soil.

In order to analyze liquefaction resistance of new site, with given seismic acceleration, CSR equation can be used to calculate stress ratio of the soil in certain depth due to the given seismic load, then compare with the stress ratio required to cause liquefaction of the soil. To determine the stress ratio where liquefaction occurred can be done in two methods, either by using field correlations or laboratory test on soil sample. In order to use the correlation with either one of the field parameters, field parameters only can be evaluated either by using test performed on site or evaluating undisturbed soil sample by using laboratory testing procedure.

For undisturbed soil sample method, there is a downside. The downside is, until now, to obtain a high quality of undisturbed soil sample, it is very hard and cost lots of money. Due to this downside, simplified methods of evaluating liquefaction potential are usually use and prefer by geotechnical engineers. Many engineers preferred to use field performance data correlation approach. The reason is this method does not give the downside of the other method by using undisturbed soil sample.

There are lots of variety field performance soil data that can be used as correlation with soil liquefaction characteristic, such as standard penetration test,

cone penetration test, shear wave velocity, electrical properties, or another possible new parameter. But only a little data available to develop good correlation between field performance soil data and soil characteristic. From all of the field performance soil data mention before, only standard penetration test has adequate data to be used to develop good correlation with the soil liquefaction characteristic. This is caused by the popularity and widely used of SPT in the past, therefore, field performance data of SPT is widely available.

In order to better represent the field performance of soil, data from SPT needs to be corrected. In the past, many studies and researches have shown potential of variability of used testing condition. The variability of SPT can be minimized or even eliminated by adopting standard test conditions. Appropriate correction of measured standard penetration test result based on proposed correlation equation also needed in order to used correlation chart herein.

Geotechnical engineers began to take serious interest in liquefaction caused by earthquake loading after Alaksa and Niigata earthquake in 1964. The first method by using SPT correlation is introduced by Professor Seed and his co-worker (Seed and Idris 1971; Seed et al. 1983, 1985) by using blow counts from the Standard Penetration Test (SPT) to evaluate liquefaction potential and become one of the widely used method across North America and the world.

CSR value of involved soil calculated and plotted as the function of normalized penetration resistance (N_1) of the involved soil (Fig 2.1.). N_1 is measured penetration resistance of soil that already corrected with following equation:

$$N_1 = C_N \cdot N$$

Where C_N = function of effective overburden pressure at the depth of analyze soil deposit and N = uncorrected penetration resistance of soil. C_N value can be determine by using chart shown in Fig 2.2. The lower boundary when liquefaction occurred is plotted based on evidence liquefied and not liquefied sites data.

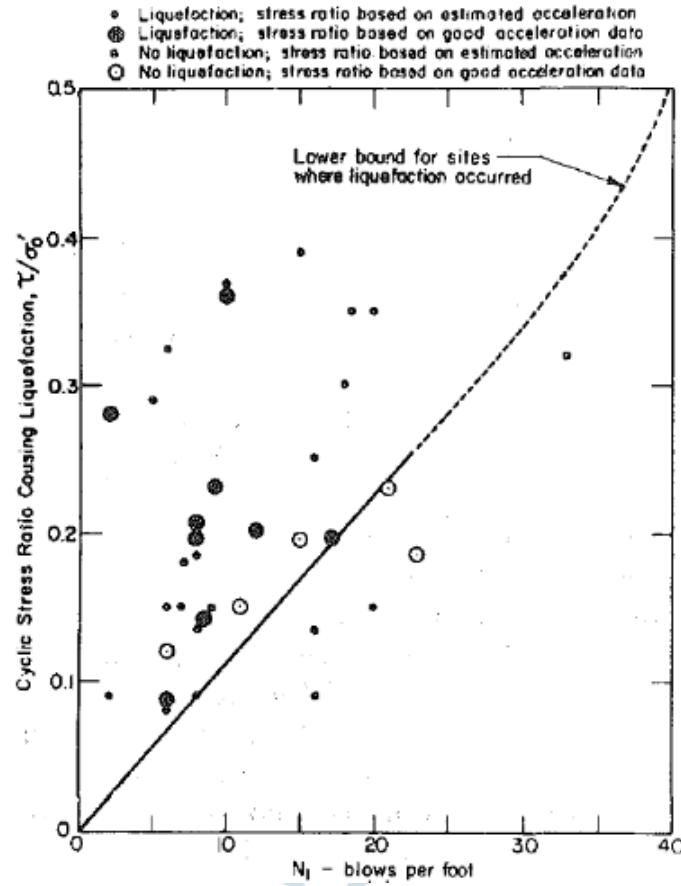


Figure 2.1. Correlation between CSR and N_1

Later on, in 1996 and 1998 NCEER/NSF Workshops on Evaluation of Liquefaction Resistance of Soils, participants in the workshop recommended to apply several change and adjustment of previous CSR – N_1 correlation chart (Fig 2.1.). One of the changes is to curve the line of the trajectory for clean-sand base curve at low $N_{1(60)}$ to intercept at CSR value about 0.05. This adjustment suggested to obtain more consistent result with CRR curve developed to make used with CPT and shear-wave velocity testing result. CRR is cyclic resistance ratio where the value can be calculate by following equation:

$$CRR_{7.5} = \frac{1}{34 - (N_{1(60)})} + \frac{N_{1(60)}}{135} + \frac{50}{(10 - N_{1(60)} + 45)^2} - \frac{1}{200}$$

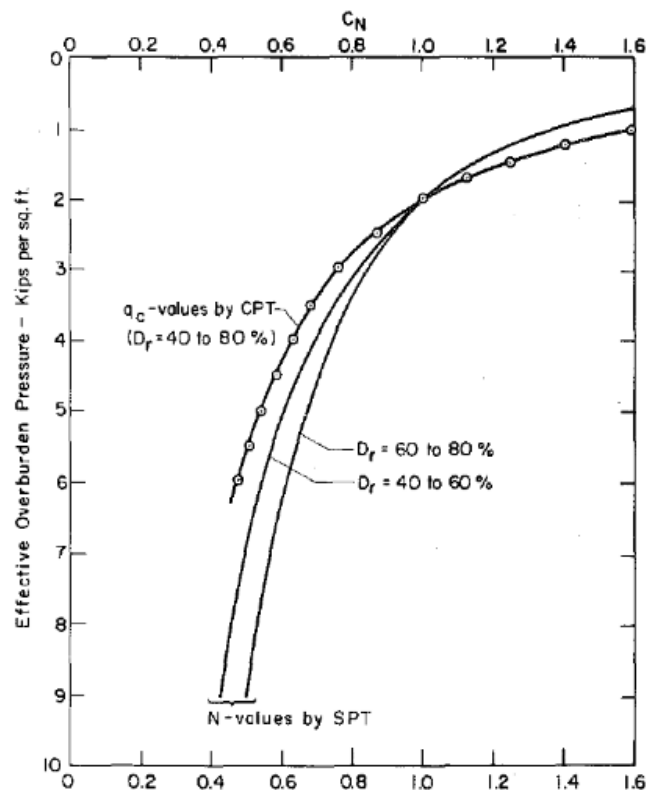


Figure 2.2. C_N correction according to effective overburden pressure

Where only applied for earthquakes with magnitude approximately 7.5 SR and for sand with $N_{1(60)} < 30$. For sand with $N_{1(60)} \geq 30$, sand considered too dense to liquefied and classified as non-liquifiedable soil. And for earthquake with magnitude other than 7.5 SR, adjustment is needed in order to use the equation above. Modified curve can be seen at Fig. 2.3.

In the modified chart in Fig 2.3., workshop participant also recommended a correction of curve for evaluating liquefaction when soil deposit with fines content observed. Fines content of 15% and 35% correlation introduced there.

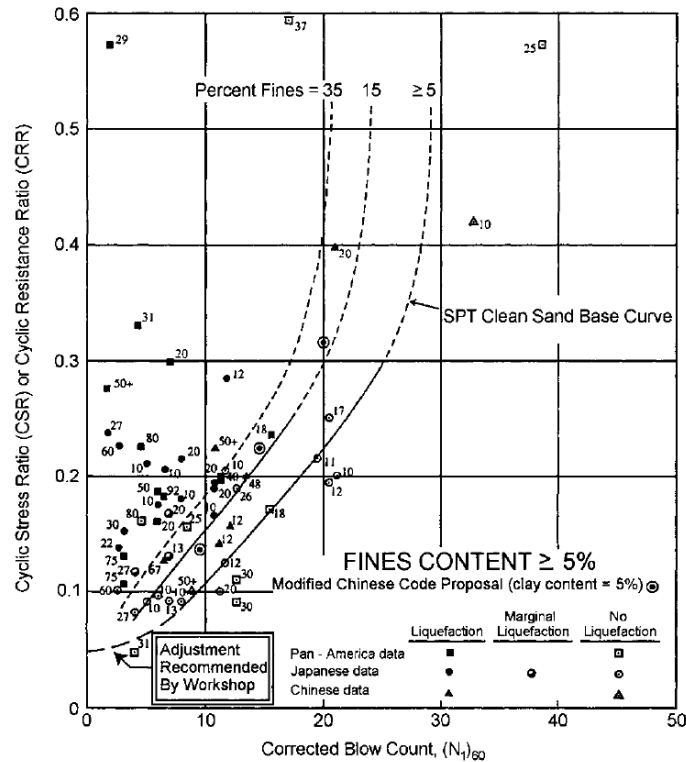


Figure 2.3. Modified CSR- N_1 correlation

Then, the other in-site test, in this case CPT (Cone Penetration Test), is used to develop new method of evaluating liquefaction potential (Robertson and Campanella 1985; Seed and de alba 1986; Olsen 1988; Shibata and Teparaksa 1988; Mitchell and Tseng 1990; Stark and Olsoa 1995; Suzuki et al. 1995; Olsen 1997; Robertson and Wride 1998). This method is preferred because of CPT can provide more consistence data rather than SPT. Other than that, CPT also more repeatable and can provide almost continuous soil profile data. CPT based liquefaction potential liquefaction must be verified with several other bore hole to further confirming soil type and verify the liquefaction-resistance (Youd et al. 2001).

Due to continuous data profile that CPT can provide, result in more detailed definition of soil layer. Although CPT has such kind of advantages compared with SPT, soil profile still must be verified with a few well-placed boreholes as needed in SPT, to further confirm soil type and profile to result in better interpretation of soil liquefaction resistance.

In Fig 2.4., chart of correlation between CRR value at earthquake magnitude = 7.5 SR and corrected cone penetration test resistance q_{c1N} shown. The chart was developed by Robertson and Wride (1998) by compiled several case history of CPT data done by several investigations before. Curve is for clean sand with fines content $< 5\%$. For other soil characteristic, adjustment of curve needed to be done to better interpret liquefaction resistance.

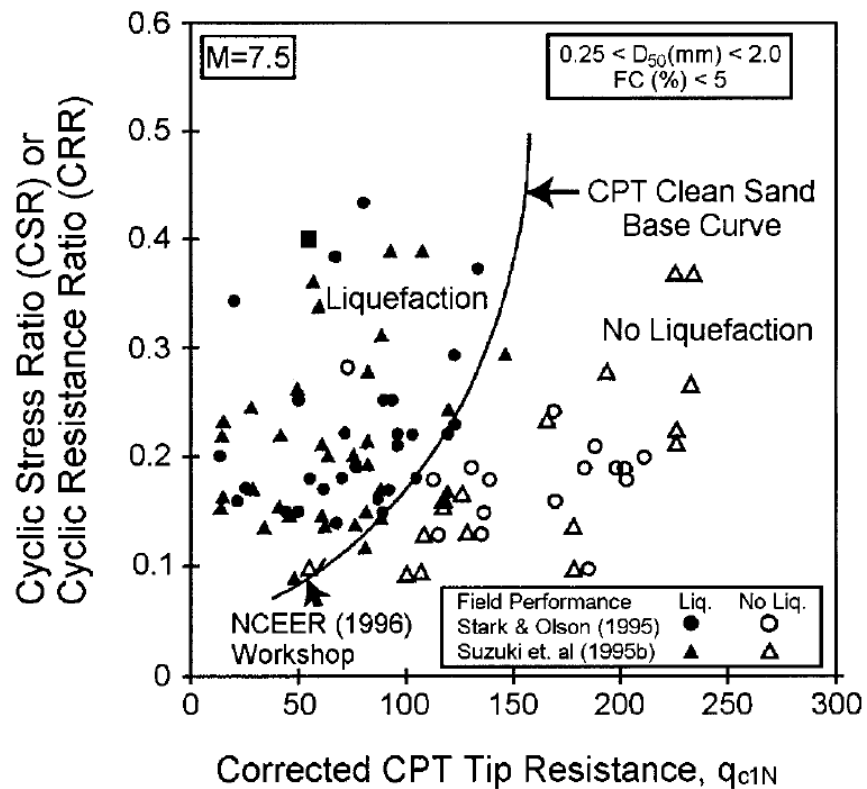


Figure 2.4. Correlation between CSR or CRR and q_{c1N}

Correlation between shear wave velocity and soil liquefaction resistance also developed. This correlation firstly introduced by Andrus and Stokoe (1997, 2000). Advantage by using shear wave velocity parameter is when the soil is difficult to penetrate either by SPT or CPT, or to get undisturbed soil sample, shear wave velocity of soil still can be measured. The next advantage is shear wave velocity is the basic mechanical properties of soil that related to the small-strain shear modulus. The last advantages by using shear wave velocity is the small-strain modulus is one

of the required parameters for estimating dynamic soil response and soil structure interaction analyses based on analytical procedures.

Corrected shear wave velocity base on overburden-stress can be calculated by using following equation:

$$V_{s1} = V_s \left(\frac{P_a}{\sigma_{v0}'} \right)^{0.25}$$

where P_a = atmospheric pressure approximated by 100 kPa and V_{s1} = corrected shear wave velocity. Andrus and Stokoe proposed the following relationship between CRR and V_{s1} :

$$CRR = a \left(\frac{V_{s1}}{100} \right)^2 + b \left(\frac{1}{V_{s1}^* - V_{s1}} - \frac{1}{V_{s1}^*} \right)$$

where V_{s1}^* = limiting upper value of V_{s1} for liquefaction occurrence, a and b are curve fitting parameters. Liquefaction relationship chart can be seen in Fig 2.5.

In this day, computer aided analysis is widely used across engineering field, with no exception in civil engineering. In geotechnical engineering, lots of programs were developed in order to help engineers analyze complex problem that nearly impossible if to solve by human. Not only that, computer aided analysis also helps to reduce problem solving duration.

For analyzing liquefaction of soil, there are lots of programs that already been developed. These programs generally used field performance like standard penetration test (SPT), cone penetration test (CPT), becker penetration test (BPT), shear wave velocity (V_s) and others method in order to analyze soil liquefaction resistance. Soil liquefaction resistance in these programs were calculated based on developed correlation equation, laboratory test and design code.

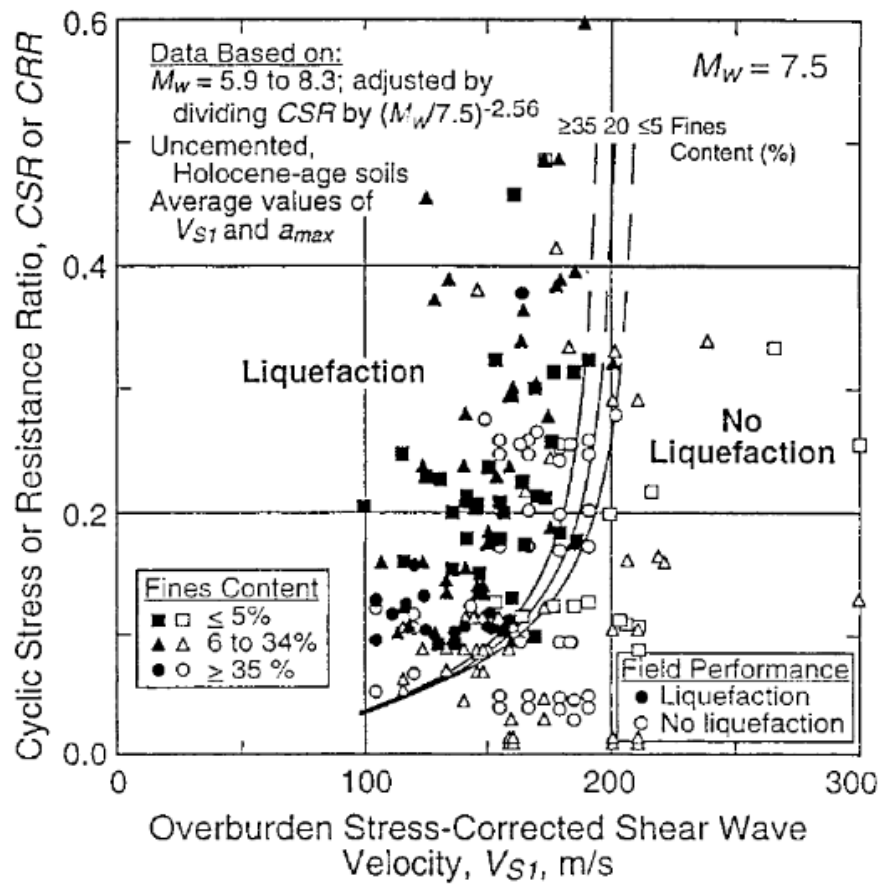


Figure 2.5. Correlation between CSR or CRR and V_{s1}

Deepsoil is one of many programs developed to help analyze soil site response. Deepsoil has been under development at University of Illinois at Urbana-Champaign (UIUC) from 1998. Deepsoil program categorized as 1D program, where Deepsoil program can perform several analyses, like 1-D nonlinear time domain analyses with and without pore water pressure generation, 1-D equivalent frequency domain analyses including convolution and deconvolution, and 1-D linear time and frequency domain analyses.

By using this program, engineers can take advantages by inputting complex soil profile into the program, applying dynamic loading of seismic acceleration with determined maximum PGA, and by calculating with dynamic calculation. This will better represent the real site condition compared to the simplified method that introduce previously by many engineers.