Empirical correlation of liquefaction potential using CPT

Une corrélation empirique entre le potentiel de liquéfaction et le CPT

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SYNOPSIS The Static Cone Penetration Test (CPT) has been increasingly for evaluating soil liquefaction potential. In order to use CPT results for this purpose, the SPT-CPT correlation, q_c/N ratio, is used, however, this ratio is so widely scattered that it may not be suitable in practical use to estimate liquefaction potential at local sites. This paper presents some direct correlations between cone resistance and cyclic stress ratio, obtained from the field performance data of the previous earthquake disasters and cyclic triaxial test results of undisturbed sample of sand deposits. These correlations show that the relationship of each parameter varies considerably according to fines content, as well as mean grain size of soil. This paper presents table for evaluating liquefaction potential in the field based on fines content. It is concluded that the CPT method has a limited application for estimating liquefaction potential, and that it should be applied in conjunction with grain size analysis of soil.

INTRODUCTION

Although the Static Cone Penetration Test (CPT) has the very significant advantages of simplicity, repeatability accuracy and continuous record, very little CPT field data is available for use in assessing liquefaction potential of sand deposits. In the present situation, it is considered to derive a relationship between the Standard Penetration Test (SPT) and the CPT. However, since the relationship between SPT-N values and CPT-q_c values shows scattering in natural sand deposits, the validity of converting SPT to CPT appears questionable. This paper examines the relationships between liquefaction potential and CPT results obtained from sites of past earthquake damage and laboratory test data of undisturbed sand samples.

RELATIONSHIPS BETWEEN N_d AND q_c

The corrected value N_d (blows/0.2 m) of Swedish Automatic Ram Sounding is the same in N value of SPT (T. Muromachi et al. (1982). Fig. 1 compares the ratio q_c/N_d with mean grain size (D_{50}) and the correlation curve given by Robertson et al. (1983). These data were obtained from sites in Niigata and Akita prefectures, where dramatic damages resulting liquefaction of sandy deposits occurred. Although the Robertson et al. curve in Fig. 1 represents a mean for non-liquefied soil, there is a considerable scatter for liquefied soil in the upper part of the curve. Also in Fig. 2, which shows the relationships between q_c/N_d ratio and fines content, there is a great deal of scatter as fines content decreases. The results mentioned above raise a doubt about the validity of treating converted SPT as CPT results.

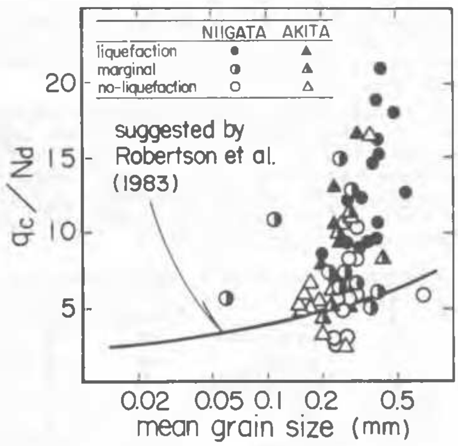

Fig. 1 Variation of q_c/N_d with Mean Grain Size

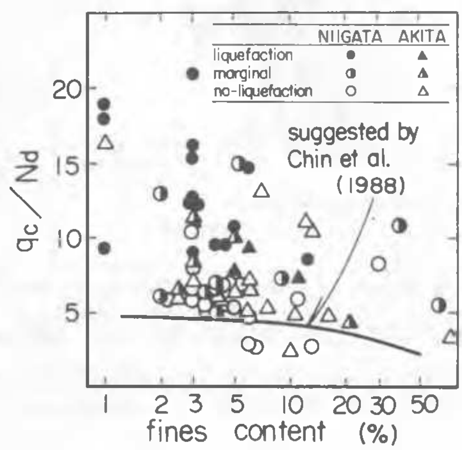

Fig. 2 Variation of q_c/N_d with Fines Content

FIELD CORRELATION OF SOIL LIQUEFACTION BASED ON CPT q_c-VALUE

We received CPT data from sites where it was confirmed that liquefaction did or did not occur during the 1964 Niigata earthquake and the 1983 Nihonkai-Chubu earthquake, to derive CPT-liquefaction relationships. The magnitudes of the two earthquakes were 7.5 and 7.7, respectively. Seismograph records showed that acceleration reached 157 gal in Niigata city and 168 gal in Akita. The CPT data were obtained from three sites in either prefecture in both cases. Liquefaction had occurred at two sites and not occurred at the third site.
Modification of cone resistance to an overburden stress level of 1 kgf/cm^2 was obtained by the following equation proposed by Tokimatsu et al. (1983):

$$q_{c1} = \left(\frac{1.7}{\sigma_o' + 0.7}\right) q_c \quad \cdots\cdots\cdots \quad (1)$$

where q_{c1} = modified cone resistance,
σ_o' = effective overburden pressure,
q_c = measured cone resistance

The shear stress ratio induced by the earthquake is estimated by the following equation:

$$\tau/\sigma_o' = 0.1\ (M-1)\ \frac{\alpha_{max}}{g}\ \frac{\sigma_o}{\sigma_o'}\ (1 - 0.015Z) \quad .. \quad (2)$$

where τ/σ_o' = shear stress ratio; M = earthquake magnitude; α_{max} = the maximum horizontal acceleration at ground surface; Z = depth in m, σ_o = total overburden pressure
Fig. 3 shows relationships between τ/σ_o' and q_{c1} at sites where liquefaction did or did not occur during the earthquakes. Open points indicate soil which did not liquefy, solid points indicate soil which underwent liquefaction and half solid points indicate soil which was estimated as marginal state.

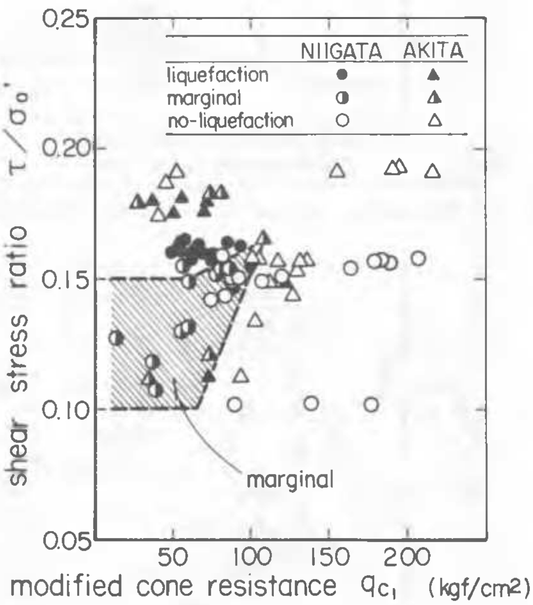

Fig. 3 Field Correlation between Shear Stress Ratio and Modified Cone Resistance q_{c1}

Fig. 3 shows a marginal zone on the border between a liquefied and not liquefied condition where shear stress from 0.1 to 0.15 under $q_{c1} \leq$ 60 kgf/cm^2 and it has a trend to increase with increase of q_{c1} from 60 kgf/cm^2 to 100.
Fig. 4 and Fig. 5 use the same data, showing relationships between q_{c1} and mean grain size of soil, and q_{c1} and fines content, respectively. In both of the figures, a boundary line

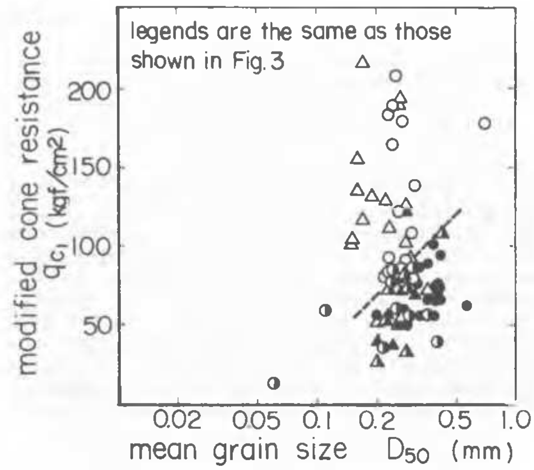

Fig. 4 Relationship between Mean Grain Size and Modified Cone Resistance for Liquefied Soil and No-liquefied Soils

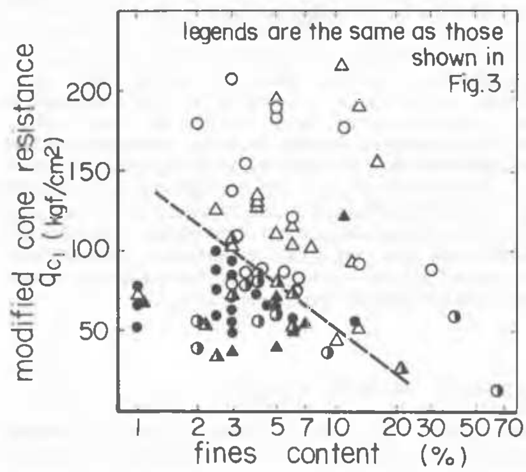

Fig. 5 Relationship between Fines Content and Modified Cone Resistance for Liquefied Soils and No-liquefied Soils

between the liquefaction and non liquefaction zones can be easily drawn.
This line is located between the shear stress ratio values of 0.16 to 0.18. Fig. 4 indicates that the distribution of mean grain size (D50) in the liquefaction zone has a limited range from 0.2 mm to 0.4 mm, and that q_{c1} increases with D_{50} along the boundary line. Fig. 5 shows that fines content varies from 1% to 10% in the liquefaction zone, and that q_{c1} decreases considerably as fines content increases along the boundary line.

CORRELATION BASED ON LABORATORY TEST

If test data of cyclic stress ratio are available together with cone resistance data for the same deposits, a correlation between these two sets of soil parameters can be established. The cyclic strength of sandy soils was obtained from cyclic triaxial compression tests on undisturbed samples. These samples of alluvial sand from land reclaimed in Tokyo Bay, were taken by stationary piston thin wall sampler. The cone resistance log reveals a considerable changes in soil characteristics within a small depth range. The cyclic test requires three or four uniform samples to determine the stress ratio at the point where liquefaction begins at a given number of cycles.
In order to coincide the depth of q_{c1} value closely with that of laboratory species, cyclic stress ratio of 15 cycles was obtained from the test result of a single species using on extraporation curve shown in Fig. 6.
Fig. 6 shows the relationship between modified stress ratio divided by 15 cycles and a given cyclic loading number. The following equation describes the apparent mean trend for the two parameter:

$$\left(\frac{\sigma d}{2\sigma c'}\right)_{Nc} / \left(\frac{\sigma d}{2\sigma c'}\right)_{15} = \left(\frac{Nc}{15}\right)^{-0.186} \quad \ldots\ldots\ldots \quad (3)$$

where $(\sigma_d/2\sigma_c')_{N_c}$ = cyclic stress ratio induced initial liquefaction or 5% double amplitude axial strain in the cource of N_c cycles; $(\sigma_d/2\sigma_c')_{15}$ = cyclic stress ratio of 15 cycles; N_c = cyclic loading number

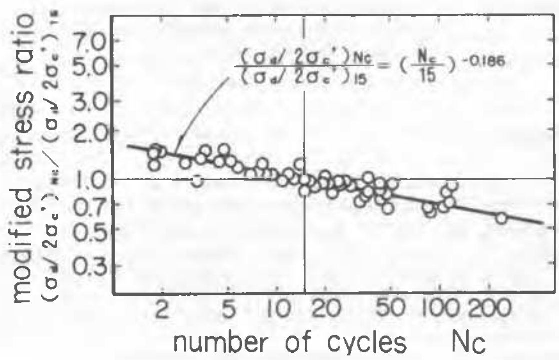

Fig. 6 Modified Cyclic Stress Ratio and Number of Cycles

Using the above equation, cyclic stress ratio for 15 cycles for each spacimen can be obtained by each cyclic triaxial test result.
The correction factor C_r = 0.57 (Alba et. al., 1976) for the relationship between undrained strength of saturated sand during earthquake and that obtained by the cyclic triaxial test will be tentatively adopted here.

$$\left.\begin{array}{l}(\tau/\sigma o')_{field} = Cr(\sigma d/2\sigma o')_{triaxial} \\ C_r \fallingdotseq 0.57\end{array}\right\} \quad \ldots \quad (4)$$

Fig. 7 shows the relationship between corrected shear stress ratio, obtained from Eq. 4 and modified cone resistance. As shown in Fig. 7, the relationship of the two parameters can be distinguished for each range of fines content. Also, the presence of fines reduces cone resistance without significantly changing liquefaction resistance.

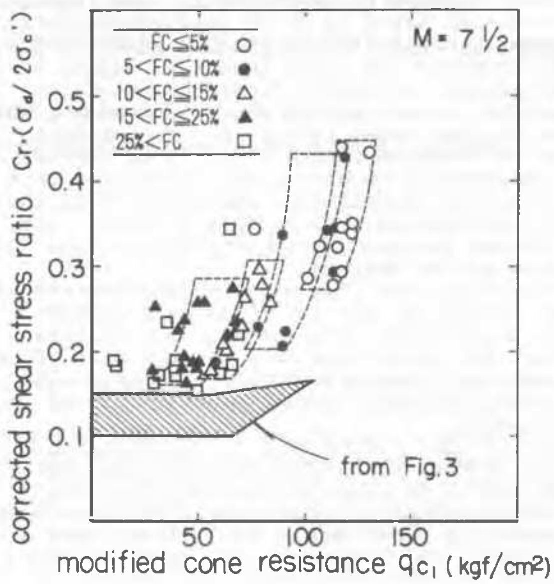

Fig. 7 Relationship between Stress Ratio Causing Liquefaction and Modified Cone Resistance Obtained by Laboratory Test

CORRELATION CURVE BETWEEN LIQUEFACTION RESISTANCE AND CONE PENETRATION RESISTANCE

The liquefied soil in Niigata and Akita were considered as a group of clean sand with almost less than 10% of fines.

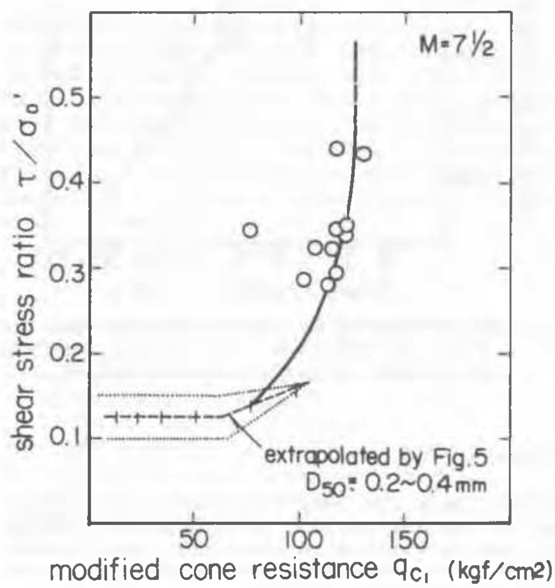

Fig. 8 Comparison of Laboratory Test Result and Field Correlation for Clean Sands (FC ≦ 5%)

The dotted line in Fig. 8 represents the boundary between liquefaction and non liquefaction of sand based on field performance data. By drawing the mean line (dashed line) of the upper boundary and lower boundary, degree of fines content is marked along the mean line according to the relationships between q_{c1} and fines content shown in Fig. 5. The critial line for clean sand with 5% of fines content was obtained by combining the laboratory test data with the dashed line determined from the field performance. Using this critical line, q_{c1} values for sand having different fines content can be compared.

Ratios of q_{c1} for sand with various degrees of fines content of q_{c1} for clean sand against fines content are shown in Fig. 9. In this figure, the solid line is a average mean of two parameters. This relationship indicates the influence on fines content of soil on cone resistance.

Combining Fig. 9 with Fig. 8, relationship between stress ratio and modified cone resistance can be obtained as shown in Fig. 10. Similar correlation curves using CPT have been presented by Robertson et al. (1985), Seed et al. (1986), and Shibata et al. (1987). All took the CPT-SPT correlation into account to correlate CPT with liquefaction resistance. For comparison, a similar correlation curve proposed by other investigators is shown in Fig. 10.

The curve proposed by Shibata et al. (1985) and Robertson et al. (1985) appear more conservative.

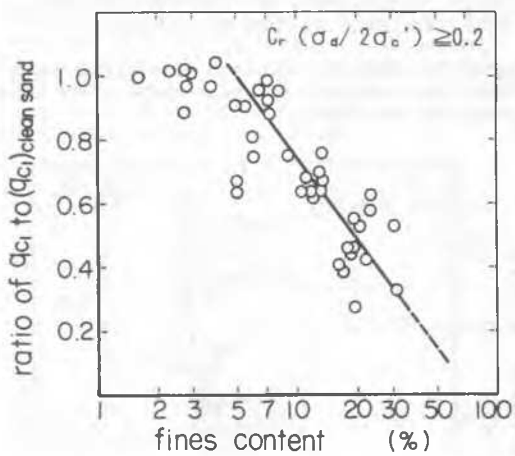

Fig. 9 Relationship between Fines Content and Ratio of Modified Cone Resistance for Equivalent Liquefaction Potential

CONCLUSION

Although there are important potential advantages to the use of CPT, there are very little field data available to establish good correlations of field performance with CPT, it has been considered rational to derive a CPT liquefaction relation by conversion of SPT to CPT. However, comparison of SPT-CPT ratio to soil gradation characteristics shows much more scatter. Therefore, using only CPT correlation to liquefaction resistance, obtained from field performance and laboratory test results, a correlation curve between liquefaction resistance and cone resistance was presented. The curve shows that liquefaction resistance varies considerably with fines content of soil. It is difficult to obtain sufficient accuracy by using the CPT only. It is better to use the results of grain size analysis of soil for evaluating liquefaction resistance from the CPT.

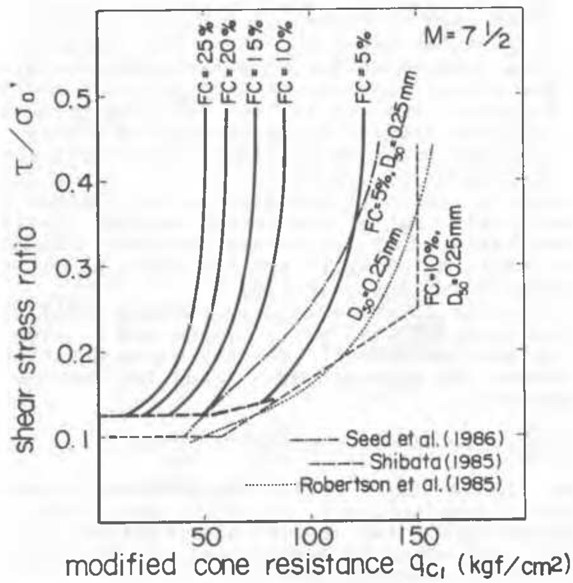

Fig. 10 Proposed Correlation between Liquefaction Resistance of Sands and Cone Resistance

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