# Study on Ground Displacement in Liquefiable soil by Shaking Table Tests

**Rui SUN[1], Longwei Chen[2], Xiaoming YUAN[3], Fanchao MENG[4], Zhenzhong Cao[5]**

[1] *Professor, Dept. of Geotechnical Engineering, Institute of Engineering Mechanics, Harbin. China*
[2] *PHD, Dept. of Geotechnical Engineering, Institute of Engineering Mechanics, Harbin. China*
[3] *Professor, Dept. of Geotechnical Engineering, Institute of Engineering Mechanics, Harbin. China*
[4] *PHD, Dept. of Geotechnical Engineering, Institute of Engineering Mechanics, Harbin. China*
[5] *PHD, Dept. of Geotechnical Engineering, Institute of Engineering Mechanics, Harbin. China*
*Email: iemsr@163.com, l.chen@meees.org, yxmiem@163.com, iemmfc@163.com, iemczz@163.com*

**ABSTRACT :**

Liquefaction is one of the important reasons in earthquake damages. The response and damage for the foundations and underground structures are dominated by soil deformation in general and in this case, displacements in liquefiable soil layer play more important role than acceleration. Generally, liquefaction displacement can be divided into two types. One is permanent displacements including the lateral spreading and the vertical settlements, and the other is the dynamic cyclic displacements related with the displacement spectra. Many research is performed for the former problem and for the later problem, however, rare study is conducted.
The shaking table test on effect of liquefaction on the cyclic displacement of the soil layer is performed. Taking the dry sand model tests as a datum, the relationship between the pore water pressure and the ground accelerations as well as the relationship between the pore water pressure and the ground displacement for the liquefiable saturated sand model are attained. The testing results indicate that the liquefaction flits the high frequency parts of the incident waves and reduce the ground acceleration amplitude. Meanwhile, the liquefaction enlarges the cyclic displacement and strain in the liquefied soil layer. For the cyclic deformation, the strain in the liquefied soil layer already reaches 1%-5%, i.e., the large deformation scope, and much larger that in the dry sand layer. During the water pressure range of 0.4-0.8, the cyclic displacement of the liquefiable soils increases significantly and reaches the maximum when pore pressure is about 0.8 other than 1.0. When the liquefaction occurs, the strain in the deep parts of the soil layer is larger than that in shallow parts. As a result, the liquefied soils reduce the rigid superstructures while amplify the cyclic displacements greatly which easily cause the damages of foundations and underground structures, especially for the interface parts between the liquefied soil layer and the below non-liquefied soil layer.

**KEYWORDS:** Shaking Table tests, Soil layer; Liquefaction; Cyclic displacement

## 1. INTRUDUCTION

Liquefaction is one of typical damage induced by earthquake and an important problem of engineering earthquake. There is serious damage and economical loses due to sand liquefaction in most of earthquake. The effect of soil displacement is more important than that of acceleration for ground, foundation, and others underground structures. Displacement induced by liquefaction is a very complex phenomenon and the ground displacement can be classified to two types. One is permanent displacement and the other is cyclic displacement. The former has been studied by many researchers, but the later has been investigated rarely.
In this paper, the shaking table test on effect of liquefaction on the cyclic displacement of the soil layer is performed. The relations between pore water pressure and acceleration, displacement in soil layers, dry sand and liquefied soil are analyzed to get some new knowledge of cyclic displacement of liquefaction soil.

## 2. SHAKING TABLE TESTS

### *2.1 Basic Idea for Test Design*

To find the basic model of the effect of liquefaction on cyclic displacement, the liquefaction shaking table tests under uniform loading is conducted. Although uniform wave is simple, the law can be got easily from the tests and irregular loading test can not be instead of regular test in this hand. At the same time, the dry sand tests are conducted for comprised.

### *2.2 EQUIPMENT*

Shaking table is 0.9m×0.7m and the sand model is 510×340×320mm. Sine wave is accepted as input loading and the test sand is Harbin sand which Mechanical composition is shown in Fig.1. The layout of instrumentations is shown in Fig.2 and the test cases are as shown in Table 1.

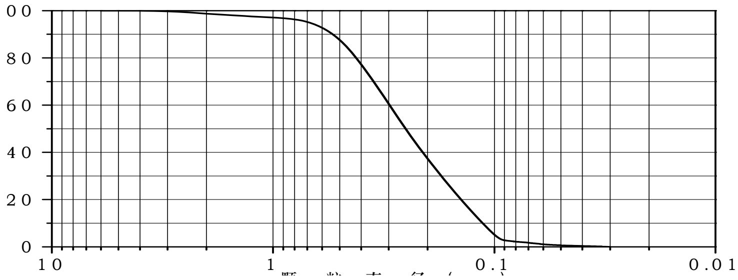



Figure 1 Mechanical composition of the test sand

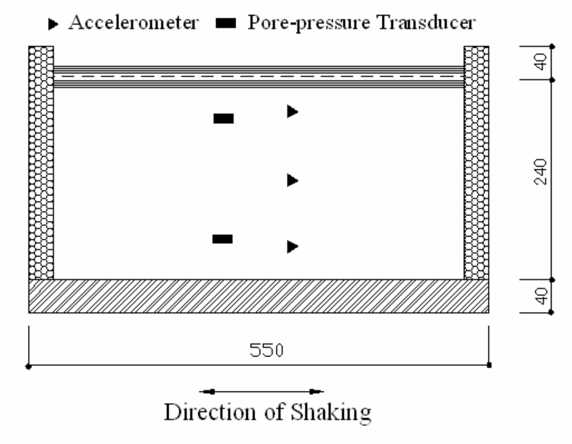



Figure 2 Layout of instrumentations

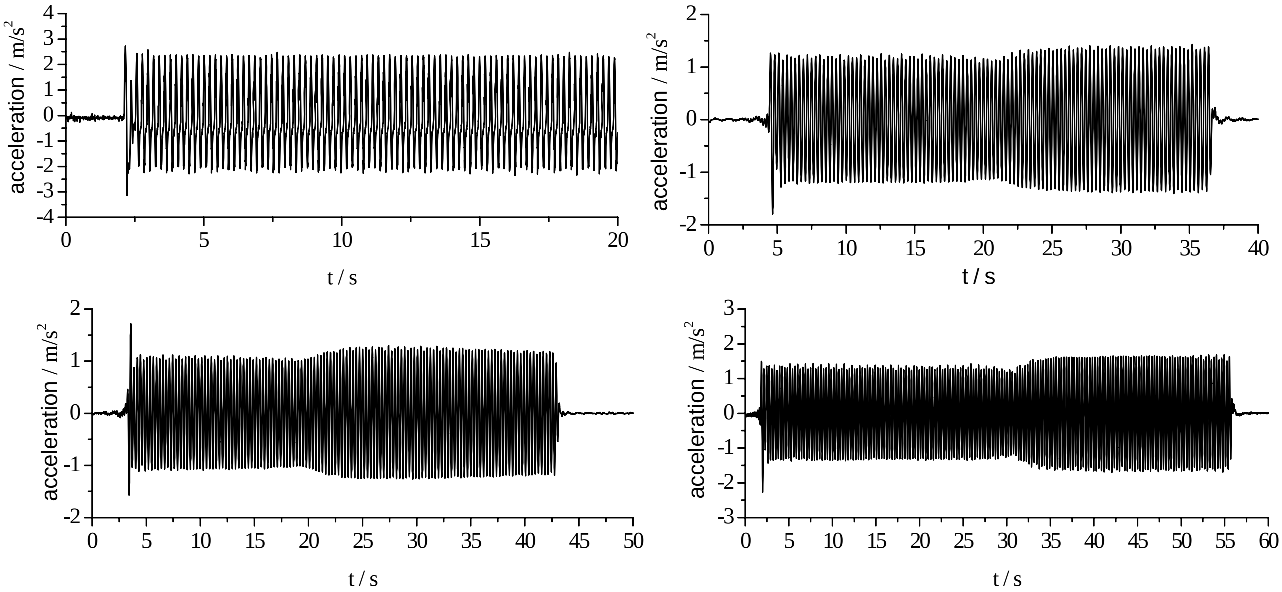
Table 1 Test cases

| Case | Dr (%) | Input Frequency (Hz) | Measured acceleration ($m/s^2$) |
|---|---|---|---|
| T1(dry sand) | 40 | 3 | 2.32 |
| T2(liquefaction) | 30 | 3 | 1.28 |
| T3(liquefaction) | 40 | 3 | 1.13 |
| T4(liquefaction) | 55 | 3 | 1.46 |

## 3. TEST RESULTS

### *3.1 Acceleration histories on the table*

The horizontal acceleration time histories of four test cases are shown in Fig.3. And the input acceleration of dry sand test is more than that of liquefaction test about 1$m/s^2$.

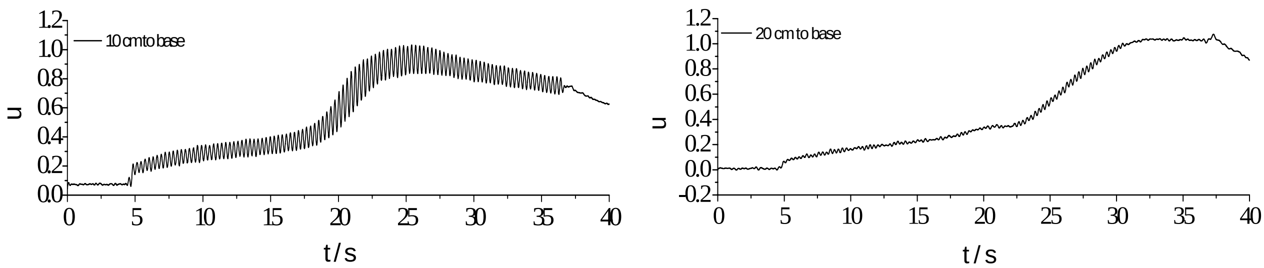



(c) T3 (d) T4

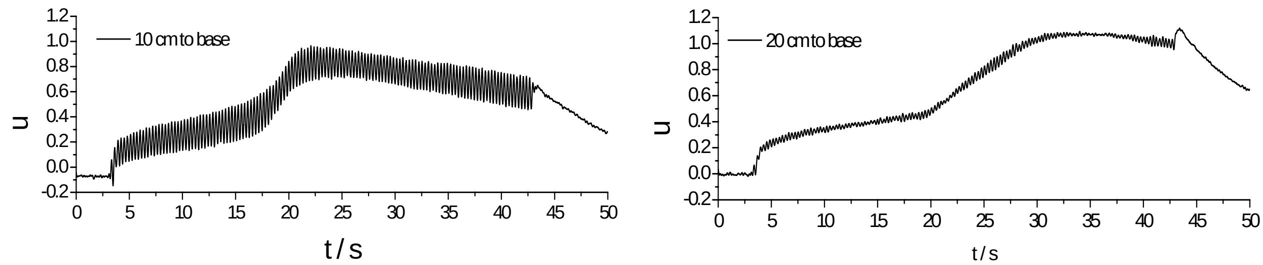
Figure 3 Acceleration histories on the table

### *3.2 Pore Water Pressure Histories in the Soil*

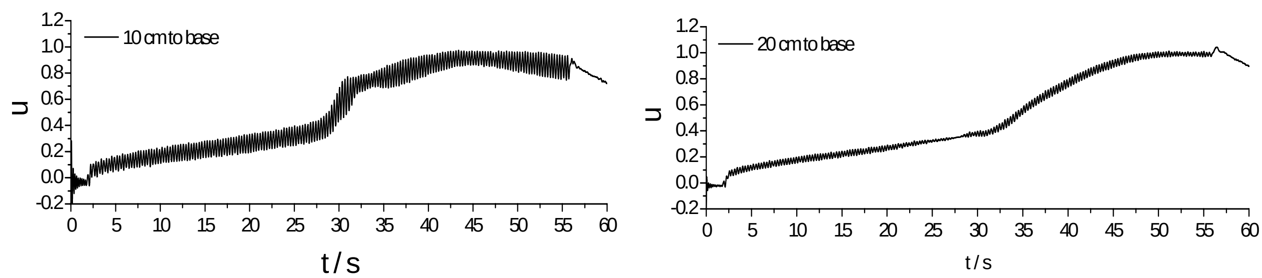
The Fig.4 shows the time histories of pore water pressure in the soil.




(a) T2




(b) T3



(c) T4

Figure 4 Time history of pore water pressure in soil layer

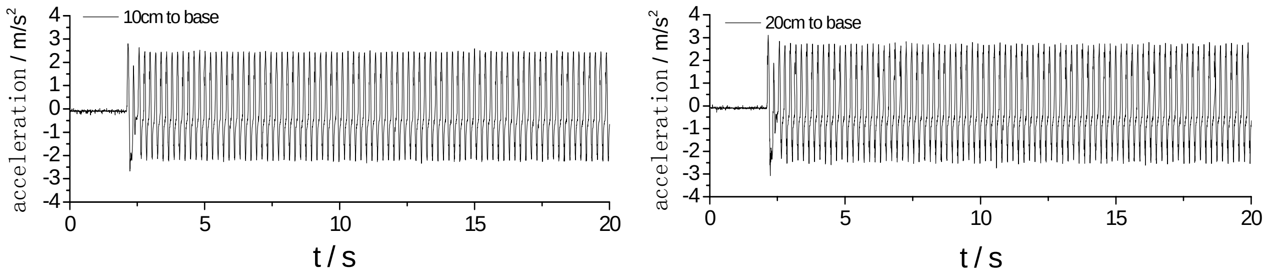
It can be seen from Fig.4 that the development of pore water pressure in different depth is not same and it rise quickly in deep soil than that in shallow soil which similar to the results of .other research.

The pore water pressure rise to 1.0 cost about 25s in T2 case and T3 case. Although the relative density in T2 case is larger than that in T3, the amplitude of input acceleration in T2 case is more than that in T3. So the time rising to 1.0 is same in these cases. In T4 case, though its input acceleration is larger than that in T2 and T3 case, its relative density is about 55% while it is 30% and 40% in T2 and T3 cases. So the pore water pressure in T4 case is the slowest in all cases about 40s to liquefy. This phenomenon indicates relative density has a great influence on water pressure.

From the existing test results, the tests in this paper are successful and relative density controls the development of water pressure. The results indicate that the water pressure in high relative density sand is slower that in loose sand.

### *3.3 Acceleration Histories in Soil Layer*

The Fig.5 shows the time histories of acceleration of all cases in soil layer.

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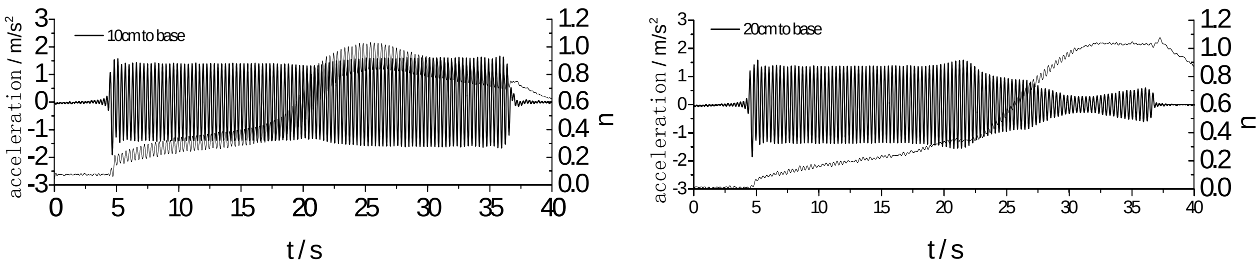
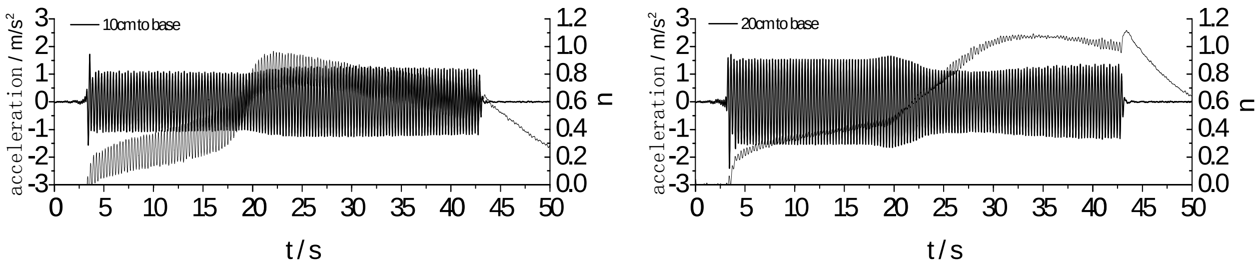
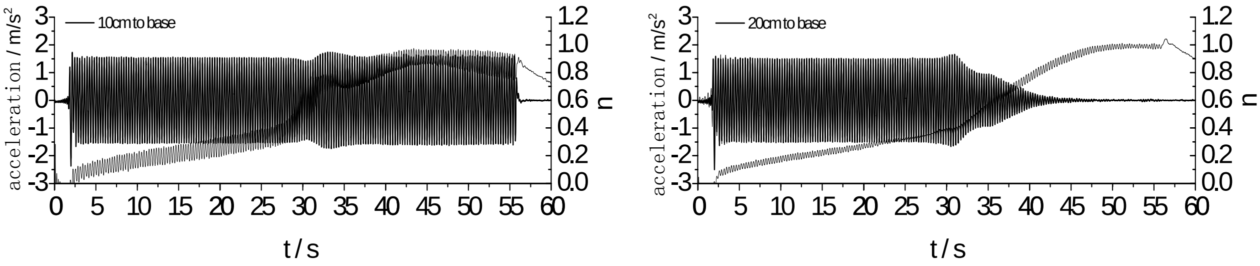
(a) T1




(b) T2




(c) T3




(d) T4

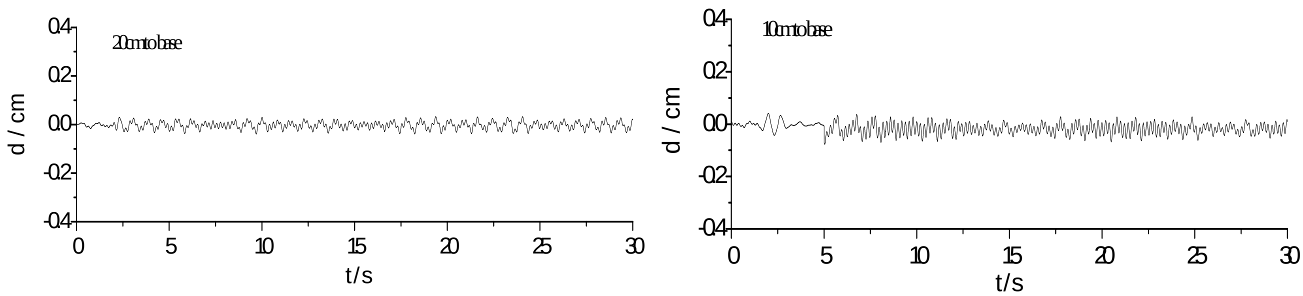
Figure 5 Acceleration histories in soil layer

From Fig.5, we can see the types of acceleration in dry sand and the saturated sand of water pressure less than 0.3 are similar to that of input which is equal amplitude. But it amplitude is changed along depth and the acceleration near to ground is the largest. After that, the acceleration in dry sand does not change and the accelerations in saturated sand change greatly with the water pressure rising. Especially in 20cm to base, the acceleration amplitude almost decrease to zero while saturated sand liquefied and there is a good corresponding relation with water pressure. So liquefaction makes the acceleration decreasing near surface ground which accord with common knowledge at present. Another new knowledge getting from the tests is that the acceleration decreasing begins at water pressure being 0.4 but not 1.0.

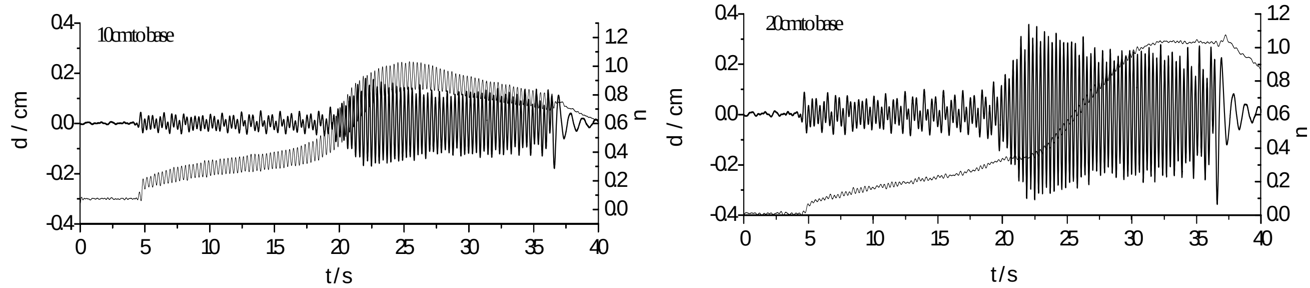
### *3.4 Displacement Histories in Soil Layer*

The horizontal displacement in soil relative to table is more important than that of absolute displacement and in this paper, the former is considered.

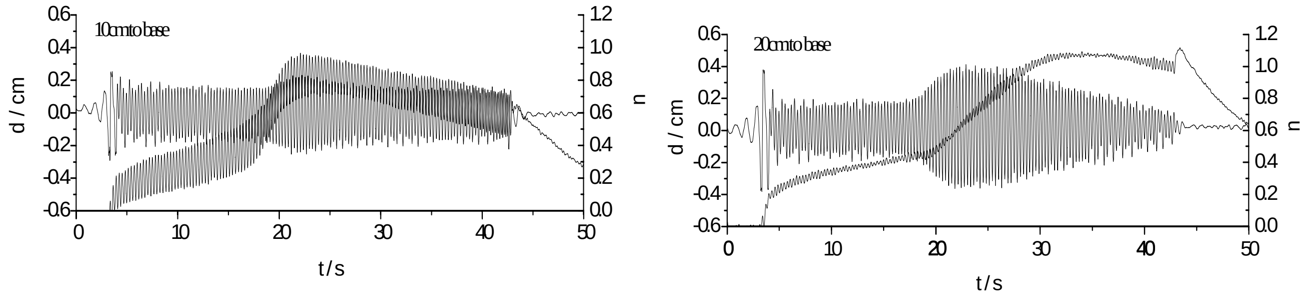
The horizontal displacement histories of all tests are shown in Fig.6 and the water pressure time histories are shown in the Fig.6 again for comparison.



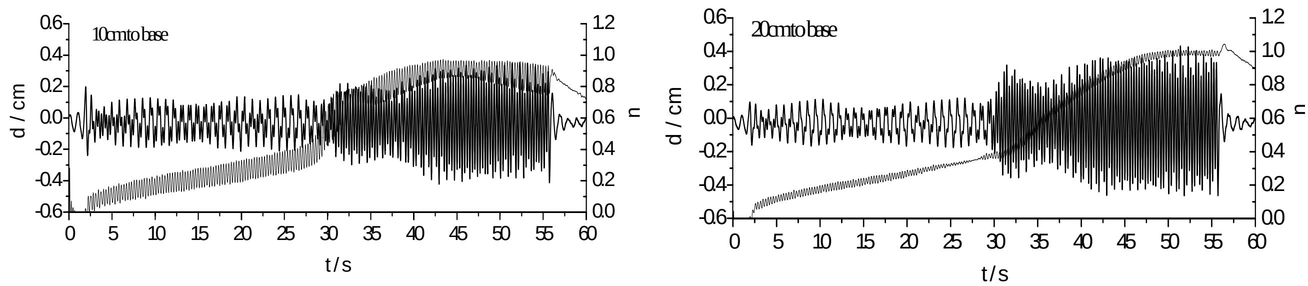

(a) T1




(b) T2




(c) T3




(d) T3

Figure 6 Displacement histories in soil layer

The Fig.6 indicates that the displacement in dry sand keep a small amplitude during the whole shaking. But for saturated sand, at the beginning it is similar to that of dry sand keeping a small amplitude and increase as soon as water pressure rising. While water pressure rise to about 0.4, the displacement in soil increase greatly and reach the peak while water pressure is 0.6-0.8.

In T2 case, the displacements in two depth are 5.6 and 9.7 times larger than that of dry sand while for T3 case they are 7.8 and 11.1 times, and for T4 case they are 10.9 and 11.9 times. In another word, although the input acceleration is larger than that in liquefaction case about 80%, the displacements in liquefaction cases are 10 times larger than that in dry sand case when water pressure reaching 0.6-0.8 not 1.0.

The horizontal cyclic shear strain can be got according to horizontal cyclic displacement. In T2 case, the shear strains in 16cm and 6cm under surface are 2.1% and 1.8% while they are 2.5% and 2.1% for case T3 and for T4 they are 3.5%and 2.2%, i.e. the cyclic shear strain in liquefaction soil has reached large strain when water pressure rising to 0.6-0.8. At the same time, it can be seen that the horizontal displacement in shallow soil layer is more than that of deep soil layer while cyclic shear strain is big in deep soil layer and small in shallow layer.

## CONCLUSION

According to the cases in this paper, the conclusion can be drawn:

1. The horizontal acceleration and cyclic displacement in soil layer would be changed greatly due to liquefaction.
2. The horizontal inertia force would decrease while soil liquefaction and thus it will make the structure vibration decrease.
3. Although liquefaction makes inertia force decrease, it makes horizontal cyclic displacement and shear strain increase and for horizontal cyclic shear strain, it could be about 1%-5% being a big deformation.
4. The cyclic shear strain is bigger in deep soil layer than that in shallow layer and this will make base and structure on the boundary between non-liquefaction soil layer and liquefaction soil layer damage easily.
5. When the water pressure rising to 0.4, the horizontal acceleration on the surface ground begin to decrease obviously and the deformation of soil layer begin to increase greatly. The deformation will be to the peak when water pressure is 0.6-0.8.

In this paper, we only conduct the tests of equal amplitude cyclic loading. The feature and regular of soil layer deformation in liquefied soil layers would be investigated in future,

## REFERENCES

LIU Hanlong. (2001). Influence of liquefied area on large ground displacement. *Journal of Hohai University* **29:5**, 1-6.

ZHANG Jianmin, WANG Gang. (2004). Pile-soil dynamic interaction analysis considering large post-liquefaction ground deformation. Journal of Tsinghua university

LI Xuening, LIU Huishan, Zhou Genshou. (1992). Study on shake-reducing effect of liquefiable layers. *Earthquake Engineering and Engineering Vibration*. **12:3**, 85-91.

SU Dong, LI Xiangsong. (2006). Centrifuge modeling of seismic response of free sand ground. *Earthquake Engineering and Engineering Vibration* **26:2**, 166-170.