Reliability Analysis of Liquefaction Evaluation Discriminant of Chinese Seismic Code

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ABSTRACT :

The liquefaction-induced damage phenomena have occurred during many earthquakes in last century in China, including the *Heyuan* Earthquake in 1962, the *Xingtai* Earthquake in 1966, the *Bohai* Earthquake in 1969, the *Yangjiang* Earthquake in 1969, the *Tonghai* Earthquake in 1970, the *Haicheng* Earthquake in 1975 and the *Tangshan* Earthquake in 1976. The discriminant for liquefaction evaluation in the Chinese code is developed by the in-situ investigation on above earthquakes. However, some researchers doubt the reliability of the discriminant and two issues are needed to be further studied. One is that there are different results for the success ratio of re-discrimination using the original data. The other is the success ratio of prediction for new earthquakes data and this work has never been conducted.

The reliability of the liquefaction evaluation discriminant of the Chinese code is analyzed in the paper. The success ratio of re-discrimination is attained by using the 159 SPT data in the earthquake of China. The 288 SPT cases in the *Chi-Chi* Earthquake are employed to verify the success ratio of prediction for new earthquakes data. The results here show: (1) The success ratio of re-discrimination is 88% and 79%, separately for the liquefied and the non-liquefied sites; (2) The success ratio of prediction for the *Chi-Chi* Earthquake data is 80% and 90%, separately for the liquefied sites and the non-liquefied sites, and the average prediction success ratio is 85%; (3) Although the success ratios of re-discrimination for original data and prediction for the new data both are accuracy in engineering meaning, the detailed analysis shows that liquefaction evaluation discriminant of the Chinese seismic code easily makes mistakes for the soft sites in the low intensity as well as for the hard sites in the high density, and the non-liquefied sites are easily evaluated as liquefied ones in these cases.

KEYWORDS: liquefaction evaluation discriminant; Chinese seismic code; success ratio of re-discrimination; success ratio of prediction

1.INTRODUCTION

Constructing the structure on the liquefiable soil layer will result in huge disaster, and many lessons were learned from the history earthquake. It is very important to judge the soil whether liquefy or not under the acting of design earthquake intensity. The liquefaction issues have been paid attention to for a long time in China. The Liquefaction-induced damage phenomena occurred during many earthquakes last century, such as *Heyuan* earthquake in 1962, *Xingtai* earthquake in 1960, *Tonghai* earthquake in 1970, etc.. The Institute of Engineering Mechanics began to select, investigate and accumulate the liquefaction case from then on, and presented a formula for assessing the liquefaction for the fist time in China, which was adopted by the Seismic Code for industry and civil buildings (TJ11-74). This is so called liquefaction evaluation discriminant of the Chinese code. The *Haicheng* earthquake in 1975 and *Tangshan* earthquake in 1976 pay a very important role in revising the liquefaction evaluation discriminant, because of providing abundant filed site for liquefaction research. Its feasibility in engineering was verified in the great *Tangshan* earthquake well to some extent. The results were conservative because of omitting the influence of the fine content and the overlying soil strata. In considering of these limitations, the code compiling workshop amended the rules from 1982 to 1987 and given the new code (GBJ11-89) in 1989. The idea of preliminary assessment was proposed for the first time. Along with the progressing of study, they supplemented the code by considering the soil between 15m and 20m and then the latest code (GBJ50011-2001) was given in 2001.

The liquefaction evaluation discriminant of the Chinese seismic code (simply called as the Code method)has formed more than 30 years and has been applied in engineering comprehensively, some main issues need to be answered:

(1) One useful way to verify the code method is to re-discriminate the liquefaction case history. There is controversy about the success ratio of re-discrimination.

(2) Another important way to verify the code method is to predict the new earthquake liquefaction case. This aspect effort has been done rarely. Moreover, the new earthquakes were occurred in China, such as *Chi-Chi* earthquake in 1999 and *Xinjiang Kashi-Bachu* earthquake in 2003, etc., and the abundant new liquefaction cases were provided to verify the code method.

2. INTRODUCTION TO THE CODE METHOD

The Code method (TJ11-74) was an empirical method in terms of history earthquake data listed in table1. The acting of earthquake was expressed as intensity, and the effect of magnitude was not considered, while the soil liquefaction resistance was express as SPT-N value.

Table 1 the liquefaction case used in establishing the Code method

Earthquake Name	date	magnitude	Intensity of epicenter
Heyuan	1962.3.19	6.1	Ⅷ
Xingtai	1966.3.8	6.8	Ⅸ
Xingtai	1966.2.22	7.2	Ⅹ
Bohai	1969.7.18	7.4	
Yangjiang	1969.7.26	6.4	Ⅷ
Tonghai	1970.1.5	7.7	Ⅹ

The formula was established by two steps, the first step was to plot the relationship figure by SPT-N value versus seismic intensity. As showed in fig.1, the critical curve that separates liquefied and non-liquefied sites, which was drew according expert experience, and the reference value of SPT blow count N_0 was obtained according to the critical cure as showed in table2.

Table 2 Reference value of SPT blow count

Intensity	Ⅶ	Ⅷ	Ⅸ
N_0	6	10	16

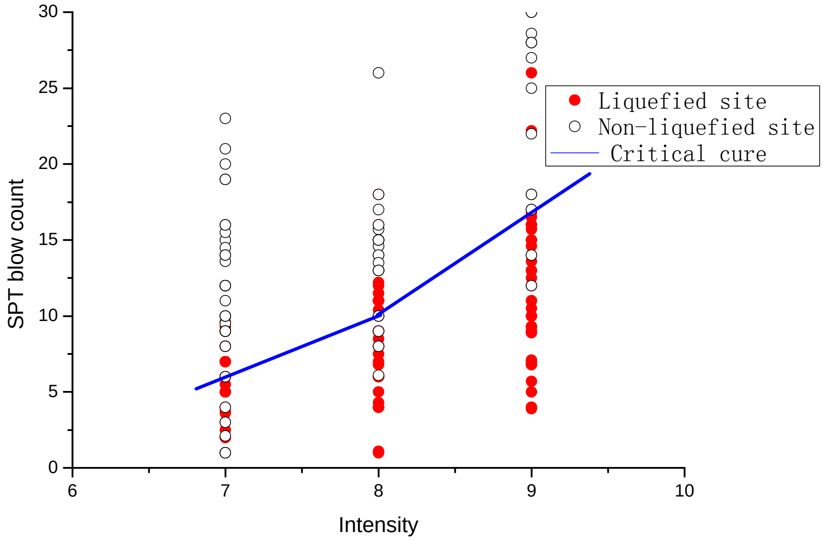


Fig.1 The determination of reference value of SPT blow count N_0

The second step was to determine the influence factor of sand depth and water table. The empirical adjust factors of soil depth and water table was obtained from the liquefaction case history. So the liquefaction evaluation formula adopted in seismic code (TJ11-74) was expressed as follow:

$$N_{cr} = N_0[1+\alpha_w(d_w-2)+\alpha_s(d_s-3)] \tag{1}$$

Where, N_{cr} is critical SPT blow counts; α_w is coefficient of water table influence, adopted -0.05; α_s is coefficient of sand depth influence, adopted 0.125; d_s is soil depth; d_w is water table.

The new code method (GBJ11-89) adjusted the coefficient of water table influence and soil depth, adopted 0.1and -0.1, respectively. And the latest code method (GBJ50011-2001) follows the old model, and the influence of clay content was considered and can be applied to the soil depth between 15 and 20. The critical SPT-N value could be calculated as follow.

$$N_{cr} = N_0[0.9+0.1(d_s-d_w)]\sqrt{3/\rho_c} \quad (d_s \le 15m) \tag{2a}$$

$$N_{cr} = N_0(2.4-0.1d_s)\sqrt{3/\rho_c} \quad (15 < d_s \le 20m) \tag{2b}$$

Where, ρ_c is percentage of fines content (adopting 3 as the value is less than 3 or it classified as sand)

If the actual measurement SPT-N value less than the critical SPT-N value, this case will be discriminated as liquefied site, otherwise will be discriminated as non-liquefied site.

3. RE-DISCRIMINATION SUCCESS RATIO ANALYSIS

3.1 THE LIQUEFACTION CASE HISTORY SELECTING AND COMPILING

The liquefaction evaluation method can't be established and verified without the liquefaction case history, and its feasibility attributes to the quality of the liquefaction case history. This paper tries to select the presented case history, including different magnitude and different area. Amount to 476 SPT cases were selected including 278 liquefied cases and 198 non-liquefied cases, they are: 55 SPT cases for establishing the 1974' code method, 12 SPT cases in *Haicheng* earthquake in 1975, 92 SPT cases in *Tangshan* earthquake in 1976, 288 SPT cases in Chi-Chi earthquake in 1999, 29

SPT cases in *Xinjiang Kashi-Bachu* earthquake in 2003.

3.2 RE-DISCRIMINATION

The code method was established based on the domestic earthquake (before 1976) SPT cases, and was mainly used in engineering construction in China. The SPT cases used in establishing and amending the code method was selected during the re-discrimination success ratio analysis. The analysis includes two steps: firstly, calculates every selected case's critical SPT-N value according to the code method; secondly, compares the actual measurement SPT-N value with their critical SPT-N value. If the actual measurement SPT-N value more than its critical SPT-N value, this case will be discriminated as non-liquefied case, moreover, if it non-liquefied in fact, then it was defined as success discrimination one. All the discriminating results were showed in fig.2a and fig.2b.

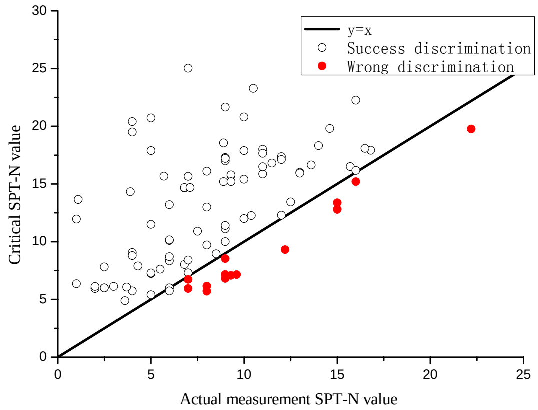


Fig. 2a Discriminating result of non-Liquefied cases

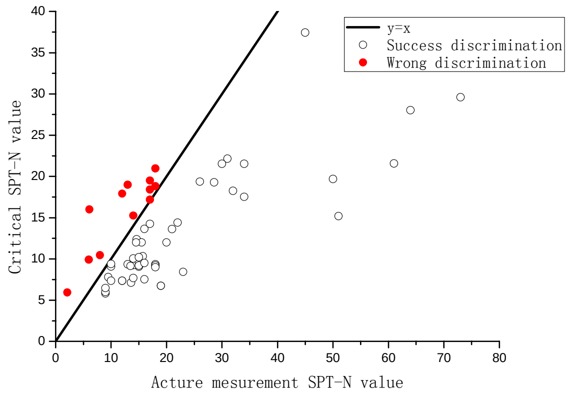


Fig. 2b Discriminating result of Liquefied cases

The points above the line y=x were success discrimination cases in fig.2a, while the points below the line y=x were success discrimination cases in fig.2b. The success discrimination ratio of liquefied cases is 84/98=85.7%, while the success discrimination ratio of non-liquefied cases is 48/61=78.7%. The success discrimination ratio of liquefied cases is more 7% than the non-liquefaction cases' one, which shows that the critical line of the code method bias to the non-liquefaction part.

4. FEASIBILITY ANALYSIS OF THE CODE METHOD

Different sand has different liquefaction resistance under the acting of different earthquake. The code method was established main based on the southwestern and northern area SPT case history in China, so it is feasible to be used for the other area?

4.1 VERIFYING THE CODE METHOD USING THE NEW *XINJIANG KASHI-BACHU* EARTHQUAKE LIQUEFACTION CASE

The Ms6.8 earthquake occurred in *Xinjiang Kashi-Bachu* area on Feb.24, 2003, caused 268 people died, 4853 people injured, and 1.37 billion RMB pecuniary lost. The liquefaction occurred within there intensity Ⅶ、Ⅷ、Ⅸ, while the maximum intensity is Ⅸ during this earthquake, showed in fig.3. Amount to 29 SPT cases were selected including 16 liquefied cases and 13 non-liquefied cases in this earthquake.

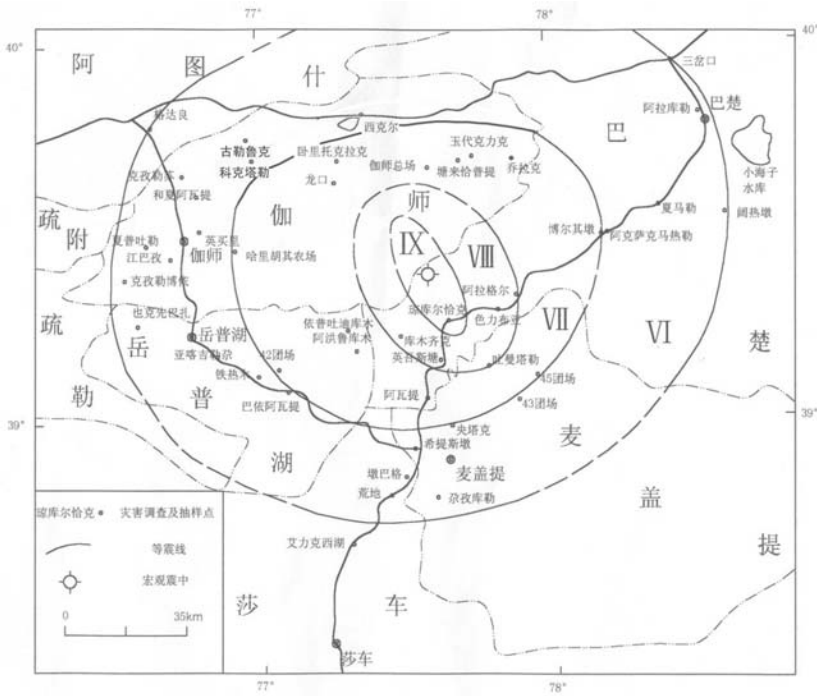


Fig.3 The intensity distribution of *Xinjiang Kashi-Bachu* earthquake

Using the same steps to predicting the selected SPT case, the results show in fig.4a and fig.4b.

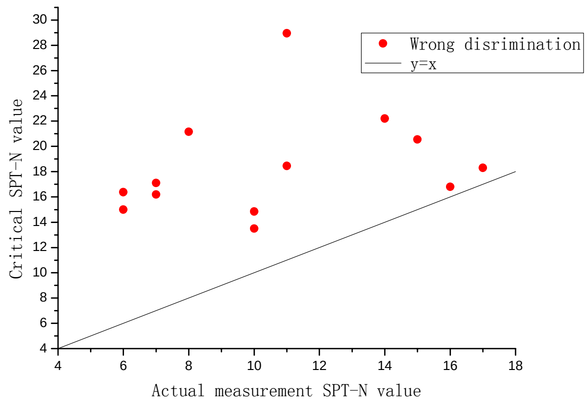


Fig. 4a Discriminating result of non-Liquefied cases

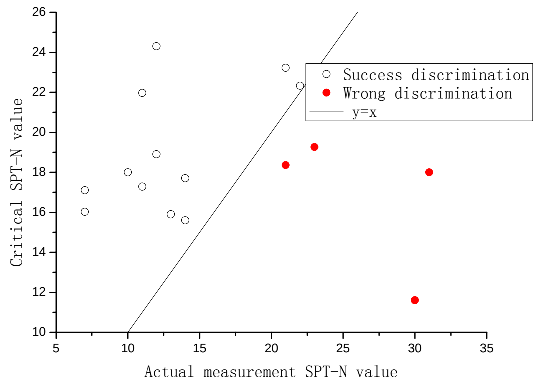
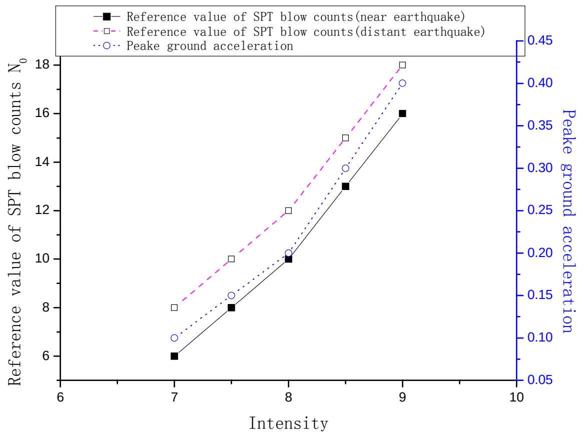


Fig. 4b Discriminating result of Liquefied cases

As show in fig.4a and fig.4b, the success ratio of predicting is 12/16=75% for the liquefied cases and 0 for the non-liquefied case. Two reason causing low success ratio of predicting: firstly, The code method was established main based on the southwestern and northern area SPT case history, while the *Xinjiang Kashi-Bachu* liquefied cases is northwestern sand. It is necessary to further study the liquefaction resistance of these different area sands. Secondly, some mistake may exist in the selected case, and their quality needs to be check.

4.2 PREDICTING THE NEW *CHI-CHI* EARTHQUAKE LIQUEFACTION CASE USING THE CODE METHOD

Chi-Chi earthquake SPT case express act of earthquake using peak ground acceleration, while the code method adopts intensity as variable of the formula, some transition need to be done. As the reference value of SPT blow count N_0 has linear relationship with the intensity, while the peak ground acceleration also has linear relationship with the intensity, so the relationship between reference value of SPT blow count N_0 with the peak ground acceleration could be established, as showed in fig.5 and fig.6.



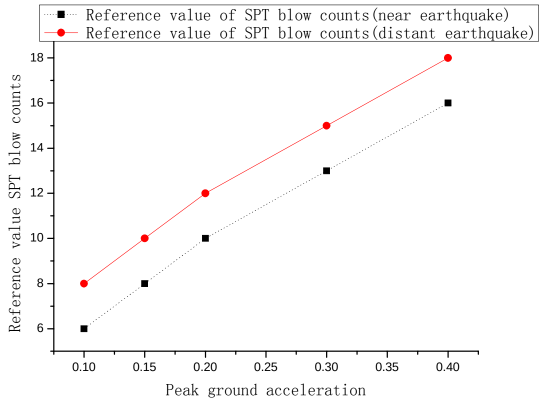


Fig.5 Relationship between intensity and N_0, intensity and PGA   Fig.6 Relationship between PGA and N_0

So, the reference value of SPT blow count N_0 has the linear relationship with the peak ground acceleration within some phase.

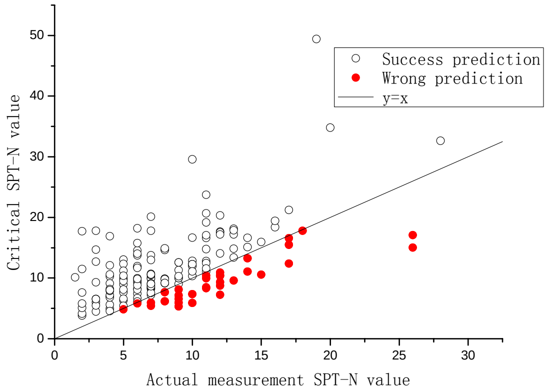
$$N_0 = 40 * a_{\max} + 2 \qquad 0.1 \le a_{\max} \le 0.2(g) \tag{3a}$$

$$N_0 = 30 * a_{\max} + 4 \qquad 0.2 < a_{\max} \le 0.4(g) \tag{3b}$$

Meanwhile, the fine content also has approximate linear relationship with the clay content:

$$\rho_c = Fc/3 \tag{4}$$

After the transition, the code method could be used to predict the *Chi-Chi* liquefaction case. Amount to 288 SPT cases were selected including 164 liquefied cases and 124 non-liquefied cases in this earthquake. Using the same steps to predicting the selected SPT case, the results show in fig.7a and fig.7b.



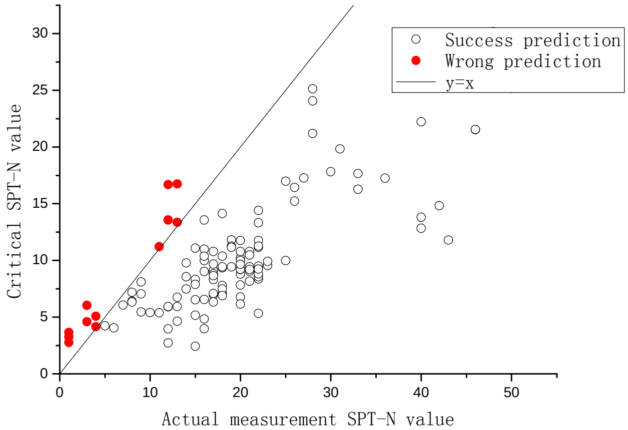
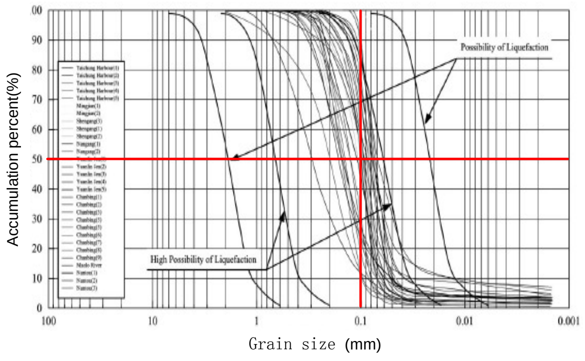


Fig.7a Predicting result of Liquefied cases   Fig.7b Predicting result of non-Liquefied cases

As showed in fig.7a and fig.7b, the success ratio of predicting is 131/164=79.9% for the liquefied cases and 112/124=90.3% for the non-liquefied case. Two reason causing high success ratio of predicting: firstly, the grain distribution cure of Chi-Chi liquefied case is close to the liquefaction cases' which were used to establish the code method, the average particle size is $d_{50} \approx 0.12mm$ and $d_{50} \approx 0.16mm$, respectively, as showed in fig.8a and fig.8b. Secondly, the difference of SPT-N value between liquefied case and non-liquefied case in *Chi-Chi* earthquake is obvious, it's easy to discriminate because the mean SPT-N value of liquefied site is 8.5 blows and the non-liquefied sites' is 19.5 blows.



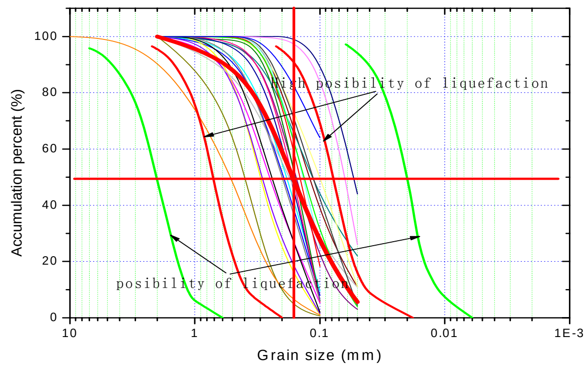


Fig.8a Grain size distribution of *Chi-Chi* earthquake case (Jin-Hung Hwang 2001)

Fig.8b Grain size distribution of *Tangshan* earthquake case

One point need to be mentioned is that the deviation can't avoid during the corresponding index transiting. Meanwhile, some discrete existing in the selected case history. So the success ratio of discriminating and predicting reflects the feasibility of the code method to some extent.

5. CONCLUSION

(1)The success discrimination ratio of liquefied cases is 84/98=85.7%, while the success discrimination ratio of non-liquefied cases is 48/61=78.7%.
(2)The success ratio of predicting is131/164=79.9% for the liquefied cases and 112/124=90.3% for the non-liquefied case.
(3)The result may be influenced by the corresponding index transition and the data discrete itself during using the code method to predict the *Chi-Chi* earthquake SPT cases.
(4)The amount and representation of liquefaction case pay an important role in establishing the code method.
(5) Using the code method to predict the *Xinjiang Kashi-Bachu* earthquake SPT cases, the low success ratio of predicting may be caused by the difference of soil characteristic and the quality of selected data, further study need to be done.

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