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## Seismic behavior of pile group in soil slope

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Seismic behavior of pile group in slope is interested for many years by researchers .In this research Shaking table tests were conducted by means of a rigid-box with 1.8m in length, 0.8 in width and 1.2 in height in order to investigate the effects of the location of pile group in sand slope on its seismic behavior .A cap supported by a pile group was set in a dry sand slope, and subjected to sinusoidal base motion with constant frequency. Soil used in this study was firoozkuh sand 161 with 60% relative density. The tests were scaled at 1/10<sup>th</sup> and the piles were made from aluminum with 95cm in length and they have fixed head condition .Discussions are focused on the behavior of pile groups in different situations. Main interests are recognition the effect of slope movement and location of pile group on bending behavior of piles.

**KEY WORDS:** shaking table, seismic behavior, pile group, sand slop, bending.

### 1-INTRODUCTION:

There are many situations where footings are constructed on sloping surfaces or adjacent to a slope crest, such as footings for bridge abutments on sloping embankments. Pile foundations of many structures in slopes such as retaining walls, support of bridge abutments, piers, overhead signs, transmission towers, anchors for bulkheads, and offshore structures, are frequently subjected to lateral loads such as wind loading or earthquakes.

Interactive behavior of soil-pile-superstructure system is a new field of investigation in recent years ( [1] E.A. Ellis et al 2001 ). In addition, the evaluation of behavior of piles during the earthquake in liquefied or lateral spreading grounds is attracted many of researchers in this field of science.( [2] Shintaro Yao et al 2004, [3] M. Cubrinovskia et al 2006, [4] J.R. Dungca et al 2006)

On the other hand, the use of stabilizing piles to support an active earth slope has been considered to be

one of the important slope reinforcement techniques in the last few decades. These piles, which can be driven at the crest or within the slope itself, act as resisting members and are usually subjected to lateral forces by the horizontal movements of the surrounding soil. The lateral force acting on each pile may be obtained in an approximate manner by multiplying the resisting force per unit width of the pile row by the center-to-center spacing between the piles. However, to evaluate the force acting on the piles more accurately, arching between adjacent piles should be considered. Several studies reported the successful use of piles in many situations in order to improve slope stability ([5] De Beer and Wallays 1970; [6] Viggiani 1981; [7] Lee et al. 1995; [8] Poulos 1995; [9] Hong and Han 1996; [10] Chen and Poulos 1997; [11] Hassiotis et al. 1997; [12] Hull and Poulos 1999; [13] Ausilio et al. 2001).

Hull and Poulos (1999) described an approach for the design of piles to reinforce slopes, in which both the total shear force needed to increase the safety

factor and the maximum shear force that each pile can provide were evaluated and, therefore, the type, number of piles, and the most suitable locations of these piles within the slope can be selected. Hassiotis et al. (1997) Proposed a method for the design of slopes reinforced with a single row of piles based on the theory of plasticity to find the lateral forces acting changes both the slope safety factor and potential failure mechanism with respect to the case without piles.

But in these researches, there isn't any consideration on the behavior of pile groups in slopes that bearing loads. Thus, the evaluation of seismic behavior of pile groups in slopes is an important subject in engineering to investigate.

The main objective of this research is evaluation of the effect of pile group position in the slope on its seismic behavior. Initial investigation focused on the lateral displacements and the rotations of the pile groups and the bending moment. For this reason four shaking table tests were conducted in geotechnical laboratory at University of Tehran.

## 2-LABORATORY MODEL TESTS:

To investigate the effects of pile group position in seismic behavior of pile group in slopes, four model tests were conducted on the 1g shaking table.

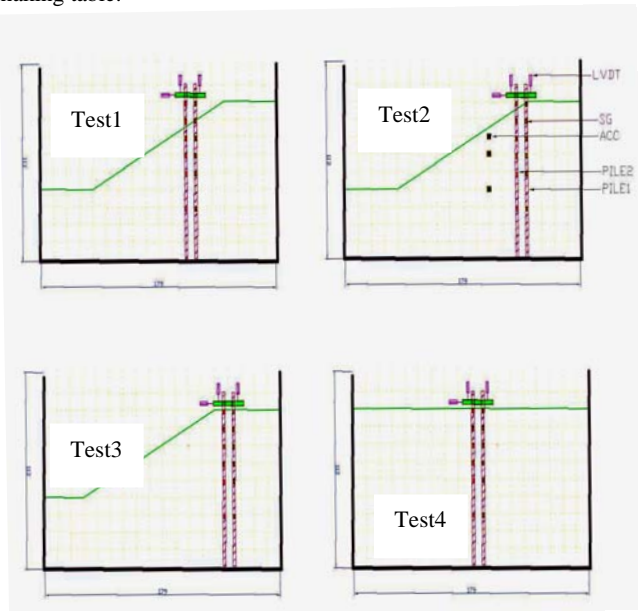


Fig.1. Schematic figure of whole tests

### 2-1-MODEL BOX:

Models prepared in rigid-box of 1-g shaking table in geotechnical laboratory at University of Tehran, which is 180cm in length, 120cm in height and 80cm in width. The glass side allows the sample to be seen during preparation and sand deformations to be observed during testing. The inside walls of the tank are polished smooth by attaching Plexiglas to minimize side friction with the sand as much as possible.

### 2-2-MODEL PILES:

A 2\*1 group with aluminum piles with a steel cap with 1490gr weight was used for these tests. The aluminum piles had 15mm and 13mm in outer Diameter and inner Diameter. two piles were strain gauged to measure the bending moment distribution The bending stiffness was  $E_p I_p = 75815 \text{ kg.cm}^2$  for each pile. The piles had 95cm length and the cap assembled on the piles with  $S/D=5.4$  (Distance over

Diameter). Dimensions of the piles are determined from the similarity law. The full scale pile is a steel pile with 60cm Diameter. The thickness is 1.35cm and the pile length is about 30m. There are several factors that affect the lateral resistance of a pile but the dominant one is the pile stiffness, which determines whether the pile behaves rigidly or as flexible pile. [14] Broms (1964) showed that a laterally loaded pile behaves as a rigid pile based on the value of the stiffness factor T. In cohesion less soils, this factor is calculated as :

$$T = \sqrt[5]{\frac{E_p I_p}{n_h}} \quad \text{Eq. 1}$$

Where  $E_p$  modulus of elasticity of the pile material ( $6.87 \times 10^7 \text{ kN/m}^2$ );  $I_p$  moment of inertia of the pile cross section ( $0.08 \text{ cm}^4$ ); and  $n_h$  constant of sub grade reaction at pile tip. Broms suggested that the embedment depth of the pile has to be less than  $2T$  to be considered as a short rigid pile and greater than  $4T$  for behavior as a long elastic pile. Possible values suggested for  $n_h$  are 1900, 6000, and 13,500  $\text{kN/m}^3$  for loose, medium-dense, and dense sands, respectively ([15] Terzaghi 1955). Furthermore, the value of  $n_h$  decreases near the crest of the slope. All of the experimental tests were carried out using a pile embedment length which is more than the value of  $4T$ , indicating that the test pile satisfy the criterion for a long elastic pile.

The pile group was installed by a jack and remained elastic during all shakings.

### 2-3-TEST MATERIALS:

The sand used in this research is coarse sand, washed, dried, and sorted by particle size. firoozkuh sand 161 is composed of rounded to sub rounded particles and the only sand used in this research with these characteristics:

TABLE1. characteristics of firoozkuh sand 161

	$G_s$	$e_{max}$	$e_{min}$	$D_{50}(\text{mm})$	%F	$C_u$	$C_c$
<b>Firoozkuh Sand 161</b>	2.658	0.943	0.603	0.3	0	2.58	0.97
<b>Toyoura</b>	2.65	0.977	0.597	0.17	0	-	-
<b>Sengenyama</b>	2.72	0.911	0.55	0.27	2.3	-	-

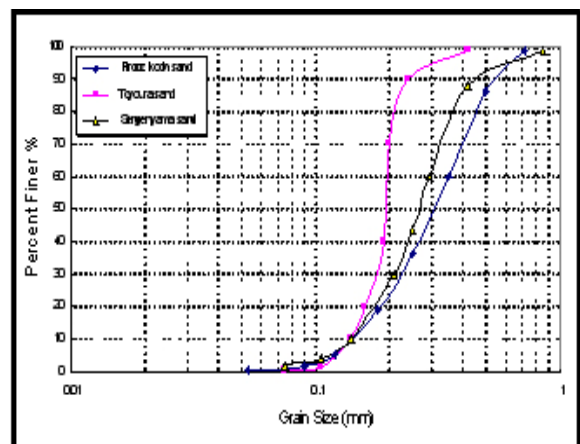


Fig 2. Grain size distribution of the model sand

2-4-INSTRUMENTATION:

Two piles using Wheatstone half bridge were strain gauged to allow calculation of pile bending moments. The strain gauges were 6 mm long, Each pile had 6 strain gauges in total, were positioned to measure axial strain. The distances between strain gages are shown in the following figure. Three LVDTs used to calculate the vertical and horizontal displacement of cap and also cap rotation (fig 3). Five accelerometers, three in soil mass, one on the cap, and one on the box for measuring the base acceleration used. The details are shown in Fig3.



Fig3. LVDTs placing

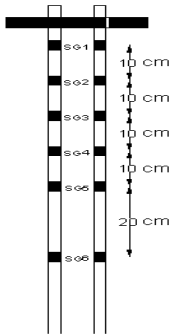


Fig4. Strain gauges placing

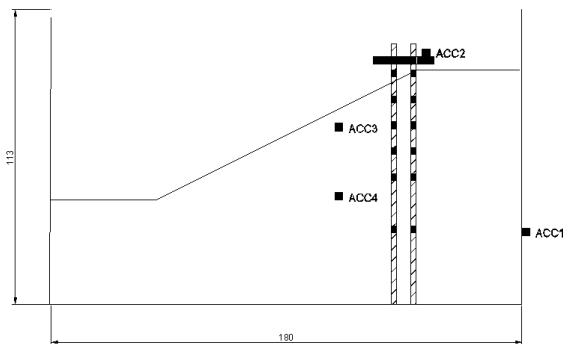


Fig5. Accelerometers placing

2-5-LOADING PROGRAM:

The shake table is vibrated so that amplitude of sinusoidal acceleration increases monotonically to the desired amplitude keeping a constant frequency. The Frequency was 5 Hz and acceleration was 0.6g. (fig 4)

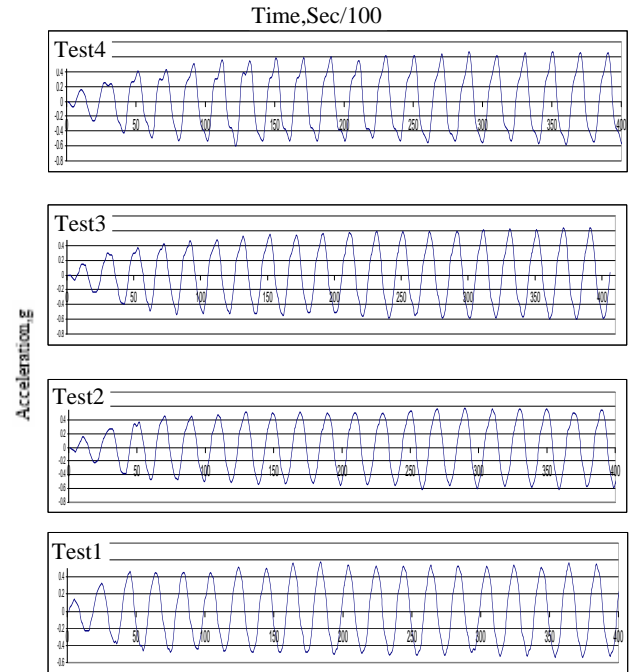


Fig6. Base acceleration time histories

2-6-MODELING PROCEDURE:

A pouring system used to pour sand in 10cm layers from 25cm height. The relative density achieved during the tests was monitored by collecting samples in small cans of known volume placed at different locations in the test. When the construction of slope finished, A jack pushed the pile group to its position in the slope. Four series of tests were conducted. All tests were conducted with an artificially made slope of 1(V):2(H) (fig 5)

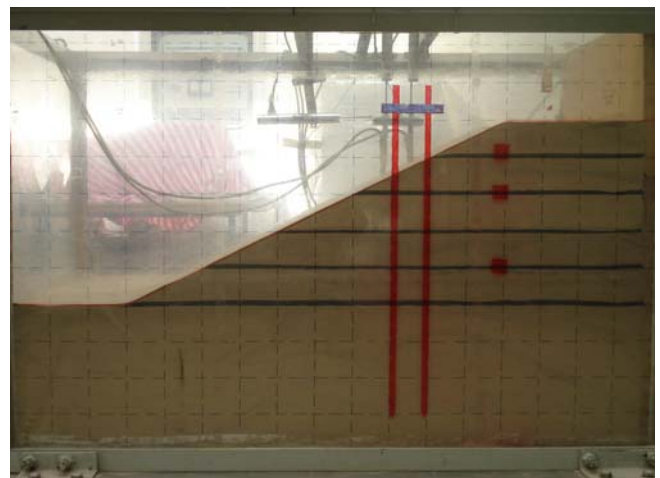


Fig7. View of Model

### 3-RESULTS AND DISCUSSION:

Time histories obtained from the tests are shown in these figures: the shaking table accelerations, cap displacement and bending moments in pile are shown in following figures (8 to 15).

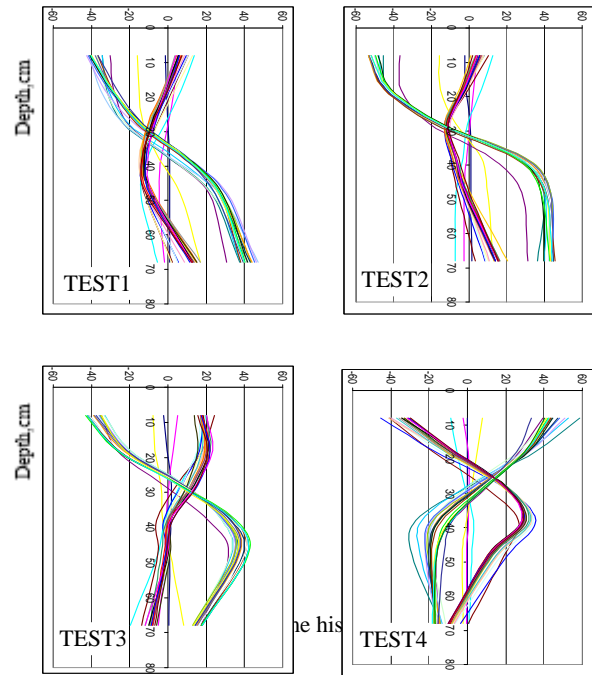
Predominant frequency of the pile-cap system is about 20 Hz (obtained from impulse to system), and that of the ground surface is about 5 Hz. Time histories of horizontal displacements and bending moments indicate that there are two components, i.e. a cyclic component and static component which increases monotonically in one direction. As described above, displacements have a cyclic component and a static component.

#### 3-1-BENDING MOMENT:

The maximum bending moment in the piles often controls the design of pile groups and therefore has to be calculate accurately. Bending moment in a pile is measured by means of strain gages attached to the surface of piles. Bending moment in two piles is shown in these figures.

As seen in the diagrams, when the pile group is moving from slope to plane ground, the bending moment changes along the piles. It was predictable that a magnificent moment will occur during shaking near cap in piles, but, in these piles when they are resting in slope or near the crest, also a magnificent moment was observed at the end of piles. Bending moments in the pile caused by lateral soil movement could be more significant than those caused superstructure loading. Fig shows the bending moment distribution along the piles in the tests.

Bending moment kg.cm



Bending moment kg.cm

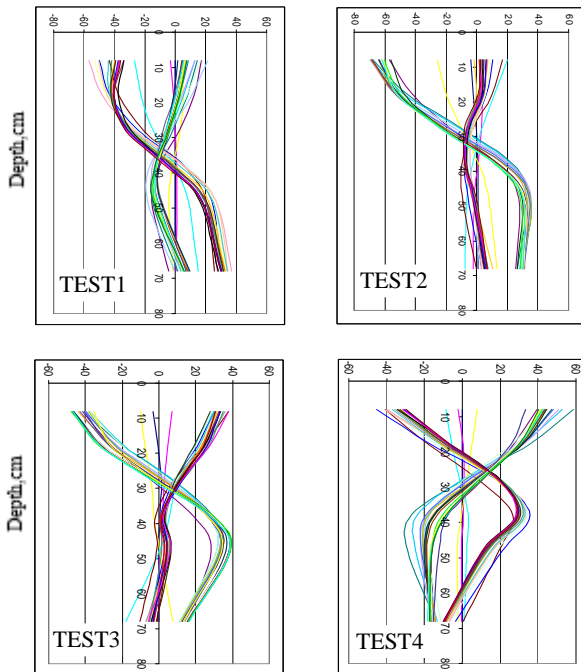


Fig 8. Bending Moment time histories in pile1

This behavior seems to agree with the slope deformation. This implies that the bending moment is controlled by the slope deformation. Therefore, consideration of slope deformation is necessary in the design of a pile in slope.

The bending moment shown in the figures 8,9 have a maximum value in test4 (plane ground), when the inertia force controls response is relatively symmetrical in both negative and positive moment. In this test, the maximum moment occurs near the cap in both ways but, in other tests the maximum positive moment occurs near the end of the piles. The results show that maximum negative moment increases near the pile head when the pile group moves from plane ground to the slope. The maximum negative moment in all tests observed in test2 when the pile group placed at the slope crest. It seemed that this maximum value is caused by maximum soil pressure due to pile position and maximum embedment length in the soil. The measured bending moments for the piles in the group are shown in Figure 10 and 11 respectively. In these tests observed when the pile group was in the slope, moment at the front pile is a bit larger from rear pile.

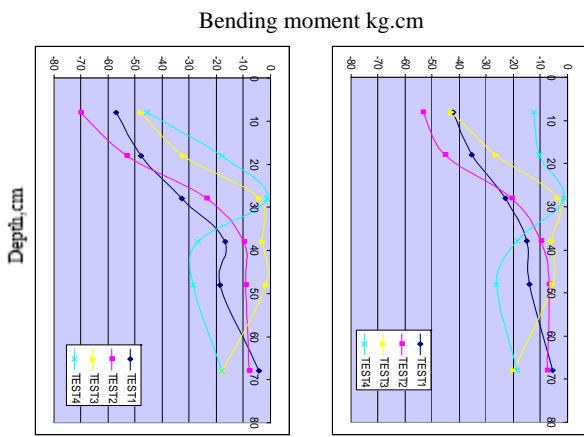


Fig 10. Maximum positive Bending Moment in piles

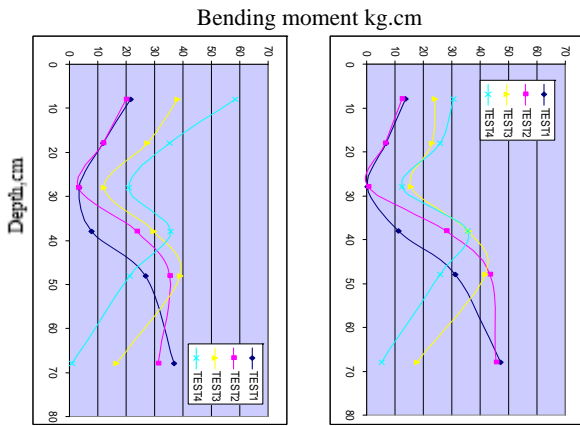


Fig 11. Maximum negative Bending Moment in piles

### 3-2- SHEAR FORCE:

The total shear could be estimated using elastic beam theory in conjunction with the moment gauge recordings. The slope of the moment distribution is equivalent to the shear distribution:

$$V(z) = \frac{dM(z)}{dz} \quad \text{Eq 2.}$$

Where  $V(z)$  is the shear distribution,  $M(z)$  is the moment distribution, and  $z$  is the depth along the pile. By differentiating the moment distribution at every time step, the time history of shear can be obtained at a number of depths along the piles.

As seen in these diagrams, the maximum shear force along the piles occurs at the middle of the pile, where bending moment is in its maximum value.

The maximum shear force in the piles (1&2) during all tests has observed in test2, where the pile placed at the slope crest. This shear force was about 4kg. In addition, when the pile group moves from slope to the plane ground, the shear force near the pile head increases. This can be due to soil profile near the pile head, caused by nonexistence of soil around the piles on that elevation.

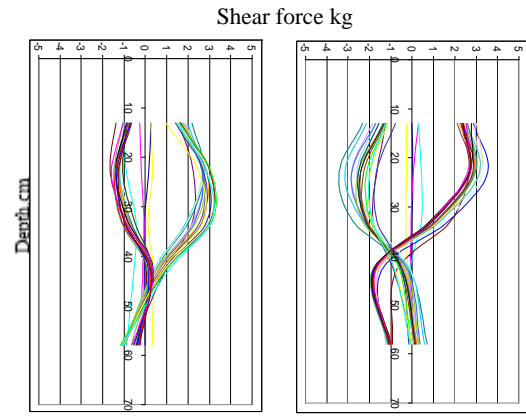
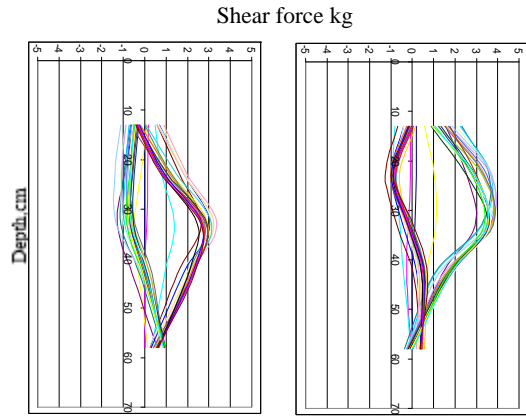


Fig 12. Shear force time histories in pile1

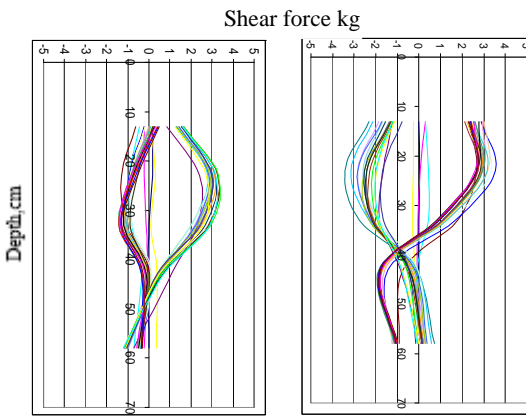
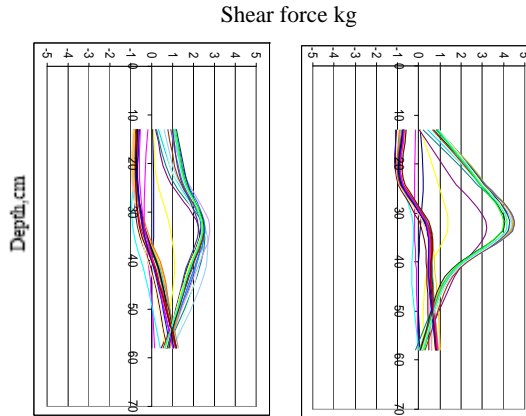


Fig 13. Shear force time histories in pile2

### 3-3-CAP DISPLACEMENT:

Three linear variable differential transformers (LVDT) were positioned to measure the lateral displacement and rotation of the pile group (one horizontal and two vertical). Three LVDTs placed on three rigid body above the box that fix to the box.

As described above, displacements have a cyclic component and a static component. Displacements time histories are shown Fig 13 . As seen in this Fig the Static component increases when the pile group moves from plane ground to the slope.

When pile groups are in slope (TEST 1, 2, 3), the cyclic component in Initial 2 Second has a little difference in tests. But in Sec 3&4, the dynamic displacement is approximately equal.

As Seen in Fig 12 the dynamic displacement for pile group in slope, is more than two times greater than pile group in plane ground.

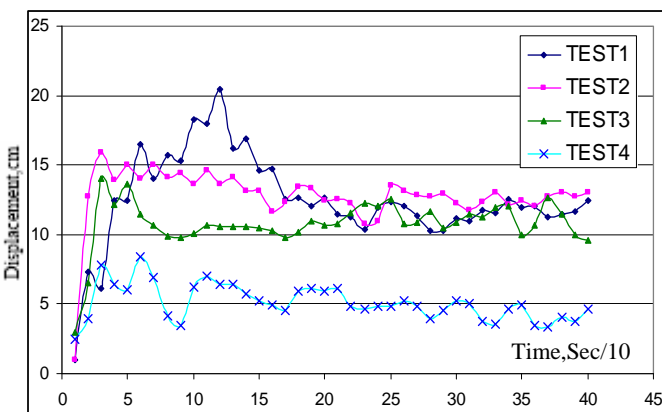


Fig 14. cyclic displacement

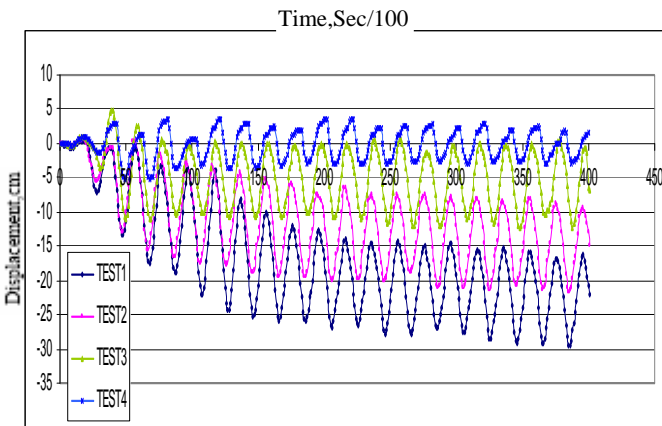


Fig 15. Displacement time histories

### 4-CONCLUSION:

A series of shake table test has been successfully performed to investigate the effects of the location of pile group in sand slope on its seismic behavior. The piles were instrumented with strain gauges which allowed determination of bending moment distribution along their length. The bending moment distributions were then used to calculate the Shear force in piles. The results have shown the following:

- 1- Bending moment of a pile can be equal in the ground to the pile head, depending on the location of pile group in slope.
- 2- Bending moment at piles in slope in pile head and pile tip may be greater than pile in the plane ground depending on the location of pile group in slope.
- 3- Bending moment and Shear force in piles in test2 was the greatest one in both piles during all the tests when the pile group placed at the crest of slope. It seemed that this maximum value is caused by maximum soil pressure due to pile position and maximum embedment length in the soil.
- 4- Both dynamic and static displacements are very larger for pile group in slope. The maximum dynamic and static displacement occurs in test1, when the pile group placed in the slope.

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