Experimental study on pore pressure generation mode of saturated remolded loess during dynamic liquefaction

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Abstract. Through dynamic triaxial tests of the saturated remolded loess, the pore water pressure generation characteristics of the samples are analysed during liquefaction processes. Based on dynamic triaxial test results, pore pressure generation characteristics of remolded sample are discussed, the effect of confining pressure on the generation of excess pore water pressure is evaluated, the particularity of pore pressure generation by comparing with the predecessor's research results is pointed out and the normalized pore pressure growth model is given. Finally, fitting curve of pore water pressure growth is drawnby using this model and fitting parameters are given.

1. Introduction

Nowadays, our country is still in seismic active period and the loess area is located in strong earthquake activity area [1]. In this area, the seismic disasters such as land slide and subsidence often occur during earthquakes. Under earthquake loads, pore water pressure can increase rapidly and effective stress can decrease, which will lead to soil liquefaction [2]. Therefore, it is important to research pore pressure generation and seismic stability during liquefaction of loess area. Initial liquefaction and cyclic mobility both can cause extensive damage during earthquakes, including sand boils, settlement and tilting of buildings and bridge abutments, collapse of offshore structures, lateral spreading and cracking of slopes, flow failures of earth dams, cracking of pavements, and flotation to the ground surface of buried concrete tanks.

Cyclic loading of saturated granular soils can result in the generation of excess pore water pressure under undrained conditions. In loose soils, the developed excess pore water pressure can be as high as the existing overburdened pressure on soil. This condition corresponds to zero effective stress and is called initial liquefaction of the granular soil [3]. Fitting pore pressure formula is given combining with the influence of dynamic size, dynamic form, vibration frequency and consolidation ratio to saturated loess vibration of pore pressure [4]. Pore pressure growth model of saturated undisturbed loess under dynamic loading is given [5-6].

For pore pressure change regularpattern of saturated undisturbed loess specimen under dynamic loading, many pore pressure growth models have been given, but research result about remolded sample is little. In this paper, loess liquefaction is studied experimentallywith a dynamic triaxial apparatus. Through the vibration liquefaction test of saturated remolded loess, the pore pressure generation characteristics of remolded sample is discussed, the particularity of pore pressure generation by comparing with the predecessor's research, is pointed out, and the normalized pore pressure growth model is given finally.

2. The test instruments and samples preparation

2.1The Test Instruments

The experiments were conducted with motor control dynamic triaxia test system manufactured by GDS Co. in the British. This instrument uses digital pressure/volume controller which improve the precision of the pressure to 0.1 kPa and the precision of the volume change to 1 cubic millimeter. All experiences can through the computer GDSLAB software for servo-type control and all the parameters are directly recorded.

2.2Samples Preparation

The soil of test are taken from XiAn area, brown yellow and soil evenly, The property indexsare shown in table 1 and granule analysis curves areshown in figure 1：

TABLE 1. Major physical parameters of silt

Specific Gravity/Gs	Natural Moisture Content/%	Wet Density/ g/cm3	Dry Density/ g/cm3	Liquid Limit/%	Plastic Limit/%	Plastic Index/Ip
2.71	24.5	1.87	1.50	28.0	17.8	10.2

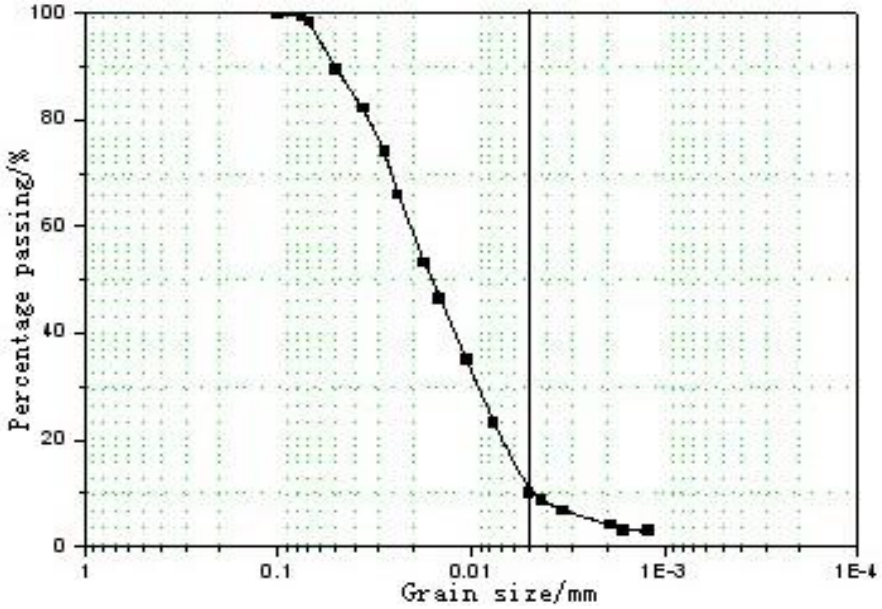

FIGURE1. Grain size distribution of tested soil.

The grain size distribution is given in FIGURE1. About 10% by weight of particles of this clay is smaller than 0.005mm, but it almost does not contain any sand. Different researchers around the world have proposed throughout the years a great number of preparation methods of sand samples for laboratory testing. For example, the water sedimentation method is one of the most popular methods for sample preparation (Kuerbis and Vaid, 1988). Wet installed molding, it is used for easy sedimentation of sand soil, silt cohesionless soil, etc； Compaction of the sample is performed by use of a thin rod, it is used for all kinds of clay soil.

During specimen preparation process, first make the soil airing dry and next shake them through the 2 mm standard soil sieve, large particles which cannot through the sieve should be ground scattered by mallets. The clay mineral composition of loess are mainly composed of montmorillonite, and bentonite predominantly montmorillonite clay minerals, so different clay content of the sample by adding bentonite directly to the loess.

The samples used in the experiment are all prepared by dry pack compaction methods which are determined by averagedry density of soil sample in situ test. Samplessize are50 * 100 mm and samples are compacted for five layers; Samples are prepared by special compaction instrument and each layer needs contact well to avoid statified phenomenon.

3. The test method

After the completion of the samples preparation, put them in a cylinder for vacuum suction to attain saturation; Then make the samples saturated by back pressure on dynamic triaxial apparatus, and when pore water pressure coefficient is equal or greater than 0.98, drainage consolidation of samples can be done. After the completion of the consolidation,close drain valve and use different dynamic load in test. In FIGURE2, The test can recordthe dynamic loading, dynamic pore pressure and dynamic strain test data.

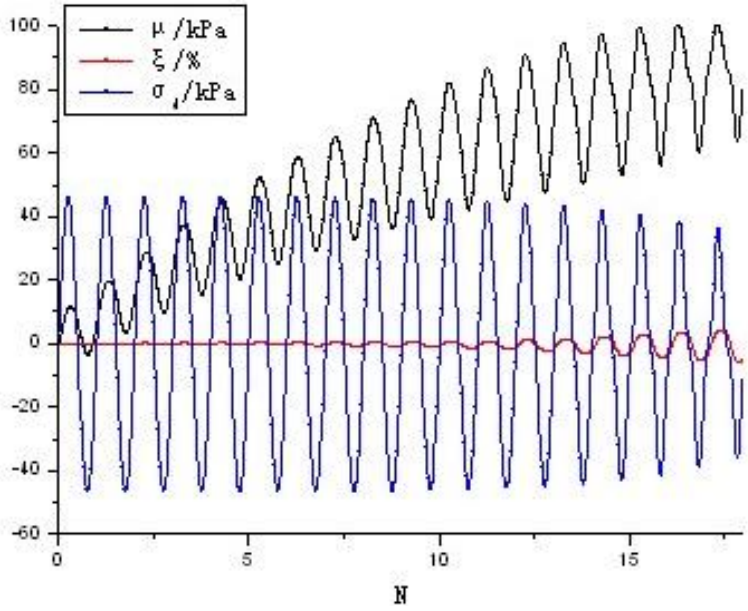

FIGURE2. Test record curve under dynamic loading

4. Analysis of test results

Through the analysis of pore pressure growth pattern by Jianmin Zhang, pore pressure growth curve is divided into A, B and C three categories (FIGURE3). It is used to simulate the seismic load which producethe pore pressure curve in the front, central and rear of seismic time history. Among them, type B curve area can better simulate hole pressure growth process of sand and loess soilpore water pressure growth curve is more close to type A curve area.

$$U_d = U_f(1-e^{-\beta\frac{N}{N_f}}) \qquad (1)$$

$$U_d = \frac{2}{\pi}U_f \sin^{-1}(\frac{N}{N_f})^{\frac{1}{2\alpha}} \qquad (2)$$

$$U_d = U_f[\frac{1}{2}(1-\cos\pi\frac{N}{N_f})]^b \qquad (3)$$

（1）Type A pore water pressure growth curve

（2）Type B pore water pressure growth curve

（3）Type C pore water pressure growth curve

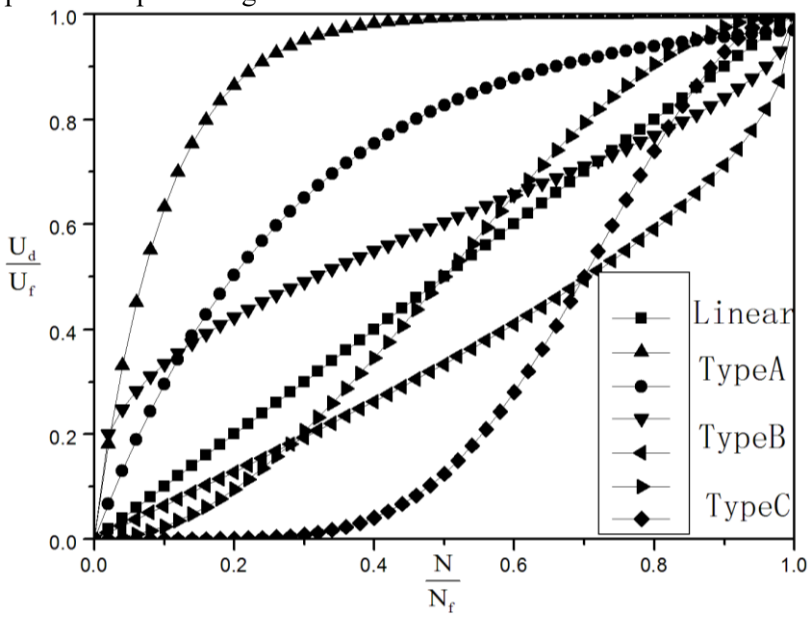

FIGURE3. Pore pressure growthRegional division

From pore water pressure growth curve under dynamic loading in figure 2, it can be seen that pore water pressure growthcharacteristics of remolded saturated loess sample is different from sand sample. This is mainly due to the uniquestructural characteristics and different contentof clay in loess.

Figures 4 shows the results of the tests performed on specimens, that is, the excess pore water pressure(μ = measured excess pore water pressure) is presented versus the number of loading cycles(N), for shear stress levels of 25, 30, 35, 40 and 50 kPa. As can be seen from Figure 4, the excess pore water pressureincreased significantly during the first 10 loading cycles for all shear stress levels, and continued its development at a slower rate with further application of loading cycles.

From figure 4, we also can see that the specimen tested at 25kPa shear stress showed a progressive increase with increasing number of loading cycles. The excess pore water pressure ratio at this stress level was 3% after the first cycle, and ascend to approximately 38% at the end of 50 loading cycles. Similarly, at the biggest applied shear stress of 50kPa, the excess pore water pressure ratio progressively increased from 10% at the end of the first cycle of loading to 100% after 17 loading cycles. At this point the specimen has reached full liquefaction in 17 cycles. It is clear that as the shear stress level increases, more excess pore water pressure is generated for the same number of loading cycles.

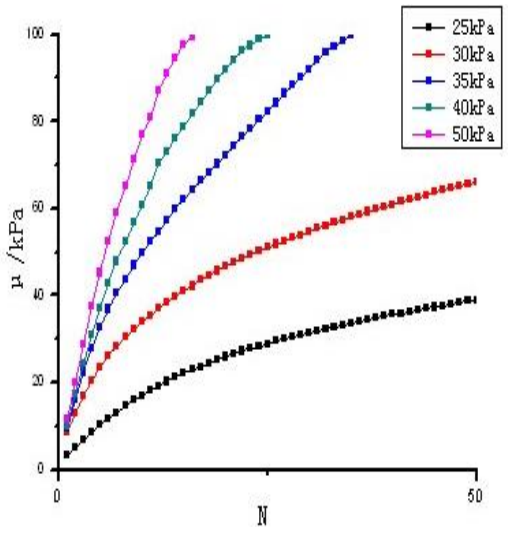

FIGURE 4. Excess pore water pressure generation as a function of number of loading cycles

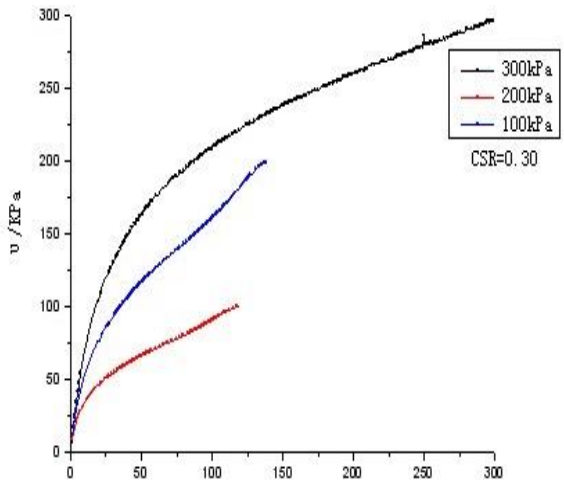

FIGURE 5. Comparison of excess pore water pressure measurements from σ3=100kPa、200kPa and 300kPa specimens at CSR=0.30

Figure 5 displays the comparison at the smallest shear stress level of CSR=0.30, The shapes of the pore water pressure responses of the big and small confining pressure specimens are again similar.The main difference is that the excess pore water pressure in the big confining pressure is about 5% more than it in the small confining pressure. This difference appears to be maintained approximately constant at all loading cycles.Interestingly, the rate of excess pore water pressure generation are similar in the different confining pressure (FIGURE 6).

From figure 6, we can see that pore water pressure growth characteristics of saturated remodedloess samples are different from sand during vibration process. In the earlyvibration days, the pore pressure is growing faster, when the cycles ratio is 0.2, pore pressure ratio has risen to about 0.5; and with vibration continues, pore pressure ratio rising will slow down and reach the final stability, pore water pressure will present a fast-slow-flat trend.DuringThe whole process, the change of pore water pressure will not appear sharply or sudden increase phenomenon, but gradually become stable, This regular pattern is different from saturated loose sand. Based on this, the author put forward pore water pressure growth normalized relations model of saturated reshapingloess samples as following:

$$\frac{U_d}{U_f}=(\frac{N}{N_f})^{\beta}\sin[\frac{\pi}{2}(\frac{N}{N_f})^{\alpha}]$$

Where U_f :maximum pore pressure under liquefaction, U_d :instantaneous pore pressureundervibration, N_f :liquefaction cyclic, N ： vibration cyclic, β are parameters of test which are determined by dynamic load size, vibration frequency, α the nature of the earthsoil such as mineral composition, grain size distribution and density; α is smaller, the curve shape is more fullness, α is 0.34 in this paper.

Using this model, the fitting curve of pore pore water pressure growth is shown in figure 7:

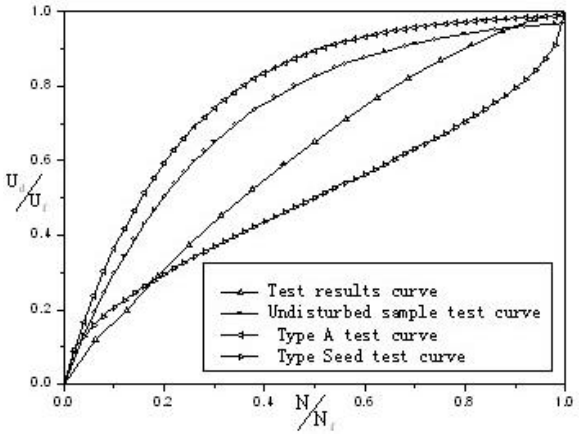

FIGURE 6. Different types of pore water pressure growth curve

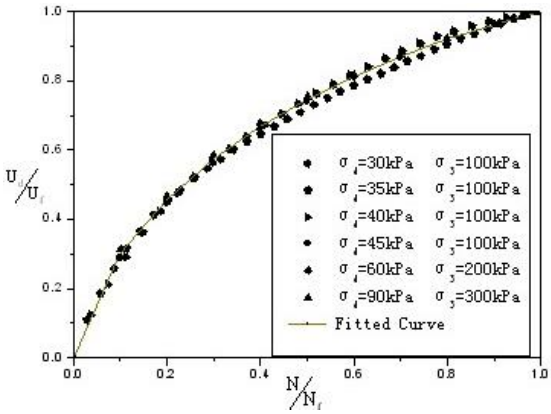

FIGURE 7. Fitting resultsof pore water pressure growth curve

5. Conclusion

The excess pore water pressure generation insaturated remolded loess is evaluated using stress-controlled and undrained cyclic triaxial tests. Then, the effect of confining pressure on the generation of excess pore water pressure is evaluated by comparing the responses of 100kPa, 200kPa and 300kPa. This comparison shows that, the excess pore water pressure generation in different confining pressure is similar in general. The pore water pressure growth characteristics of saturated remolded loess samples are different from sands'. Through the analysis of data, pore water pressure growth model is established.

Acknowledgments

[1]Liu Jian-min, Male, Master graduate student, Mainly engaged in the study of soil dynamics, tel: (15963101199).

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[3]ContractalResearchProjectofEarthquakeAdministrationofShandongProvince,China（13Y86）

[4]Spark ProgramofEarthquakeSciences,China（XH16014）

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