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STUDY ON LIQUEFACTION OF LOESS SITE

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ABSTRACT

Using dynamic triaxial test the liquefaction of saturated loess and sand secured from a civilian airport near Lanzhou is evaluated. Based on the liquefaction test and using probability shear stress obtained through seismic hazard analysis and 1-D FEM calculation, a integrated assessment on the liquefaction potential respectively of loess and sand are given. The results show that under the earthquake effect with exceedance probability of 10% within 50 years, loess is more prone to liquefaction that sand.
Key Words: loess, sand, liquefaction, dynamic triaxial test

INTRODUCTION

Due to its high vulnerability, liquefaction, seismic landslides and seismic subsidence could be easily triggered under earthquake in loess ground or loess slope. In 1989, a 5.5 earthquake jolted former Soviet republic Tajik and a series of liquefaction caused landslides developed on a nearly flat ground and buried homes. This aroused great interest of study on loess liquefaction. Recent laboratory study also shows that saturated loess or loess with high water content has a fairly high potential of liquefaction and becoming mud flow and thus incur dangers to human life and properties. Therefore, it is necessary to evaluate the liquefaction potential of loess during seismic design of ground and geotechnical structures.

For seismic safety assessment of construction site, liquefaction assessment is one of the important content. In case of the civilian airport near Lanzhou, liquefaction assessment is necessary, because agricultural irrigation conditions raises underground water table and thus could lead to the saturation of soil layers.

GENERAL INFORMATION OF THE SITE

The airport is in a tectonic basin formed in tertiary in Qinwangchuan. The bedrock is red mudstone with layers of sandstone. The overburden is Pleistocene and Holocene(surface layer) alluvial or diluvial deposit. The ground is level land.

The surface layer is loess or lossial soil with thickness ranging from 1.0 to 2.0m at the North part, 3.0 to 6.0 at the Middle part and 13.0 to 16.0 at the South part of the planned runway area. The loess soils are have self water collapse from Ⅱ～Ⅲ degree according to Chinese code. And silt sand lens are found in loess layers.

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SEISMIC HAZARD ANALYSIS RESULTS

According to seismic hazard analysis done by Lanzhou Institute of Seismology, the seismic intensity of this area is Ⅶ degree plus and PGA with exceedance probability of 10% within 50 years is 165.6gal.

AN OVERVIEW ON LIQUEFACTION TEST

The samples used in the tests are given in Table 1, all these samples are secured from exploratory well dug in the runway area.

Table 1. Physical Indices of Samples

Sample Group	Depth/m	γ/KN/m^3	W/%	w_l/%	w_p/%	I_p	Soil
KT-1	11.0-11.2	15.39	11.75	24.2	16.6	7.6	Loess
KT-2	9.0-9.2	15.77	16.84	26.0	17.0	9.0	Loess
KT-3	8.9-9.1	16.66	17.81	23.7	16.5	7.2	Loess
KT-4	9.0-9.2	15.39	11.27	24.9	16.8	8.1	Loess
KT-5	7.4-7.6	15.78	2.48				Fine sand
KT-6	10.0-10.2	17.35	5.85				Fine sand

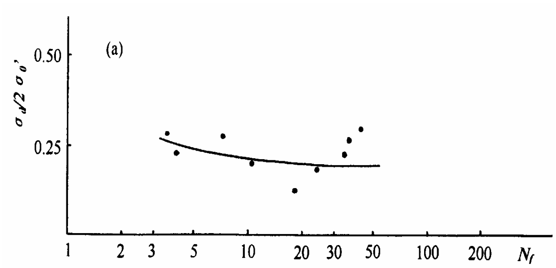
The test facility is DSD-160 electromagnetic-driving triaxial system and the method of test adopting the "Geotechnical Test Code (SL237-1999)" recommendations. The samples prepared are 100mm high with diameter of 50mm. The saturation is achieved with water head pressure, with which the degree of saturation can reach over 80% within one hour to meet the requirements of the code[3], which requires the preserve of the structure of loess during process of saturation.

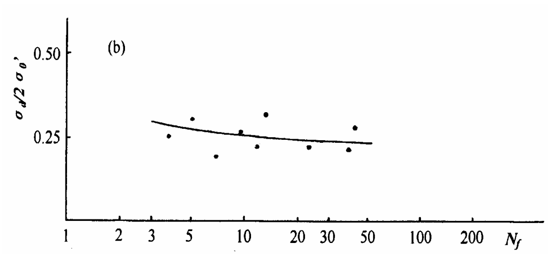
Three levels of confining stress, namely, 80kPa, 140kPa and 200kPa are applied for homogenous consolidation. The sinusoid load has frequency of 1Hz.

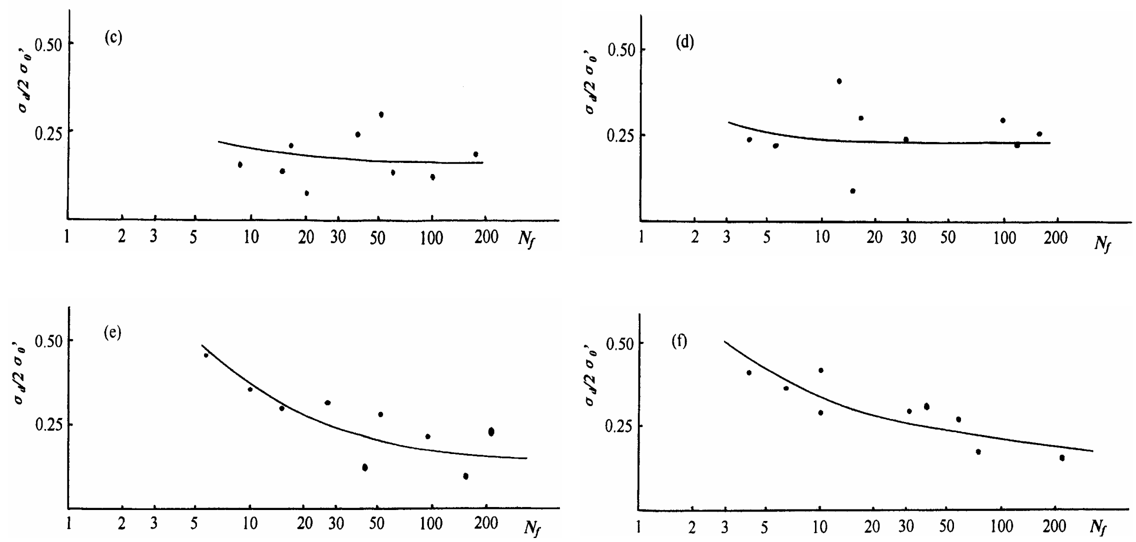
According to "Geotechnical Engineering Survey Codes(GB50021-94)[4]", the criteria of liquefaction defined as the two following situation: 1. the pore water pressure rises to equal that of initial confining pressure, or 2. the axial strain reaches 5%. In this test, the second criterion is used.

LIQUEFACTION TEST RESULTS

The results of six group of samples are given in Fig.1, which shows the relationship between cyclic stress ratio ($\sigma_d/2\sigma_0$') and number of cycles causing liquefaction. From Fig.1, cyclic stress ratio for cyclic number of 10 and 20 can be derived to for code procedures (Table 2). This is to be coincide with code stipulation.







(a. KT-1 b. KT-2 c. KT-3 d. KT-4 e. KT-5 f. KT-6)

Figure 1. The cyclic stress ratio versus cycles of liquefaction

Table 2. Cyclic stress ratio for 10 and 20 cycles

Sample Group	Soil	Cyclic stress ratio	
		N=10	N=20
KT-1	Loess	0.210	0.190
KT-2	Loess	0.260	0.250
KT-3	Loess	0.200	0.180
KT-4	Loess	0.240	0.230
KT-5	Fine sand	0.365	0.280
KT-6	Fine sand	0.340	0.290

LIQUEFACTION ASSESSMENT

Liquefaction resistance calculation

Under natural condition, liquefaction resistance (τ) of soil is calculated using formula (1) [5]:

$$\tau = C_r \sigma_v^{'} \frac{\sigma_d}{2\sigma_0^{'}} \qquad (1)$$

Where C_r is correction coefficient, $\sigma_v^{'}$ is initial overburden stress in KPa, $\frac{\sigma_d}{2\sigma_0^{'}}$ is cyclic stress ratio, σ_d is dynamic stress in KPa, $\sigma_0^{'}$ is effective consolidation stress in KPa..Table 3 gives the liquefaction resistance of the sample group respectively under 10 and 20 cycles.

Table 3. Liquefaction resistance of each group of samples for 10 and 20 cycles

Sample Group	Soil	$\sigma_v^{'}$ /KPa	τ/KPa	
			N=10	N=20
KT-1	Loess	166.4	19.2	17.4
KT-2	Loess	144.6	20.7	19.9
KT-3	Loess	155.5	17.6	15.8
KT-4	Loess	142.5	18.0	14.8
KT-5	Fine sand	119.1	26.5	20.3
KT-6	Fine sand	174.0	38.5	32.8

Note: 10 and 20 cycles corresponds to seismic intensity of Ⅶ and Ⅷ

Earthquake shear stress calculation

There are two approaches to estimate the shear stress caused by earthquake: 1. using 1-D FEM method or 2. using formula (2) to get equivalent shear stress.

$$\tau_e = 0.65K \frac{\alpha_{\max}}{g} \gamma d_s \tag{2}$$

where K is stress modification factor, $\alpha_{\max}$ is Peak ground acceleration, g is gravity acceleration, γ is unit weight and d_s is depth of soil layer in consideration.

Table 1 gives shear stress got using two different approaches. Clearly, there is some variation of results, so it is better to consider the range of shear stress for safety purpose.

Table 4. Earthquake shear stress (τ_e)

Sample Group	Soil	Depth/m	τ_e/KPa	
			Approach 1	Approach 2
KT-1	Loess	11.0-11.2	18.3	16.3
KT-2	Loess	9.0-9.2	15.1	15.1
KT-3	Loess	8.9-9.1	27.4	16.5
KT-4	Loess	9.0-9.2	14.8	14.2
KT-5	Fine sand	7.4-7.6	11.5	12.2
KT-6	Fine sand	10.0-10.2	13.3	17.6

Liquefaction potential assessment

Liquefaction assessment is based on the comparison of earthquake shear stress and liquefaction resistance of each group of samples If the former larger that the latter, liquefaction is very likely otherwise it is considered non-liquefiable.

Using this method, liquefaction potential assessment can be got based on data from Table 3 and 4. The final result is given in Table 5 for liquefaction potential under earthquake effect with exceedance probability of 10% within 50 years.

Table 5. Liquefaction Assessment considering effect of earthquake with exceedance probability of 10% within 50 years

Group	$\tau_e > \tau$?				Liquefiable?				Liquefaction Assessment
	Approach 1		Approach 2		Approach 1		Approach 2		
	N=10	N=20	N=10	N=20	N=10	N=20	N=10	N=20	
KT-1	No	Yes	No	No	No	Yes	No	No	Liquefiable(N=20)
KT-2	No	No	No	No	No	No	No	No	No
KT-3	Yes	Yes	No	Yes	Yes	Yes	No	Yes	Liquefiable
KT-4	No	No	No	No	No	No	No	No	No
KT-5	No	No	No	No	No	No	No	No	No
KT-6	No	No	No	No	No	No	No	No	No

It can be seen from the assessment that[7,8], there is liquefaction potential under seismic intensity VII if the soil in KT-3 area would saturated because of rising of ground water table in the future. Under effect of lager seismic intensity, degree VIII in this case, ground of both KT-1 and KT-3 may liquefy. But under either situation, the saturated sand layer are unlikely to liquefy.

CONCOLUSIONS

The following conclusions can be got based on liquefaction assessment:

(1) For liquefaction resistance in terms of shear stress, that of saturated loess is lower than Sand's. Also, the loess needs less cycles to trigger liquefaction that sand, indicating shorter duration needed for loess liquefaction.
(2) For soil of nearly the same depth, liquefaction resistance of loess is lower than that of sand, so loess has a higher potential of liquefaction.
(3) The integrated method used in this study is reasonable to assess the liquefaction potential of loess. The result can serve as reference for seismic design.

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