Study on Cyclic Shear Strength of Soils from Different Methods

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SYNOPSIS This paper compares the cyclic strengths of soils from different methods using intensive investigations at a recent alluvial site on the southwest Taiwan. Generally speaking, the cyclic shear strengths deduced from different methods exhibit the following trend: Block sample > Tube sample ≒ SPT -N (Standard Penetration Test) method > seismic Vs method > CPT-q_c (Cone Penetration Test) method.

INTRODUCTION

The island of Taiwan is located at a complex juncture between the Eurasian and the Philippine Sea plates which is a highly seismic active zone. In historical strong earthquakes, sand boils had been reported several times in the area of alluvial plains of Taiwan. To establish liquefaction design criteria for public works, an intensive investigation for liquefaction study was carried out at the Peikang site which is situated on the southwest coast of Taiwan. This investigation provides a good opportunity to compare the cyclic shear strengths of soils predicted by different methods, such as, SPT-N, CPT-q_c, Vs and cyclic triaxial test using tube and block samples which are commonly used in engineering practice. In this paper, various simplified methods are reviewed first and then site condition, in-situ testings and undisturbed sampling are described. Finally, comparisons of cyclic shear strengths deduced from different methods are presented.

REVIEW OF SIMPLIFIED METHODS

The simplified methods investigated herein include:

1. SPT-N methods
   - Seed's methods (1983, 1984, 1987)
   - Japanese Bridge Design method (JBD method, 1990)
   - Tokimatsu and Yoshimi method (T-Y method, 1983)
2. CPT-q_c method
   - Shibata et al. (1988)
3. Seismic-Vs method
   - Tokimatsu et al. (1990)

The backgrounds of these simplified methods are briefly described as below.

1. SPT-N methods

The Seed's method (1983, 1984) was developed on large data bases of field performances during earthquakes all over the world to establish a critical curve of SR_{15} vs. $(N_1)_{60}$ for separating liquefiable or non liquefiable sites, in which, SR_{15} is cyclic stress ratio corresponding to 15 equivalent number of cycles when earthquake magnitude M ≒ 7.5, $(N_1)_{60}$ is the in-situ SPT-N value modified to effective overburden pressure = 1 kg/cm^2 and SPT rod energy ratio = 60%. The relation of $\triangle(N_1)_{60}$ vs. FC(%) proposed by Seed (1987) is used to estimate the effect of fines content on cyclic shear strength, in which, $\triangle(N_1)_{60}$ is the increment of $(N_1)_{60}$ and FC is fines content of soils in percentage. The JBD method was derived from the research efforts of Iwasaki et al. (1978). In this method, correlations of SR_{20} vs. N and D_{50} (or FC%) were deduced from a number of cyclic triaxial test results on high quality tube samples, in which, SR_{20} is the cyclic stress ratio corresponding to 20 cycles in liquefaction curve from cyclic triaxial test and D_{50} is mean diameter of grain size distribution curve. The T-Y method (1983) used the data base of field performances in Japan and test results of in-situ frozen samples to set up the critical curve separating liquefaction or non-liquefaction of soils. The cyclic shear strengths of clean sand predicted by these three methods using common-based parameter $(N_1)_{60}$ are shown in Figure 1, which shows that the estimated cyclic strengths have the following trend:

JBD ≒ T-Y > Seed for $(N_1)_{60} \leqq 12$
Seed > T-Y > JBD for $(N_1)_{60} \geqq 12$

The effects of fines content in terms of $\triangle(N_1)_{60}$ from these methods are shown in Figure 2 which shows that estimation by both JBD and T-Y are greater than that of Seed.

2. CPT-q_c method (Shibata et al., 1988)

This method was developed using normalized CPT-q_{c1} parameter based on field performances mainly from 1976 Tangshan earthquake in Mainland China to establish the critical curve separating liquefaction or non-liquefaction of soils. D_{50} was used to evaluate the effect of fines content on cyclic strength in this method. Because D_{50} can not be obtained in CPT test, thus it was obtained from laboratory test on split samples in nearby boreholes in this investigation.

3. Seismic - Vs method (Tokimatsu et al., 1990)

This method was developed on the correlation of normalized shear modulus with 15-cycles cyclic stress ratio in liquefaction curve from cyclic triaxial test. The shear modulus can be deduced from shear wave velocity at the site. In this paper, fines content in percentage FC (%) was used to evaluate the effect of fines content on cyclic strength. FC(%) also could not be obtained from in-situ seismic shear wave test. It was also obtained from physical properties test on split samples from SPT test nearby.

IN-SITU TESTING AND UNDISTURBED SAMPLING

1. Site Conditions

The study site is located on the bank of the Peikang river on the south-west alluvial plain of Taiwan. The surface layers of this site are recent alluvial deposits consisted of loose silty sand and sandy silts, as shown in Figure 3. During the period of investigation, the ground water table is around 4 meters below the ground surface.

2. In-situ Testing

An intensive in-situ tests, including the SPT with energy measurement, the seismic cone penetration test (SCPT), the cross-hole Vs measurement, the dilatometer test (DMT), and the pore water pressure (PWP) measurement, were carefully conducted at the site. The arrangement of these in-situ tests is shown in Figure 4. The test results obtained were used to correlate the field shear strength deduced from each method with those of laboratory tests, and therefore, to compare the results estimated by different methods.

3. Undisturbed Sampling

To correlate the cyclic shear strength of soils with the results of in-situ tests, undisturbed tube and block samples were taken at the test site for laboratory tests. For undisturbed sampling in loose sand layers, a vertical shaft with diameter of 2m was excavated by hand shovel. Down to the depth of 8m below the ground surface, 30cm cubic block samples and hand-pushed tube samples were taken at every meter in the shaft. Besides, some tube samples were taken in the drilled-holes by using the hydraulic Osterberg sampler. All samples were free drained and frozen at the site and then transported to the laboratory for testing.

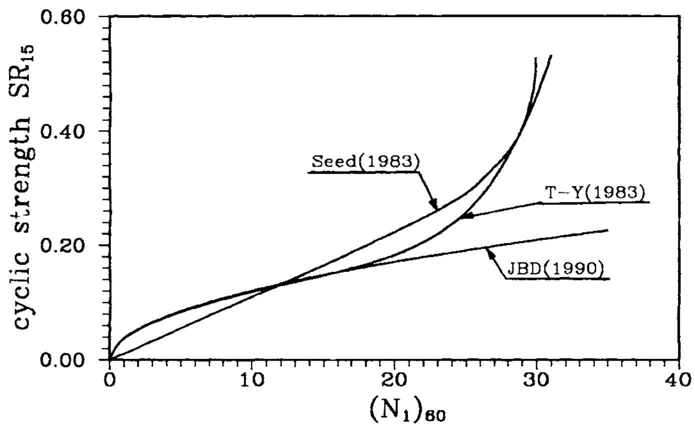

Fig.1 Variation of cyclic strength SR_{15} with $(N_1)_{60}$ predicted by the SPT-N methods

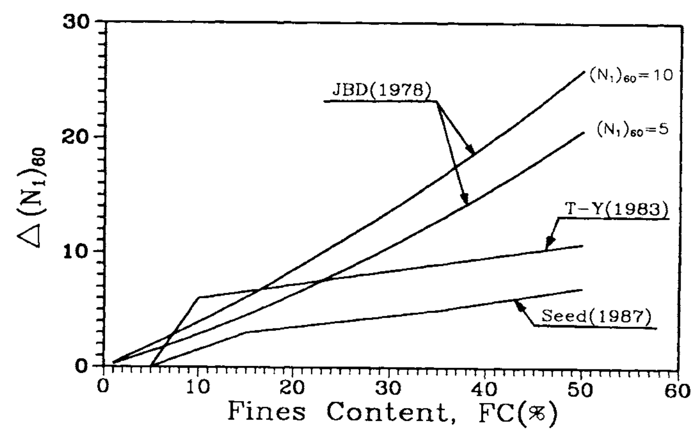

Fig.2 Variation of increment of $(N_1)_{60}$ with fines content

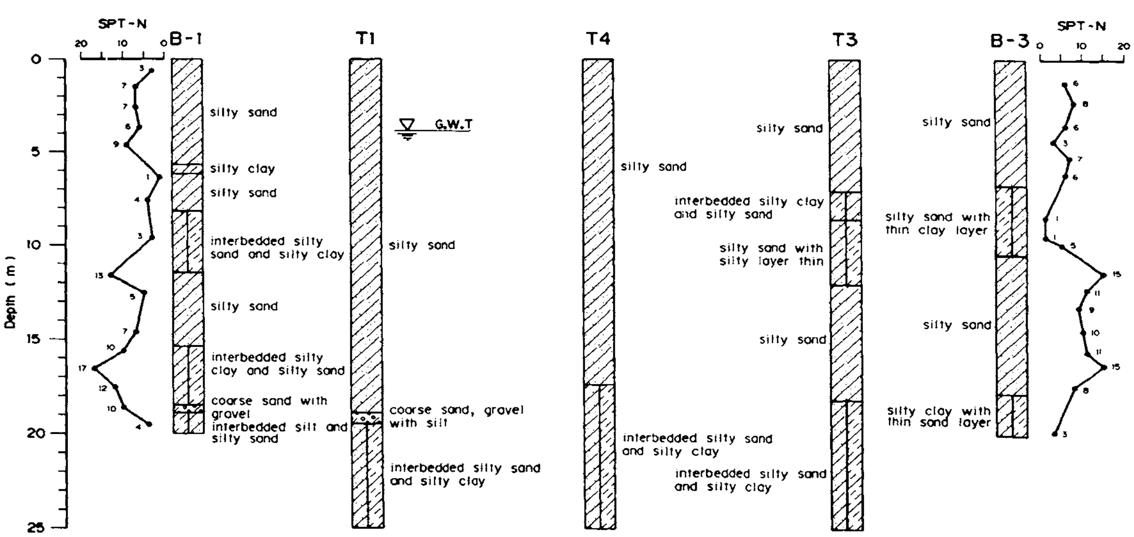

Fig. 3 Geological logging in test site

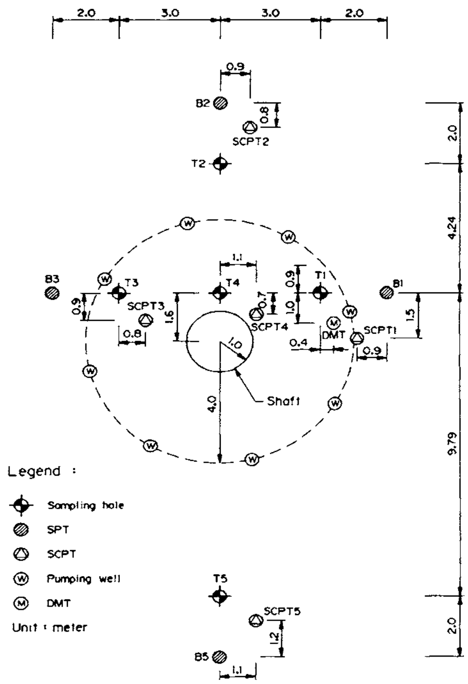

Fig. 4 The layout of the in-situ tests

CYCLIC SHEAR STRENGTH EVALUATION FROM TRIAXIAL TEST

The cyclic shear strengths of block samples and hand-pushed tube samples obtained in the shaft were tested in triaxial apparatus. Then the field strength $(SR_{15})_f$ were estimated from laboratory strengths by corrections according to the relationship as shown below.

$$(SR_{15})_f = (SR_{15})_{triaxial} \times 0.9 \times \frac{1+2Ko}{3}$$

in which

$(SR_{15})_{triaxial}$ = 15 cycle cyclic shear strength in triaxial test

0.9 = correction factor for two direction shaking

$\frac{1+2Ko}{3}$ = correction factor for difference of stress condition between the test and field, Ko is the earth pressure coefficient at rest from the DMT test.

The cyclic strengths $(SR_{15})_f$ of shaft samples and tube samples are then compared with those calculated by using simplified SPT-N methods.

COMPARISONS OF DIFFERENT METHODS

1. Comparisons between Different SPT-N Methods

Comparisons of cyclic strengths predicted by different SPT-N methods were conducted with design earthquake M=7.1, PGA=0.15g, 0.2g, 0.25g, 0.3g for B1, B2, B3, B5 boreholes. Generally, the trends are similar for all boreholes. The typical result is shown in Figure 5, which is comparison of B5 hole. It can be seen that the predicted strengths (corresponding to number of cycles for M=7.1) by JBD and T-Y are higher than that of Seed for shallow depth (e.g. less than 10 m), while the predicted results of Seed and T-Y methods are higher than that of JBD for greater depth (e.g. greater than 10 m).

2. Comparisons between CPT-q_c and SPT-N methods

Comparisons between CPT-q_c and SPT-N methods for B1, B2, B3, B5 holes was also conducted. The typical result is that the predicted strength vs. depth by CPT-q_c method is generally unanimously lower than those predicted by SPT-N methods, as shown in Figure 6 which shows the result of B3 hole.

3. Comparisons between Vs and SPT-N methods

The similar comparisons were conducted. The typical result indicated that the predicted strength vs. depth by Vs method is generally consistently lower than those predicted by SPT-N methods

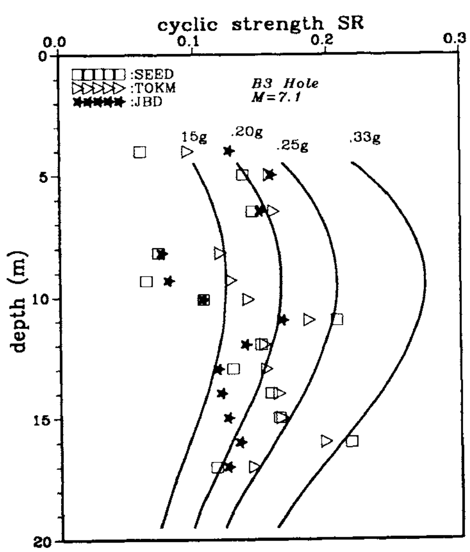

Fig.5 Comparison of cyclic strength vs. depth predicted by different SPT-N methods

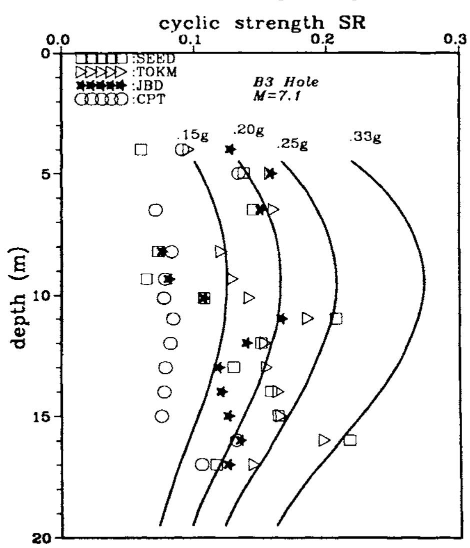

Fig.6 Comparison of cyclic strength vs. depth predicted by CPT and SPT-N methods

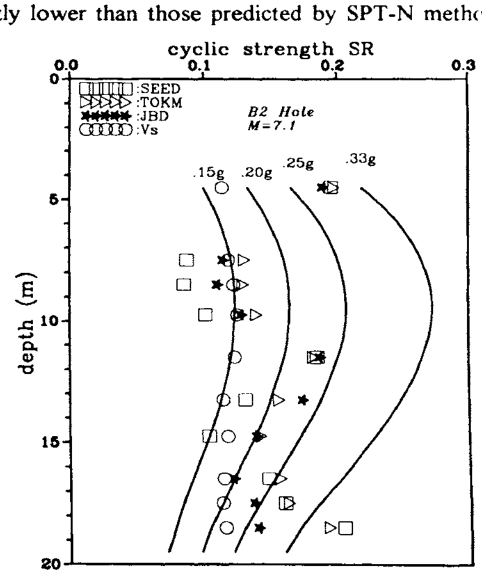

Fig.7 Comparison of cyclic strength vs. depth predicted by Vs and SPT-N methods

for greater depth, as shown in Figure 7 which was obtained from B2 hole.

4. Comparison between Tube samples with SPT-N methods

Figure 8 summarizes the result of comparison between which shows that the cyclic shear strengths of tube samples are approximately equal to those predicted by SPT-N methods.

5. Comparison between Block Samples with SPT-N methods

Figure 9 presents the result of comparison between which shows that the cyclic shear strengths of block samples are significantly higher than those predicted by SPT-N methods.

6. Overall Assessment

Comparison of cyclic strengths vs. depth predicted by all these methods is typically shown in Figure 10 which is the result of B1 hole. Generally speaking, the cyclic shear strengths deduced from different methods exhibit the following trend which may be attributed to the undisturbed block sampling and the inherent conservativeness of simplified methods.

Block sample > Tube sample ≒ SPT-N method > Vs method > CPT-q_c method

CONCLUSIONS

From the results of this study, the following general conclusions can be deduced.

1. For the SPT-N methods investigated in this study, the Seed method is more conservative than the rest methods for shallow depth, but for greater depth, the JBD method is more conservative than the rest methods. The probable reason is that among these methods, the predicted cyclic strengths of Seed method are highest for soils with high $(N_1)_{60}$ with low fines content, and the predicted values of JBD method are highest for soils with low $(N_1)_{60}$ with high fines content.

2. The CPT-q_c and Vs methods as observed from this study are rather conservative as compared with SPT-N methods, and parameters as fines content and D_{50} can not be obtained in these tests. Therefore, these methods are suggested to be used as auxiliary methods for liquefaction evaluation.

3. The cyclic strength of tube samples approximately equals to those predicted by SPT-N methods. This result is consistent with the research results inherent in JBD method.

4. It appears that the cyclic strengths of block samples are significantly higher than those predicted by all the rest methods considered in this investigation.

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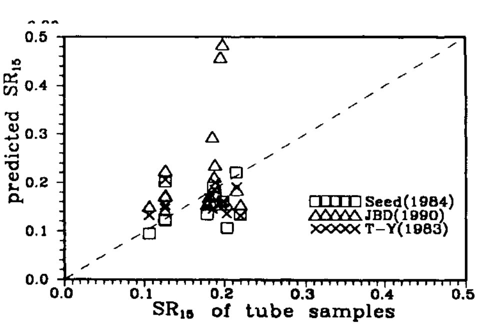

Fig.8 Comparison of the predicted cyclic strengths of 15 cycles with those of tube samples

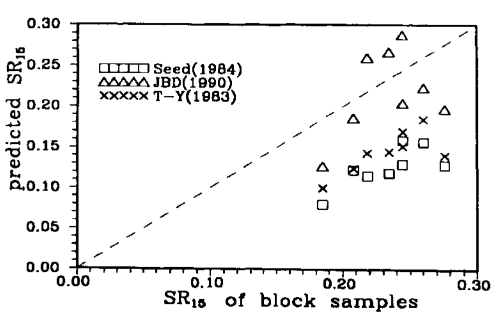

Fig 9 Comparison of the predicted cyclic strengths of 15 cycles with those of block samples

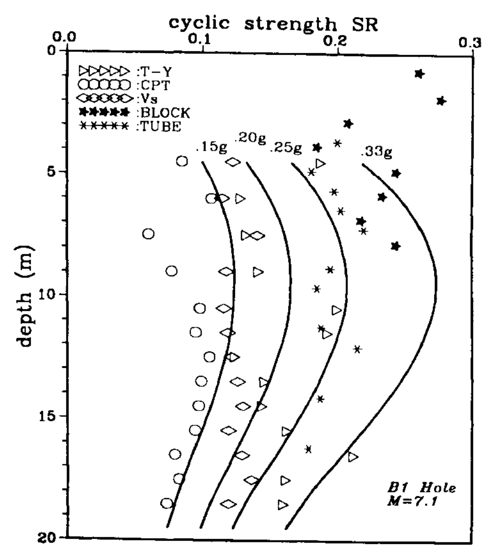

Fig.10 Variation of cyclic strengths with depth