Reinvestigation on the Liquefied Sites in the Tangshan Earthquake

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ABSTRACT :

Liquefaction is one of the typical damages in earthquakes. The liquefaction area in Tangshan Earthquake in China on July 1976 has reached to 2400 KM^2, accompanied by a large-scale ground settlement, deformation, sliding, sand boiling and severe damages of the buildings, roads, farmlands and bridges. Some researchers have made a detailed in-site investigation on the liquefaction damages and took testing of liquefied sites during 1977 to 1979. The obtained data have been used to develop liquefaction criteria of Chinese seismic code. However, the testing equipments employed then are limited in the function. Moreover, with the changing of geological condition after 30 years, the present scene is also an interesting question which needs to be answered.
On July 2007, we go to the liquefaction sites of Tangshan Earthquake and investigate the scenes again. 23 testing boreholes are selected to conduct SCPT and V_s testes by using international advanced equipments which are quite different with those 30 years ago. the work in the paper is: (1) Analysis of the geological circumstance; (2) Testing of soil samples for learning the physical properties; (3) Comparing the historic and present information, the factors of tip resistance and friction resistance have been given; (4) Comparison of the liquefaction possibility by the seismic code using the new data with the original situation and explanation of the possible difference; (5) Prediction of liquefaction for the present circumstance by using the new methods.

KEYWORDS: Tangshan Earthquake, reinvestigate, liquefaction

1. INTRODUCTION

Liquefaction is one of the typical damages in earthquakes. Tangshan is located in the coastal plain of eastern Hebei, where the terrain is low and flat. The broad plains are covered with young sedimentary cap rock of the late Quaternary without a consolidation. And Tangshan region is a zone of tectonic activity for a long time, with active earthquake mechanism. Therefore, in this region most of the area, there are all the necessary conditions for liquefaction. The liquefaction area in Tangshan Earthquake in China on July 1976 has reached to 2400 KM^2, accompanied by a large-scale ground settlement, deformation, sliding, sand boiling and severe damages of the buildings, roads, farmlands and bridges.
On July 2007, we go to the liquefaction sites of Tangshan Earthquake and investigate the scenes again. 23 testing boreholes are selected to conduct SCPT and V_s testes and soil samples are collected.

2. INVESTIGATION

2.1 Distribution of The Test Points

There are 23 pilot sites of CPTU. The basic information of each testing borehole is shown in Table 1.

Table 1 Basic information of each testing borehole

Number	Liquefied in Tangshan Earthquake?	Site	Latitude	Longitude
T1	Y	Bridge of Douhe	N39.68541	E118.20774
T2	Y	Guili	N39.69860	E118.34025

T3	N	Xugezhuang of Fengnan	N39.54396	E118.11207
T4	N	Gaozhuangzi of Fengnan	N39.54745	E118.13343
T5	N	Liangzhongchang	N39.56293	E118.18641
T6	Y	Xidafutuo	N39.56293	E118.18641
T7	Y	Dongdafutuo	N39.55876	E118.19913
T8	Y	Laobianzhuang	N39.54255	E118.20538
T9-1	N	Daodi of Fengnan	N39.52287	E118.21356
T9-2	N	Daodi of Fengnan		
T10	Y	Jingzhuang of Fengnan	N39.53253	E118.20206
T11-1	Y	Fanzhuang of Fengnan	N39.51628	E118.20302
T11-2	Y	Fanzhuang of Fengnan		
T12	Y	Xuanzhuang of Fengnan	N39.50315	E118.13576
T13	Y	Caogezhuang of Fengnan	N39.58128	E118.32427
T14	Y	Yanjiazhuang of Fengnan	N39.57511	E118.34322
T15	Y	Yuzhuang of Luanxian	N39.75145	E118.64855
T16	N	Dongtuozitou of Luanxian	N39.75266	E118.68437
L1	N	Chemical Fertilizer Plant of Lutai	N39.32172	E117.83062
L2	Y	Agricultural Machinery factory of Lutai	N39.32503	E117.82849
E1	N	Machinery factory	N39.62901	E118.20882
E2	N	Former NO.10 Middle School	N39.60696	E118.19716
E20	N	KaiPing District	N39.68682	E118.24636

2.2 The Results of Physics Character Tests

The results of physics character tests are shown in Table 2. If the proportion that the sample's mass whose particle diameter is smaller than 0.075mm account for more than 15% of the total mass, the plasticity index will be tested by liquid-plastic limit combined measurement.

Table 2 The results of physics character tests

Number	E2	E2	E2	T5	T5	T6	T6	T9	T11	T12	T13	T14	T15
Depth（m）	2.3	2.9	4.4	2.4	3.1	2.6	3.3	2.5	1.6	2.5	2	2	1
Number	1	2	3	4	5	6	7	8	9	10	11	12	13
Nonuniform coefficient	—	2.36	2.96	—	—	4.54	—	4.27	—	—	2.43	2.72	2.72
Curvature coefficient	—	0.83	0.96	—	—	0.85	—	1.29	—	—	0.83	1.10	0.88
The maximum dry density（g/ml）	—	1.34	1.41	—	—	1.34	—	1.33	—	—	1.35	1.48	1.41
The maximum dry density (g/ml)	—	1.69	1.78	—	—	1.78	—	1.82	—	—	1.70	1.83	1.74
Plasticity index	12.5	—	—	12.3	10.4		10.4	—	12.1	11.5	—	—	—

3. COMPARISON OF NEW AND OLD DATA

The liquefied area in Tangshan Earthquake has reached to 2400KM^2. During 1977-1978, the Survey Corporation of the First Mechanical Industry Ministry, the Scientific Research Institute of Railway Ministry and

the Third Survey and Design Research Institute of the Railway Ministry made the earthquake damage investigation and foundation exploration in liquefied sites of Tangshan district. They carry on three works in the test points: sample drilling, SPT and CPT. But the probe of CPT can only obtain the specific penetration resistance Ps, which is not in line with international practice. In this paper, "the old data" and "the historic information" mean the data which was obtained by this test during 1977-1978.
The general penetration resistance includes the static point resistance Qc and side friction P_f:

$$P = Q_c + P_f \tag{1}$$

$$P_s \cdot A = q_c \cdot A + F \cdot f_s \tag{2}$$

The specific penetration resistance Ps of the new data can be obtained by equation (1) and (2), which is shown in Table 3. The relation of the Ps between new data and old data is shown in Fig.1.

Table 3 The specific penetration resistance Ps

Number	Water table (m)	Depth (m)	Layer	qc(MPa)	fs(KPa)	Ps(MPa)
T1(new)	3	5.9	5.4-6.4	6.68	189.25	9.52
T1(old)	3.7	4.95	4.1-5.8			4.59
T2(new)	2.8	3.45	2.5-4.4	3.19	257.2	7.05
T2(old)	1.25	3.45	2.5-4.4			1.97
T7(new)	3	6.6	4.6-8.6	13.5	132.6	15.49
T7(old)	3	7.35	5.5-7.8			11.63
T8(new)	4	7.6	5.2-10	11	93.61	12.4
T8(old)	2.2	7.6	5.2-10			9.12
T10(new)	3	5.85	5-6.7	4.95	93	6.35
T10(old)	1.45	8.15	6.5-9.8			5.22
T11(new)	2.6	3.7	2.7-4.7	15.25	107.35	16.86
T11(old)	0.85	4.85	2.7-7			14.15
T12(new)	2.5	3.4	2.2-4.6	2.37	48.4	3.1
T12(old)	1.55	3.4	2.2-4.6			3.01
T13(new)	4.8	4.5	3.0-6.0	11.63	106.01	13.22
T13(old)	1.05	4.8	3.8-5.8			9.45
T15(new)	2.9	2.9	1.2-4.6	12.65	101.07	14.17
T15(old)	1	3.45	1.1-5.8			5.6
T16(new)	0.3	2.85	2.0-3.7	11.63	123.42	13.48
T16(old)	3.5	3.1	2-4.2			9.83
L1(new)	0.5	6.4	6-6.8	1.89	18.32	2.16
L1(old)	0.4	6.4	5.9-6.9			3.2
L2(new)	1.1	6.4	6.2-6.6	2.99	29.8	3.44
L2(old)	0.21	6	5.7-6.3			1.89

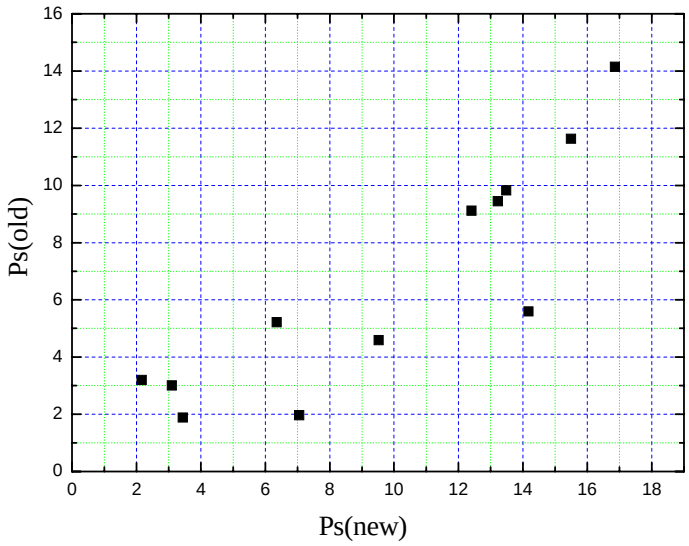

Figure 1 The linear relationship of Ps between new data and old data

From table 3, it can be found that most numerical of the new data's Ps is larger than the old data's. With the changing of geological condition after 30 years, the soil strength has enhanced and most water tables in Tangshan have descended.

The index which is obtained from the old data is Ps. But because the Bi-bridge static penetration test, which is used in most country, may simultaneously obtain the q_c and f_s, which can not only reflect the mechanical character, but also reflect the physical properties such as clay content better. So in this paper, comparing the historic and present information, using the equation 3 and 4, the factors of tip resistance and friction resistance of the old data have been supplied, which is shown in Table 4.

$$f_{s1} = \frac{f_s}{P_c} \cdot P_{s1} \tag{3}$$

$$q_{c1} = \frac{q_c}{P_c} \cdot P_{s1} \tag{4}$$

Table 4 The tip resistance and friction resistance of the old data

Number	Depth(m)	Layer	Tip resistance qc1(MPa)	Friction resistance fs1(KPa)	Ps1(MPa)
T1(old)	4.95	4.1-5.8	4.537	128.61	6.467
T2(old)	3.45	2.5-4.4	2.158	174.08	4.769
T7(old)	7.35	5.5-7.8	9.211	90.521	10.57
T8(old)	7.6	5.2-10	7.492	63.57	8.446
T10(old)	8.15	6.5-9.8	3.343	63.027	4.288
T11(old)	4.85	2.7-7	10.41	73.278	11.51
T12(old)	3.4	2.2-4.6	1.571	32.257	2.055
T13(old)	4.8	3.8-5.8	7.926	72.237	9.009
T15(old)	3.45	1.1-5.8	8.626	69.096	9.662
T16(old)	3.1	2-4.2	7.927	84.063	9.188

L1(old)	6.4	5.9-6.9	1.233	11.74	1.409
L2(old)	6	5.7-6.3	1.989	19.957	2.288

4. PREDICTION OF LIQUEFACTION AND ANALYSIS OF RESULTS

4.1 The results of prediction

"Prediction of liquefaction 1" in Table 5 means the result of present Tangshan's prediction of liquefaction, which is based on improved Seed Method and the each ground motion peak acceleration a_{max} is taken by Seismic Design Code (GB50011-2001) and Seismic Ground Motion Parameter Zone Map of China(each ground motion peak acceleration a_{max} is taken 0.2g except T15 and T16's a_{max} is taken 0.15g). The magnitude is taken 7.8. "Prediction of liquefaction 2" in Table 5 means the result of present Tangshan's prediction of liquefaction, which is based on the method of Chinese code, when the seismic fortification intensity is 8-degree and reference value of tip resistance q_{c0} is taken 10.5. "PL-1" in Table 5 means probability of liquefaction which is calculated by the C.Hsein Juang's method (2002). "PL-2" in Table 5 means probability of liquefaction which is calculated by the method which was based on bayesian theory and drawn by Doctor Moss.

Table 5 Prediction of liquefaction and probability of liquefaction

Number	Layer (m)	Prediction of liquefaction 1	PL-1(%)	PL-2(%)	Prediction of liquefaction 2	Liquefaction index
T1	3-3.6	Y	95.22	97.71	Y	20.97
	3.65-4.9	Y	97.06	99.21	Y	
	4.95-5.25	Y	96.43	94.66	Y	
	5.3-5.8	Y	89.51	53.24	Y	
	5.85-6.6	N	37.45	0.09	N	
T2	2.8-4.15	Y	85.1	11.12	Y	27
	4.15-6	Y	88.31	27.23	Y	
	6-6.9	Y	93.95	81.94	Y	
	6.9-7.75	Y	93.91	96.31	Y	
T4	2.5-3.45	Y	98.73	99.97	Y	17.58
	3.5-4.35	Y	98.99	99.96	Y	
	4.35-5.65	N	28.56	0.13	Y	
T6	2.35-3	N	15.68	0.04	Y	5.17
	5.05-5.55	Y	73.46	38.73	Y	
T7	4.5-6.2	N	0.09	0	N	0
	6.2-8.2	N	0.21	0.5	N	
T8	5.7-7.8	N	5.98	0	N	1.8
	7.8-8.15	Y	86.70	93.38	Y	
	8.15-10	N	4.10	0	N	
	10.7-11.35	Y	88.39	91.64	Y	
T9-1	2.8-3.35	Y	93.96	99.92	Y	5.01
	3.5-5.35	N	4.59	0	N	
T9-2	3-4.1	Y	58.71	54.08	Y	5.72
	4.1-4.95	N	0.25	0	N	
	4.95-6.7	N	28.85	3.71	Y	

T10	3-4.9	Y	95.18	98.41	Y	23.62
	4.9-6.7	Y	81.96	66.32	Y	
T11-1	2.6-4.7	N	0.02	0	N	0
T11-2	2.7-3.15	N	0.68	0	N	0
T12	3.15-4.75	Y	94.15	95.77	Y	12.56
	4.8-8.6	N	11.46	0	N	
	8.65-10.05	Y	95.95	99.83	Y	
	10.25-12.65	N	8.85	0	N	
T13	4.8-8.6	N	3.32	0	N	1.34
	8.65-10.05	N	0.06	0	N	
	10.25-12.65	Y	84.74	99.19	Y	
T15	2.9-4.85	N	0.14	0	N	0
	4.9-6.25	N	0	0	N	
T16	0.75-1.7	Y	85.84	78.09	Y	8.51
	2.05-3.5	N	0	0	N	
	6.4-10.2	N	0	0	N	
	11.35-12.55	N	1.48	0	N	
L1	5.95-7.15	Y	99.4	100	Y	33.58
	11.8-13.9	Y	95.96	99.9	Y	
L2	6.5-7.2	Y	95.92	99.47	Y	3.07
	12-13.8	Y	95.77	99.88	Y	

In 47 groups of soil layer's prediction of liquefaction, for most of them the results of prediction is consistent that obtained by improved Seed method and the results by the method based on Chinese code; meanwhile the results of each testing borehole's prediction of liquefaction, which are calculated by the two methods, is also consistent.

4.2 Comparing the result of prediction and liquefaction in Tangshan Earthquake

Table 6 Comparing the liquefaction in Tangshan Earthquake and prediction of liquefaction

Number	Liquefied in Tangshan Earthquake?	Prediction of liquefaction by the seismic code using the new data
T1	Yes	Yes
T2	Yes	Yes
T6	Yes	Yes
T7	Yes	No
T8	Yes	Yes
T10	Yes	Yes
T11-1	Yes	No
T11-2	Yes	No
T12	Yes	Yes
T13	Yes	Yes
T15	Yes	No
T16	No	Yes
L1	Yes	Yes
L2	Yes	Yes

Through the Table 6, the conclusion that most liquefied sites in Tangshan Earthquake will still liquefy by the designing fundamental acceleration of the seismic code can be drawn. In other words, after 30 years, the liquefaction resistance of the liquefied sites in Tangshan Earthquake does not meet basic fortification requirements.

The prediction result of T16 in the Table 6 is liquefaction, which was not liquefied in Tangshan earthquake. The liquefied layer of T16 in the liquefaction is 0.75m-1.7m. The present water table is 0.3m, which was 3.5m when the Tangshan earthquake happened. The result that the water table of T16 rises could be considered as the impact of the tectonic activity and of human activity during these more than 30 years. Through the comparison of the new data and old data, it can be seen that the water table of most sites in Tangshan district falls after 30 years' geologic structural activity and the impact of human activities. Only T16's water table rises in the reinvestigation.

It is noteworthy that the value of actual earthquake acceleration of Tangshan Earthquake is larger than the value of designing fundamental acceleration of seismic code. T7, T11-1, T11-2 and T15's prediction are not liquefaction. The site of T7 is intensity ten in Tangshan Earthquake. The site of T11-1, T11-2 and T15 are intensity nine in Tangshan Earthquake. To this point, according to the method of Chinese code, when the seismic fortification intensity is 9-degree and reference value of tip resistance q_{c0} is taken 17, the prediction of T7, T11-1, T11-2 and T15 is liquefaction. If in Tangshan the same earthquake happens which happened in 1976, the sites which liquefied in Tangshan Earthquake would still liquefy again.

In a word, most liquefied sites in Tangshan Earthquake will still liquefy by the designing fundamental acceleration of the seismic code, and if the same earthquake happens, the liquefied sites would still liquefy again.

CONCLUSION

These conclusions can be drawn:

1. There is a linear relationship about Ps between new data and old data. Based on this, the factors of tip resistance and friction resistance of the old data have been supplied.
2. With the changing of geological condition after 30 years, the soil strength has enhanced and most water tables in Tangshan have descended.
3. Most liquefied sites in Tangshan Earthquake will still liquefy by the design acceleration of the seismic code. If in Tangshan the same earthquake happens which happened in 1976, the sites which liquefied in Tangshan Earthquake would still liquefy again.
4. It is mostly same for the results of improved Seed method and the methods based on Chinese code. But the improved Seed method, which uses the inputted ground motion peak acceleration a_{max}, links up with the new generation of zoning map, can obtain the probability of liquefaction. And it is more suitable for prediction of the critical points.
5. The strength of present soil in Tangshan is larger than former, but the value of seismic intensity that will lead to liquefy in all sites now is lower than the value of intensity of Tangshan Earthquake, no more than 9 degree.

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