# DISCUSSION ON THE PROBLEM ABOUT SATURATED LOESS DYNAMIC PORE PRESSURE BY VIBRATION

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## SUMMARY

Based on the dynamic triaxial test of the saturated loess, according to the undisturbed and saturated loess's liquefaction course caused by cyclical load and random load, the loess framework shrinkage, elastic shear, framework expansion with different status changes and the basic origin and type can be revealed. In the condition of isotropic consolidation, the pore pressure change law of the saturated loess liquefaction under different loads can be gotten.

## INTRODUCTION

China loess characterizes the complete soil layers, many sorts and large thickness. The loess thickness in Lanzhou district is 410 meter. The distribution rank first in the world. The two disasters -landslide and subsidence by earthquake in loess district have been recognized. Liquefaction is the first reason causing disaster, about 50 percent of foundation destabilization was caused by liquefaction. But the earthquake survey recently and lab initiative experiments indicate that loess have big liquefaction potential such as the flow damage potential. When the loess contain much water, it can be change into liquefaction and flow under certain earthquake. So the liquefaction property test study on saturated loess is a new subject, the information about this respect is very rare in the world today. The pore water development is the critical factor relating with loess liquefaction.

The pore pressure developing laws of saturated non-cohesive soil under cyclic load has been well studied. The material about loess with little adhesiveness can not found much, experience and test reveal that adhesive grain existing in soil strengthens its liquefaction. The test in this paper shows that loess is obviously different from the soil without adhesiveness and silt, the vibration pore water rule of loess is very special.

## TEST SUMMARY

The loess clay particle (d<0.005mm)content in this paper is about 10.5 percent. Its relative parameters are showed in table 1.

The loess pore pressure rule by vibration in this paper is gotten by electromagnetic dynamic triaxial vibration apparatus. The frequency of constant amplitude load is 1 Hz, the diameter of soil sample D=50.0cm, its height H=100cm, the shape is cylinder, the saturation degree in test exceed 80 percent (loess code rule that when the saturation degree reach 80 percent, it can be called saturation). The side stress $\sigma_{3c}$ is 50,100 and 150kpa

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**Table 1: The physical index for sample**

| Soil sample NO. | Water Content | Unit Weight $KN/M^3$ | Porosity Ratio | Plastic Limit(%) | Plasticity Index | Soil component (%) | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | Silt particle | Clay particle | Sand Particle |
| L95-2 | 18.7 | 17.95 | 0.753 | 8.5 | 9.8 | 68.6 | 9.3 | 22.1 |
| L94-2 | 11.3 | 15.2 | 0.973 | 9.1 | 10.02 | 76.1 | 10.2 | 13.7 |
| L94-1 | 9.8 | 14.6 | 0.876 | 8.6 | 9.4 | 76.5 | 9.1 | 13.0 |
| L89-1 | 15.1 | 13.83 | 1.14 | 13.1 | 8.7 | 67.4 | 11.0 | 21.6 |

respectively, when the consolidation ratio $k_c$ equals 1.0, the undrained shear triaxial dynamic test was carried out. Based on the test, the analysis and summary of dynamic pore pressure was done. The initial conclusion can be gotten.

## THE DEVELOPMENT LAW OF DYNAMIC PORE PRESSURE IN SATURATED LOESS

The pore pressure change in saturated loess under cyclic load and random load not only have the monotonous and cumulative increase property, also have the transient and wavy property. The pore pressure increase by different loads was mainly determined by the status of load-on and load –off, effective stress history, stress path and the framework structure change. So the pore pressure by different loads has different tendencies and characters due to different factors, this will determine the pore pressure increase speed. Different soils, different dynamic loads and static loads and pore pressure increase phenomenon relating with soil framework shrinkage will produce the complicated pore pressure varieties of development course and change shape.

### The Basic Type of Pore Water Pressure

The pore pressure in saturated loess was produced when the water in soil framework was pressed. But different reasons correspond different properties. For example, the pore water pressed by static water decreases the soil weight because of floatage. Thus it reduces the effective stress delivered by soil article, but this type of pore pressure increase does not affect the soil framework deformation. Take another example, saturated loess in the condition of consolidation without water drainage can produce some volume change due to certain reason(such as various loads), this shows the pore pressure change. If the volume change was caused by soil structure damage, which was produced by external load, the irrecoverable deformation appears, then the pore pressure will remain after the load-off. If that was caused by recoverable structure deformation, then the pore pressure will immediately disappear after load-off. If in the condition of unchangeable external load, the permeable tendency which pore water flow from high pore pressure to low one because of different pore pressure in saturated soil produce the pore water diffusion and slaking. If the framework volume change occurs while pore water is in the course of seepage, this certainly cause expansion and shrinkage in soil framework. Therefore, pore pressure can be classified as several types according to their origin, which was shown in table 2. The basic definition, forming conditions and their characters were included in table 2.

The former two types of pore pressure stated in table 2 were determined by static principles and porous medium theory respectively. But the pore pressure in saturated loess under cyclic load mainly show elastic pore pressure, structural pore pressure and delivery pore pressure.

### Pore Pressure Development Historical Part in Saturated Loess

The pore pressure development course involving in vibration from beginning to liquefaction in saturated loess can classified as three time intervals. During the course of dynamic load, soil experienced different time intervals. The stress, pore pressure and deformation caused by structural damage in different time intervals are related with different change properties. It can be seen from figure 1, in the first time interval, dynamic stress remains a constant, but the dynamic deformation of soil sample is small. Pore pressure increases steadily with the vibration times. The pore pressure amplitude changes a little. There is only the alternative change of shear shrinkage with load-on and elastic shuttle with load-on or load-off. Deformation increases slowly, but the stress and strain rate have less change than it in former stage because the soil framework have a light change in soil structure, strain is little bigger. In second time interval, dynamic stress amplitude reduce rapidly, dynamic deformation increase sharply, pore pressure increase while its amplitude reduce. In this time interval, the shear expansion section begins to appear and gradually develop with circles at the moment corresponding to stress peak in the half tension circle, it indicates that lasting time are increasing. On the one hand, the deformation corresponding to half tension circle increases a lot. On the other hand, the pore pressure lasting time corresponding to half tension circle increase too, and the relative opposite shear section which develop with circle gradually appear( the former two changes are similar to soil without adhesiveness). In the third time interval, dynamic stress was reduced to a steady value, deformation increases to certain amplitude then keeps it( this is the difference with non-cohesive soil ). The attenuation rate of remain deformation increase rapidly, pore pressure do not increase, and keep a steady value. In this time interval, the time interval of two half circles of tension and press is becoming shorter and shorter with the load-on shear shrinkage and the load-off rebound, the sequence of the opposite shear shrinkage section appear repeatedly.

**Table 2: Five pore pressures**

| Sorts of pore pressure / Terms | Static pore pressure | Seepage pore pressure | Elastic pore pressure | Structural pore pressure | Delivered pore pressure |
|---|---|---|---|---|---|
| Basic Definitions | The pore pressure in saturated soil under static water load | Pore water is caused by seepage in saturated soil when the soil framework stress potential is zero, generally called seepage Pressure | Without drainage, the pore pressure was caused the elastic volume strain potential in saturated soil framework, also called stress pore pressure | No drainage, the pore pressure was caused by non-elastic volume strain potential which was produced by soil framework in saturated soil | No drainage, the pore pressure was caused by volume strain potential because of pore water slaking and diffusion in saturated soil framework |
| Formation Conditions | 1 saturated<br>2static water pressure | 1 saturated<br>2drainage<br>3certain hydraulic gradient | 1 saturated<br>2no drainage<br>3the change of external load or total stress | 1 saturated<br>2no drainage<br>3the change of external load or total stress | 1 saturated<br>2no drainage<br>3steady eep the external load or total stress |
| Basic Properties | 1soil has a little change of framework shrinkage and expansion, volume change is zero<br>2soil weight reduction which was affected by floatage reduce the effective stress<br>3the change of static water do not change effective stress | 1soil has a little change of framework shrinkage and expansion, the volume strain potential is small<br>2change relate with seepage gradient<br>3effective stress involve in the seepage direction | 1the plastic damage in soil structure do not appear, it has certain elastic strain potential, no volume strain<br>2change do not relate to load path<br>3effective stress has change<br>4the effective stress portion in total stress relate to structural strength, elastic property and load | 1the soil structure was destroyed, with certain non-elastic strain potential and volume strain,<br>2change involve in load path closely<br>3effective stress path has conversion to pore pressure<br>4the change rate relate to external load, soil structural damage and soil status | 1have the shrinkage and expansion of soil framework and change of volume strain potential<br>2change involve in load path<br>3redistribution of effective stress<br>4the value was determined by the extent of structural damage and lasting time for pore pressure slaking |

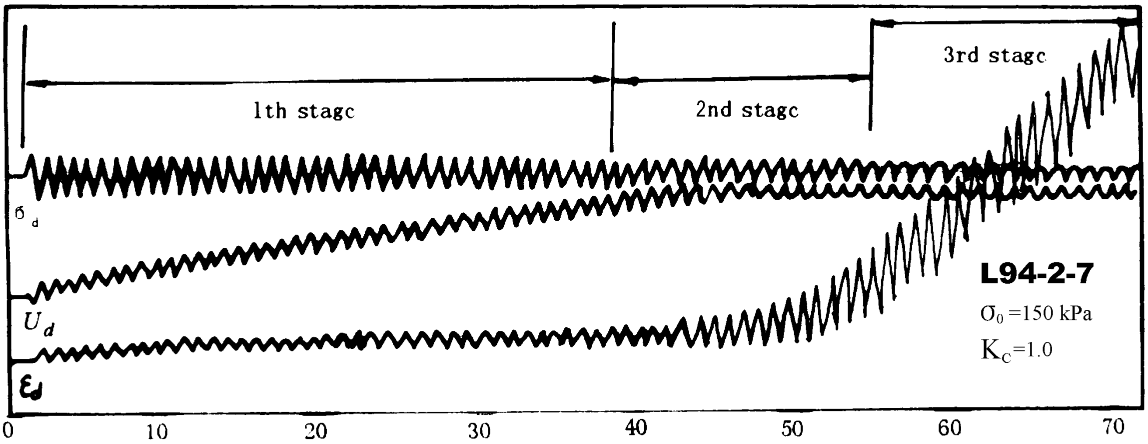


**Figure 1:The historical curves of stress, strain and pore pressure in liquefaction test**

The above conclusions indicate that saturated loess have four physical states: shear shrinkage after load-on, shear expansion after load-on, rebound and opposite shear shrinkage after load-off. The organic relationships among dynamic stress, strain and pore pressure in saturated loess under cyclic load was disclosed, the common liquefaction property on various kinds of loess was also shown.

**The Development Law of Pore pressure under Cyclic Load**

The test results in this paper show that the good normalization property between the dynamic pore pressure and vibration number in saturated loess with the same Kc and different $\sigma_3$ was found, it was shown in figure 2.

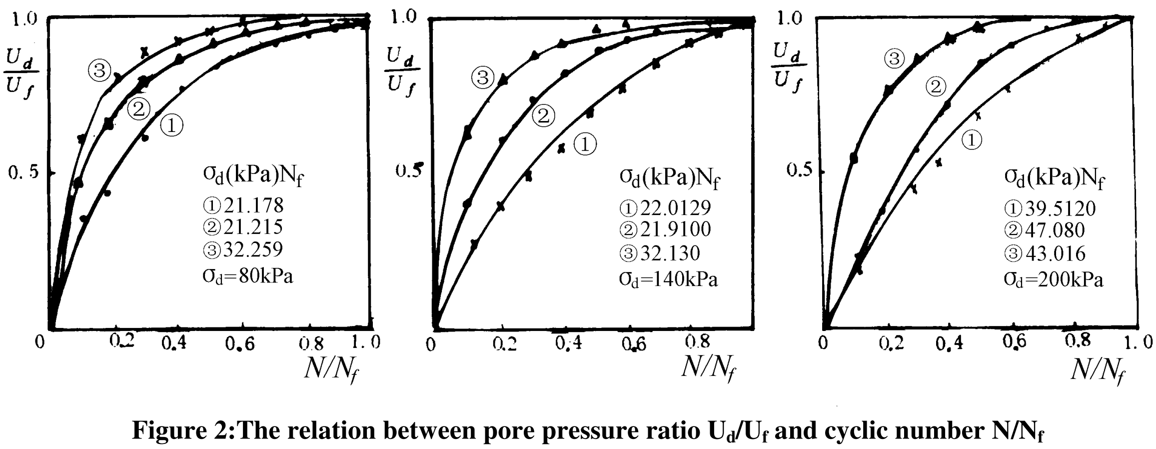


**Figure 2:The relation between pore pressure ratio $U_d/U_f$ and cyclic number $N/N_f$**

Figure 2 indicates that the pore pressure increase sharply in the initial one-fifth vibration number, then increase gradually, finally its increase rate change slowly and intend to a steady value. This become very obvious when

$\sigma_3$ reduce. However , for non-cohesive soil, the pore pressure generally increases very slowly in the initial time interval, when it is closed to damage, it increase abruptly. There is obvious difference in the two kinds of soil, because the permeability coefficient is smaller than the non-cohesive soil. Therefore, the pore pressure is not easy to dissipate and deliver in the initial vibration. The pore pressure distribution is not homogeneous, because the tiny clay particle in loess first intends to move the area with low pore pressure. This destroys the soil structure rapidly and produce large volume stress potential, this cause the rapid increase in pore pressure in initial stage. In addition, because of tiny particles and some clay particles in loess , loess has definite structural

strength and cohesion. This hinders and limits the increase in pore pressure, so in final stage pore pressure increase slowly, and intend to a steady value.
The fitting in test results indicate that the relation between the vibration pore pressure ratio $U_d/U_f$ and vibration number $N/N_f$ with different $\sigma_3$ in saturated loess can fit the following power function model.

$U_d/U_f=( N/N_f)^{1/b}$ (1)

Where N is vibration number, $N_f$ is liquefaction vibration number, $U_d$ is dynamic pore pressure, $U_f$ is pore pressure limit, b is test constant, b= 0.94-0.18$K_c$ for loess.

**The Pore Pressure Development Law under Random Seismic Load**

The figure 3 indicate that the pore pressure difference exist in saturated loess under different random seismic loads in the condition of isotropic pressure consolidation. First, the pore pressure increases have the skipped phenomenon under the seismic load with striking property, this will became faint with dynamic load development. But the pore pressure do not have the skipped phenomenon under cyclic seismic load, this is similar to the course under isotropic load. Second, the pore pressure increase rate was also affected by the dynamic stress amplitude. The lager the dynamic stress amplitude is , the more rapidly the pore pressure increase. The results show that in the initial stage the pore pressure increase sharply, then gradually intend to a steady value.

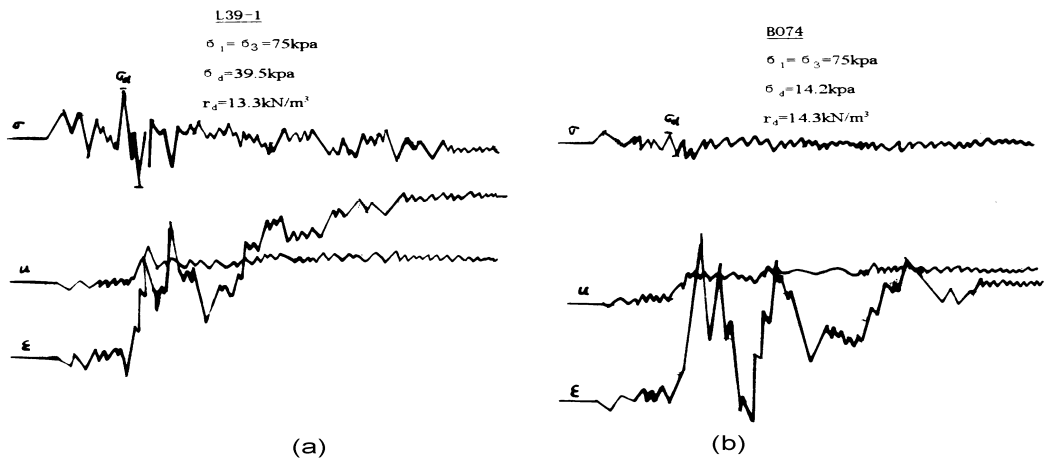


**Figure 3:The liquefaction test recordings in saturated loess under random seismic load**

Figure 4 is the relation between $U/U_{max}$ and T(time) in different load course. It can be seen from the figure that different random seismic loads have a little effect on pore pressure increase for saturated loess, the average of pore pressure change intend to close . The main cause is the viscous damp property showing under cyclic load for saturated loess, which diminishes the pore pressure effect on dynamic load. Figure 4 shows that the type of Dynamic load has a little effect on the change course of the pore pressure ratio with time.

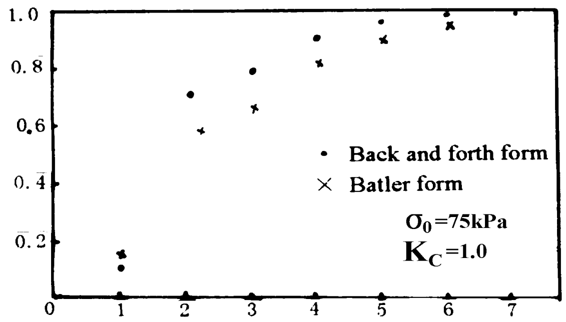


**Figure 4:The $U_d/U_{max}$-T relation under two loads**

## CONCLUSION

(1) The vibration pore pressure has its own characters for saturated loess under isotropic load. In the initial stage, the pore pressure increase rapidly, finally its increase rate become slowly, then tend to a steady value.

(2) The saturated loess in different states has different development law. The pore pressure rise when it is sheared and pressed; the pore pressure decrease when it is sheared and expanded. The pore pressure does not change when it is sheared elastically. The formation conditions and characteristics are different because of different basic origin for pore pressure.

(3) In the initial consolidation state and when $K_c$=1.0, The basic model for vibration pore pressure can be expressed in following equation:

$U_d/U_f=( N/N_{f)})^{1/b}$

(4) The initial study on dynamic pore pressure for saturated loess has been carried out, the further study should be done.

## REFERENCES


1. Dingyi Xie(1988), *Soil Dynamics*, Xi'an Traffic University Press, Xi'an.
2. Dingyi Xie and Zhang Jianmin(1995), *The Transient Dynamic Characters and Mechanics Analysis on Saturated Sand,* Shaanxi Science Press, Xi'an.
3. Hongzhi Yu(1994), "The development law of the dynamic pore pressure in saturated silt", *The Proceeding of 4th state conference on soil dynamics*, Zhejiang University, Hangzhou, pp107-110.
4. Lan Li (1998), " Several discussion on dynamic property of saturated loess", *The Proceeding of 5th state conference on soil dynamics, Dalian University of Science and Technology Press,* Dalian, pp138-143.

Lanmin Wang, Jun Wang and Lan Li (1997), "The prediction method for loess liquefaction in city", *The Northwest Journal of Seismology*, No. 19(Supplement), pp7-12.