Laboratory study of effect of the dry density on the liquefaction stress and charisitic of the saturation compacted loess

Wang Qian, Wang Lanmin & Ma Haiping
Lanzhou Insititute of Seismology, Lanzhou, China
Key Laboratory of Loess Earthquake Engineering, Gansu Earthquake Administration, CEA, Lanzhou, China
Gao Zhongnan
Lanzhou Insititute of Seismology, China
Gansu Institute of Earthquake Engineering, China

SUMMARY:
Loess liquefaction was one of the cutting-edge topics in geotechnical earthquake engineering study, especially in China and the USA, where loess deposit distributed extensively. According to the research results of Prakash, Puri, Idriss, Boulanger and the scholars of Lanzhou institute of seismology, CEA, the dry density is one of major factors on the liquefaction stress, even it is the most major factors. In this paper, several compacted loess samples of different dry density was prepared, which made by the typical loess in Lanzhou city, Gansu province, China. The dynamic triaxial liquefaction tests were conducted on the WF-12440 hollow cyclic apparatus. Depend on collation and analysis of experimental data, the relationship between dry density and vibration times of the saturation compacted loess was proposed, and critical dry density under different seismic intensity was built.

Keywords: loess, liquefaction, dry density, influence factors

1. INSTRUCTIONS

Since 1989, a mass of outdoor observe and laboratory test results show that loess of high water content could be able to produce the phenomenon of liquefaction under the impact of dynamic load. While the dynamic triaxial tests for the undisturbed loess samples from different area in China show that the dry density is one of the most important factors of loess liquefaction.

The previous researches show that, the increase of dry density could reduce liquefaction potential of the loess foundation. Moreover, foundation treatments methods which contain various methods of compaction are widely used in lighten or remove the collapsibility and seismic settlement of loess foundation, and its effect also won the recognition of the engineering. Therefore, it can be proved as a kind of effective method to reduce or eliminate liquefaction potential of the loess foundation, which adopt compaction processing method on the loess foundation processing.

2. SAMPLES, TEST EQUIPMENTS AND METHODS

The loess samples which used in the test were taken from a site in Lanzhou city. All of the samples are Malan loess in Quaternary period. The physical parameters are shown in Table 2.1.

Table 2.1. The Basic Physical Parameters Of Undisturbed Loess

Samples	Depth (m)	ρ_d (g/cm^3)	Water contents (%)	Grain contents (%)		
				Clay	Silt	Sand
LZU-1	4	1.30	4.5	17.3	68.2	14.5

The compacted loess samples are prepared in using a sampling machine, which is followed the Chinese code "Specification of soil test (SL237-1999)", the average dry density and water content range of different sample groups are shown in table 2.2.

Table 2.2. The Physical Parameters Of Compacted Loess

Samples	Average dry density	Water content range (%)
LZ-1	1.59	9.8~10.2
LZ-2	1.50	9.8~10.2
LZ-3	1.42	9.8~10.2
LZ-4	1.35	9.8~10.2
LZ-5	1.29	9.8~10.2
LZ-6	1.23	9.8~10.2

Used a hollow cyclic apparatus typed WF-12440 to accomplish the dynamic triaxial test, and the test methods are also followed the "Specification of soil test (SL237-1999)". The loess samples are the cylinders with 50mm diameter and 100mm height. The back pressure method was used to saturate the samples. It has been shown that the method can saturate loess samples with a saturation degree of more than 90% with the residual strain less than 1%. The saturated samples were consolidated isotropically and the consolidation stresses were 100, 150, 200 kPa respectively. The loading was equiamplitude sinusoidal wave with 1Hz frequency.

According to previous study, the two standards of loess liquefaction failure are proposed: if the pore pressure ratio $U_d/\sigma_0/\geq 0.7$, or $U_d/\sigma_0/\geq 0.2$ and the axial strain $\varepsilon_d \geq 3\%$, the saturated loess may liquefy. In this paper, we adopted the second standard because the pore pressure ratio can't be easily achieved 0.7 for the loess.

The curve of dynamic stress, dynamic strain and the dynamic pore water pressure curves which is recorded by dynamic triaxial test of the typical compacted loess are shown in figure.1.

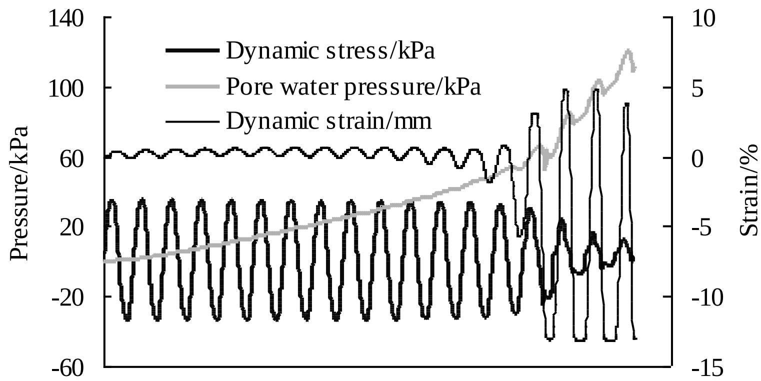

Figure 1. The stress, strain and pore pressure curves under dynamic triaxial liquefaction test

3. TEST RESULTS AND ANALYSIS

3.1. The influence on liquefaction stress

Liquefaction stress ratio is the specific value of the dynamic shear stress and the effective stress, which can characterize the liquefaction strength of the loess foundation. In this study, the main factor, liquefaction stress ratio, is chosen to sign the liquefaction strength of the foundation. The liquefaction curves of the compacted loess under different dry density is shown in figure 2.

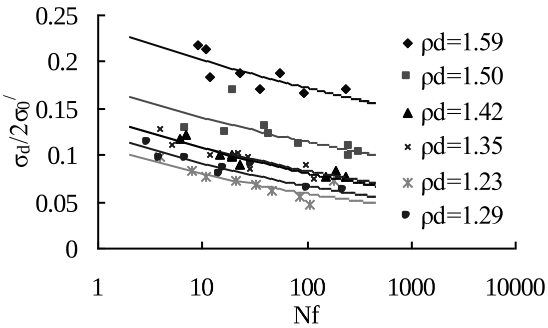

Figure.2. The relationship between (σd/2σ0') and (Nf) of different compacted loess

The chart shows that, firstly, the liquefaction stress ratio of the saturation compacted loess decrease with the growth of dynamic stress cycling times, all the liquefaction curves of different dry density of saturation compacted loess have the same change trend, which can be existed as a power correlation in a single logarithm coordinate system. Secondly, the liquefaction stress ratio of the compacted loess increase with the growth of dry density, when dry density is more than 1.35g/cm^3, the liquefaction stress ratio add markedly. Thirdly, the slope of the different liquefaction stress ratio- vibration times curve don't vary with the dry density changes, it can be proved that the dry density is not the main factors to control the attenuation trend of loess liquefaction curves.

According to the figure 2, the relationship between liquefaction stress ratio and dry density of different compacted loess cab be drawn, which as shown in figure 3, it is visibly that the liquefaction stress ratio of the saturation compacted loess increase with the growth of dry density, there has a good relativity while fitting by three polynomial function, such as equation (3.1) and table 3.1 as shown.

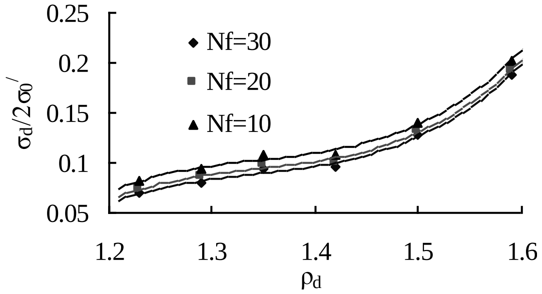

Figure3. The relationship between liquefaction stress ratio and dry density of different compacted loess

$$\frac{\sigma_d}{2\sigma_0'} = a\rho_d^3 + b\rho_d^2 + c\rho_d + d \qquad (3.1)$$

Table3.1. The Fitting Parameters And The Correlation Coefficient

Nf	Parameters				R
	a	b	c	d	
10	5.056	-20.431	27.633	-12.406	0.9971
20	4.863	-19.634	26.536	-11.912	0.9975
30	4.590	-18.473	24.902	-11.153	0.9976

To sum up, dry density has the important influence to saturated compaction loess liquefaction strength, liquefaction strength is increase with dry density increases, and even the impact is particularly significant while dry density greater than 1.35 g /cm^3.

3.2.The influence on dynamic residual strain

In order to study the influence of dry density on the dynamic characteristic of saturation compacted loess under a considerable dynamic stress and vibration times, in the study, a group of samples which has similar dynamic conditions, saturation degree and the same consolidation conditions is chosen, the variation tendency of the dynamic residual strain with the vibration times change is analyzed though the records of the dynamic triaxial tests. The physical parameters and dynamic stress of the chosen compacted loess is shown in table 3.2. The results of the research are shown in figure 4.

Table3.2. The Physical Parameters And Dynamic Stress Of The Chosen Compacted Loess

Samples	ρ_d (g/cm^3)	Sr (%)	σ_3 (kPa)	σ_d (kPa)
LZ-1-150-1	1.59	86.1	150	40
LZ-2-150-1	1.50	82.9	150	30
LZ-3-150-2	1.42	97.2	150	30
LZ-4-150-2	1.35	84.2	150	30
LZ-5-150-3	1.29	92.3	150	30
LZ-6-150-1	1.23	96.4	150	30

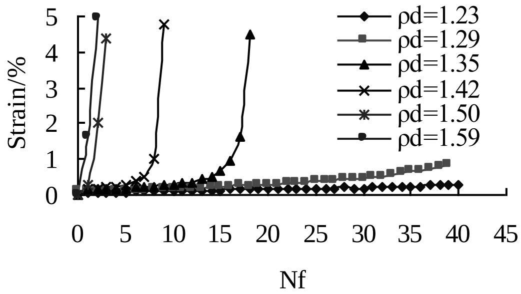

Figure 4. The dynamic residual strain characteristics of different compacted loess

As seen in the figure, the bigger the dry density is the variation tendency of the dynamic residual strain change slowly. When the dry density ρd⩽1.29g/cm^3, the dynamic residual strain increase almost as a straight line, and the sample is liquefied at 2 or 3 times. When the 1.35g/cm^3⩽ρd⩽1.50g/cm^3, the dynamic residual strain grows slowly at the first few times, however, which has a sharp increase in the following times due to the accumulation of the rupture energy, and the loess is liquefied. When the ρd ＞1.50g/cm^3, the growth of the dynamic residual strain slow slight, even to 0.8% with the vibration times to 40, while when the ρd＞1.59g/cm^3, the structure of the loess tends to a stable level, and the dynamic residual strain almost as a horizontal line with the vibration times increase.

4. COMPREHENSIVE EVALUATION OF LIQUEFACTION STRESS AFTER COMPACTION TREATMENT

In the above studies, the influence of the dry density on liquefaction stress and dynamic residual strain is analyzed though the results of the dynamic triaxial test on the compacted loess, and the dry density is proved to be the most significant factors to influence in the liquefaction of the loess. Moreover, the compaction treatment is as a effective measure to prevent the loess foundation liquefied. However, the concomitant question is, to determine the critical dry density of foundation liquefied under different seismic intensity, which is the key problem to resolve the liquefaction of the loess foundation.

According to the Simplified discriminate method proposed by R.B.Seed, the soil is no longer to liquefaction when the liquefaction stress of the soil bigger than the equivalent shear stress. In this study, the critical liquefaction stress ratio under different seismic intensity is calculated though the proposed method and the critical dry density under different seismic intensity is computed though equation (3.1), which is shown in table 4.1.

Table4.1. The Critical Liquefaction Stress Ratio And Critical Dry Density Of Different Seismic Intensity

Seismic intensity	Critical liquefaction stress ratio	Critical dry density (g/cm^3)
6	0.092	1.260
7	0.184	1.571
8	0.369	1.711

5. CONCLUATION

Dry density is proved to be the most important factors to influence in the liquefaction of the loess, the liquefaction stress of the compacted loess dramatically increase with the dry density increase, and the attenuation trendy of dynamic residual strain was very obviously. In addition, compaction treatment is an effective method to improve the liquefaction stress of the loess foundation. The critical dry density of the saturation compacted loess are1.260g/cm^3, 1.571g/cm^3 and1.711g/cm^3, respectively, which under the seismic intensity of 6, 7 and 8. However, the critical values will be necessary to confirm though the in-situ test when it as the basis of the liquefaction treatment.

AKCNOWLEDGEMENT

This paper financially supported by the Science and Technology Foundation from Gansu Earthquake Administration, CEA (2011S01), the Basic Scientific Research Business from Institute of Earthquake Science, CEA (2012IESLZ07) and the National Natural Science Foundation of China (50978239).

REFERENCES

Ishihara K, Okusa S, Oyagi N, et al. (1990). Liquefaction- induced flow slide in the collapsible loess deposit in soviet Tajik.*Soils and Foundations*, 30:4, 73-89.

Wang Qian, Wang Lanmin, Yuan Zhongxia, et al.(2012). Study on loess liquefaction in Tianchuan, Qingshui county, Gansu province induced by Wenchuan Ms8.0 earthquake. *Hydrogeology & Engineering Geology*, 39:2, 116-120.

Wang Lanmin. (2003). Loess Dynamics. Seismological Press, Beijing, China.

Wang Lanmin, Wang Yaqiang, Wang Jun, et, al. (2004). The liquefaction potential of loess in China and its prevention. *13th World Conference on Earthquake Engineering Vancouver.* B.C. Canada.

Ivan B. Gratchev, Kyoji Sassa , Victor I. Osipov , Viatcheslav N. Sokolov. (2006). Liquefaction of clayey soils under cyclic loading. *Engineering Geology* , 86, 70-84.

Seed H B, Idriss I M. (1988). Ground motions and soil liquefaction during earthquake. Seismological Press, Beijing, China.