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MODEL TESTS TO DEMONSTRATE THE EFFECTIVENESS OF A NAILING METHOD ON THE STABILITY OF NATURAL SLOPES DURING EARTHQUAKES

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ABSTRACT

Non-frame method is one of the nailing methods to stabilize natural slopes against heavy rains and earthquakes. This method can be applied without cutting trees. The authors carried out several model tests by using a shaking table, to study the mechanism to stabilize slopes by the Non-frame method. Based on the tests it was concluded that the Non-frame method can prevent failure of slopes with the combination of iron rods, plates and wire ropes. And the stabilization is effected by anchoring method of the nails and width of plates.

Keywords: Earthquake, Slope stability, Model test

INTRODUCTION

Failure of natural slopes during earthquakes causes severe damages to human lives, houses, roads, railways etc. In Japan, many natural slope failures have occurred during past earthquakes. For example, huge number of landslides, more than 1700, occurred and hit many towns and villages during the 2003 Niigataken-chuetsu earthquake. However, only few natural slopes have been treated against earthquake in Japan, because costs for the treatments are too huge. Development of economic treatment methods is desired. Non-frame method is one of the economic methods.

OUTLINE OF NON-FRAME METHOD

. Non-frame method is one of the nailing methods to stabilize natural slopes against heavy rains and earthquakes. In this method, drill bore holes, insert iron rods, grout-fill the bore holes, and set plates and caps as shown in Fig.1. The bore hole is drilled with the direction perpendicular to slope surface. Iron rods are inserted in the bore holes with triangle alignment as shown in Fig.2. Tips of the iron rods are inserted in stable rock or soil for 1m. Then, place the tops of iron rods by plates and caps. The tops of rods are connected by wire ropes as show in Fig.2. Unstable layers of a slope can be stabilized due to the combination of the iron rods, plates and wire ropes. This method can be applied without cutting existing trees. Therefore, stabilizing effect by the roots of existing trees is not diminished. Moreover, treated slopes are beautiful because the slopes are covered with natural grasses and trees. As drilling machines are small and light, the method can be applied to steep slopes.
The method must prevent failure of slopes due to the following three effects:
(1) prevent the slide of soil mass by bending resistance of iron rods,
(2) prevent the deformation of slope surface by the pressure between plates and slope surface
(3) prevent the deformation of slope surface by the pressure between wire ropes and slope surface

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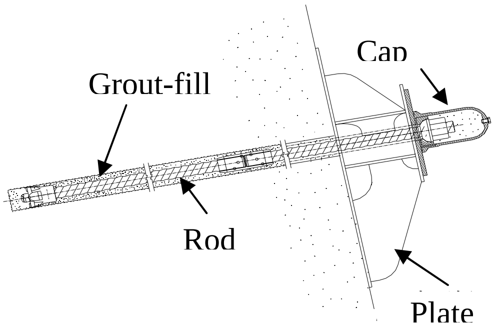
However, these effects during earthquakes are not clear. Then the authors conducted shaking table tests to demonstrate the mechanism of stabilization and effect of each factor.



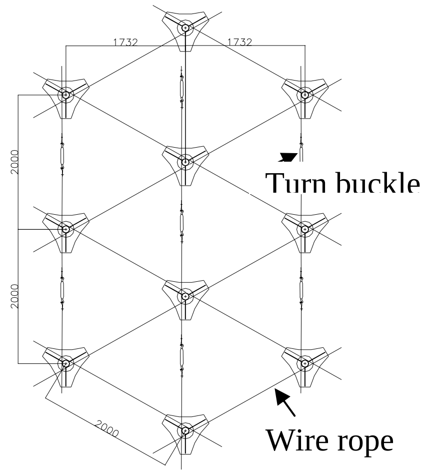
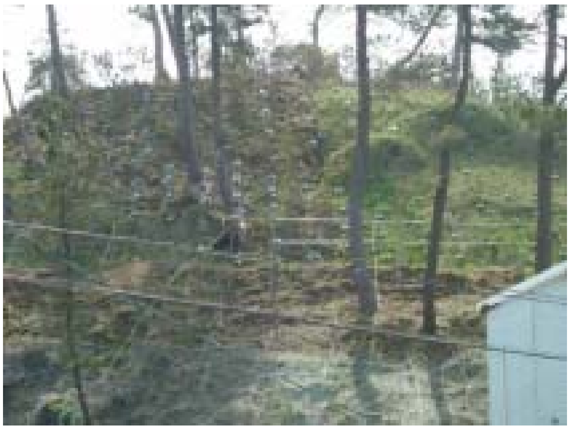


Figure1. Cross section Figure2. Connection of nail heads by wire ropes

BEHAVIOR OF THE SLOPES TREATED BY NON-FRAME METHOD DURING RECENT TWO EARTHQUAKES

One slope in Kashiwazaki City was protected by Non-frame method in spring of 2004 in Japan, as shown in Photo 1. Heavy rain and Typhoon hit the slope in July and October. No deformation occurred due to two triggers. Moreover, the 2004 Niigataken-chuetsu earthquake hit this area on October 23. Liquefaction-induced damage to houses occurred at several sites in Kashiwazaki City. However, no deformation was induced at the treated slope. In 2004 Fukuokaken-seiho-oki earthquake occurred and caused slope failure at several sites. However, one slope protected by the method in Fukuoka City, was also stable. These examples imply the effectiveness of this method during earthquakes. Seismic intensities at the treated slopes during two earthquakes were about 5 in JMA scale.

Photo1. One slope in Kashiwazaki City was protected by Non-frame method

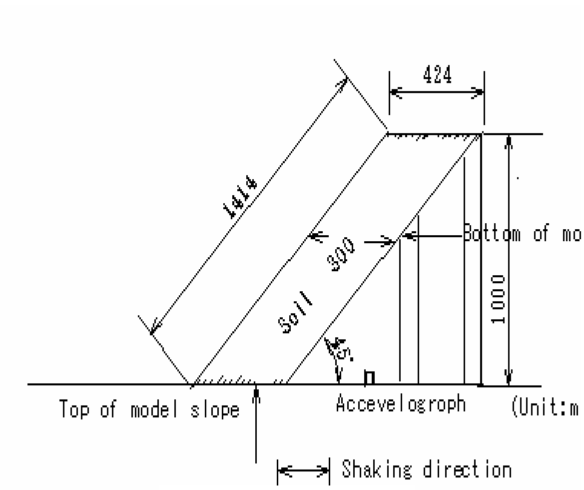


METHOD AND PROCEDURE OF SHAKING TABLE TESTS

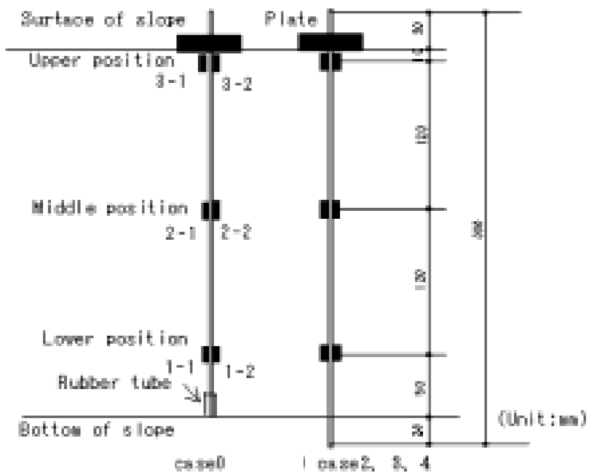
The authors carried out several 1G shaking table tests, to study the mechanism of the Non-frame method. In these tests, a soil container with a length of about 1,400mm and a depth of about 400m was used as shown in Photo 1 and Fig.3. Weather granite soil with a moisture content of 11.5%, which is the optimum moisture content, was filled in the container with a thickness of 100mm. The soil was compacted to be the density of 1.5 g/cm^3, which is 71% of the degree of compaction. After the compaction of the first layer, the following other layers were filled and compacted in the same way. Then the soil container was tilted to make a slope.

Table 1 shows test conditions. Five types of model slopes were selected: i) without iron rods, ii)with non-anchored iron rods,, iii)with anchored iron rods,, iv)with anchored iron rods, and connected by wires, and v)with iron rods, but the plates are small.

50 sine waves at 5 Hz were applied to these model slopes . Acceleration of the shaking table increased from 50 Gals up to the acceleration to cause slope failure with an increment of 50 Gals. The input acceleration to cause slope failure is called as the critical acceleration. During the shaking, accelerations on the ground surface, displacements of the ground surface, stresses of iron rod, stresses of wires and pressures of plates were measured, as shown in Fig.3.



(a) Soil container



(b) Iron rods and plates

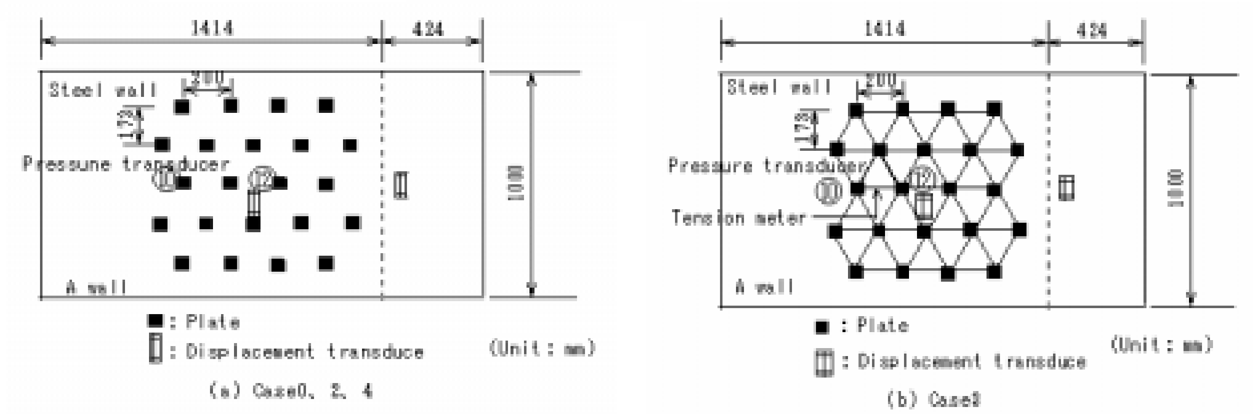


Fig3. Structure outline chart

Table1. Test conditions

Test	Anchore of nails	Plate			Tension
No.	to bottom plate	Shape	Width(mm)	Thickness(mm)	of wire
Case0	Non-anchored	Square	50	5	—
Case1	—	—	—	—	—
Case2	Anchored	Square	50	5	—
Case3	Anchored	Square	50	5	3N
Case4	Anchored	Square	30	5	—

CRITICAL ACCELERATION TO CAUSE FAILURE

In Case No.1, not treated, settlement of top of the slope increased with input acceleration. Then entire slope failure occurred when input acceleration reached to 295 Gals, as show in Photo 2(a). After the test, the ground was excavated carefully. And a clear slip surface was observed at the depth of about 10cm.
In Case No. 0, treated with non-anchored nails, settlement of top of slope increased with input acceleration also. When the input acceleration reached to 650 Gals, non-treated zone failed as shown in Photo 2(b). As the critical acceleration was higher than that in Case 0, it can be said that the inserted iron rods resisted against sliding, even the iron rods were not anchored to bottom steel plate.

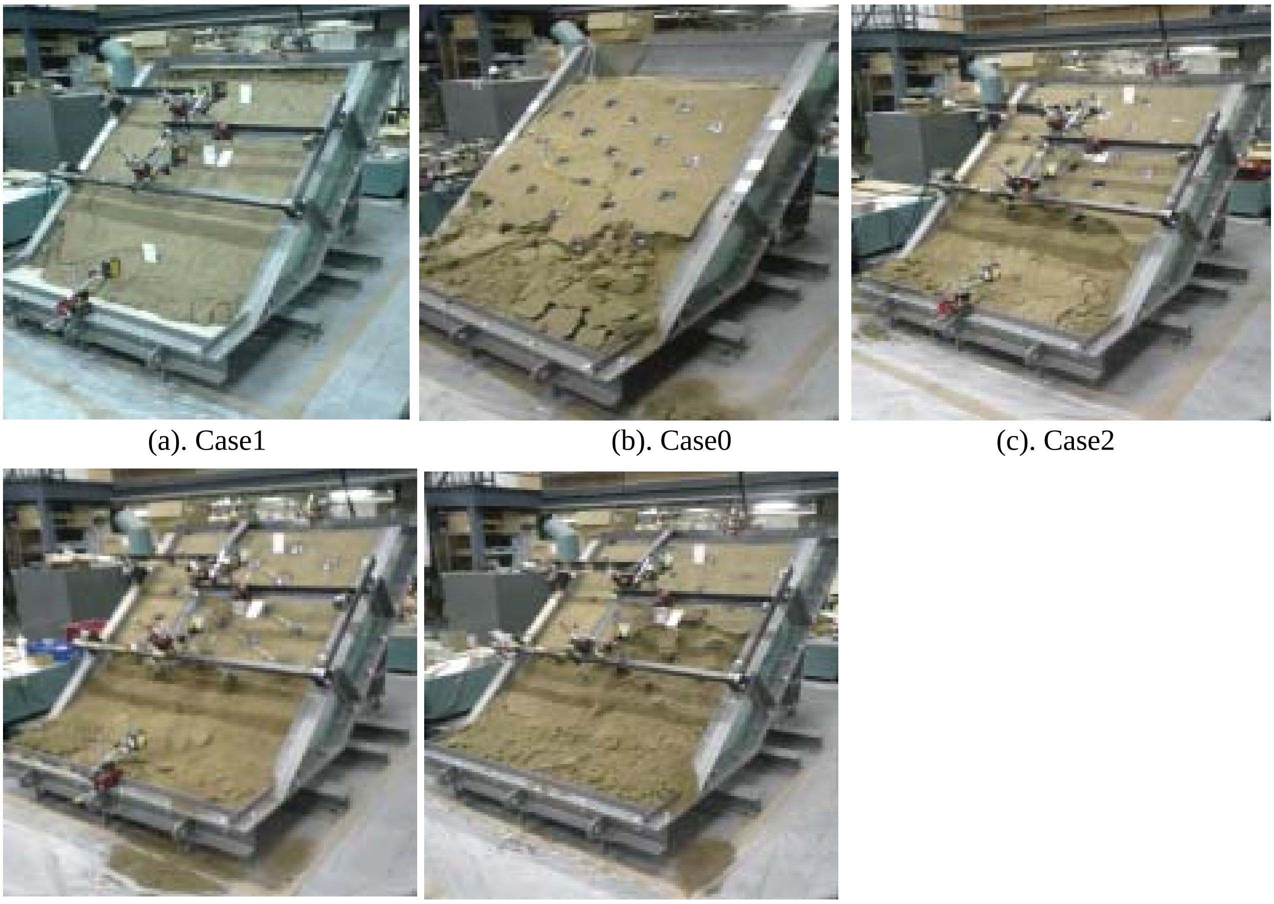
In Cases 2 and 3, treated with anchored iron rods, no obvious settlement or deformation occurred in treated zone even input acceleration exceeded 900 Gals. Partial sliding occurred in non-treated zone when input acceleration exceeded 900 Gals, as shown in Photos 2(c) and 2(d). Anchored iron rods were very effective to resist against sliding. By comparing Case 2 and Case 3, deformation of the slid soil in Case 3 was smaller than that in Case 2. Therefore, it seemed that wire ropes could decrease the deformation of slope.

In Case 4, slide occurred at 770 Gals as shown in Photo 2(e). The critical acceleration to cause failure was smaller than that in Case 2. Size of plates must be important.

COMPARISON OF SETTLEMENT OF THE TOP OF SLOPE

Figure 4 shows relationships between input acceleration and settlement of top of slope. Settlement increased with input acceleration in all case. However, amount of settlement was different in each case. The settlement in Case 3, which was not treated, was smallest. And the settlement increased in the order of Case 2, Case 4, Case 0 and Case 1. The order was same as the order of critical acceleration to cause failure, as mentioned before.

At 600 Gals, the settlement in Case 2 was 3 to 6 mm less than that in Case 4. This difference must be attributed to the difference of size of plates. The settlement in Case 3 was about 6 mm less than that in Case2. This implies the importance of wire ropes.



(a). Case1 (b). Case0 (c). Case2

(d). Case3 (e). Case4

Photo2. Bahavior stopes at critical acceleration

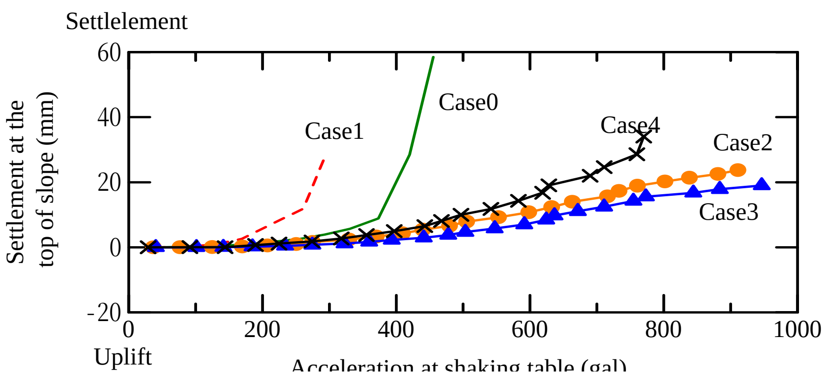


Figure4. Relationships between input acceleration and settlement at the top of slope (all Case)

BENDING STRAIN AND AXIAL STRAIN OF IRON RODS

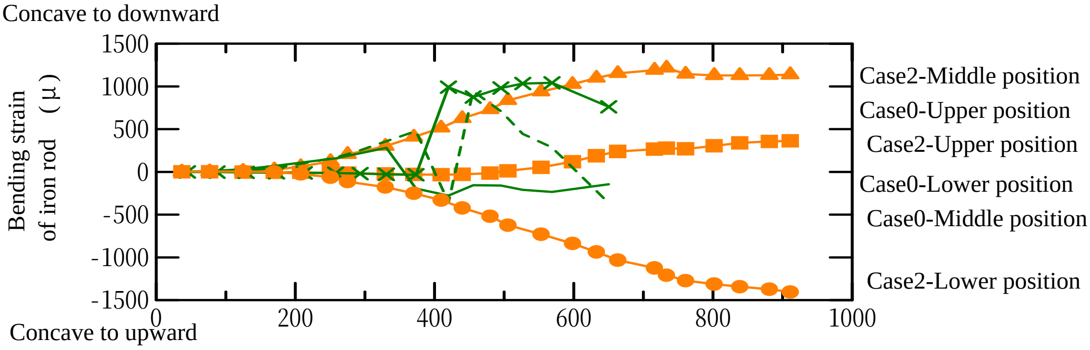
Figure 5 shows relationships between input acceleration and bending strain of iron rods in Case 0 and Case 2. In case 2, bending strain of the middle iron rods increased with input acceleration. At lower iron rods, bending strain decreased with input acceleration. In Case 0, on the contrary, bending strain did not increase when input acceleration exceeded 400 Gals. This means that iron rods were pulled out from base plate when input acceleration reached 400 Gals. It is estimated that resistance to sliding due to bending stress did not increase with input acceleration in higher acceleration, because the bending strain did not increase with input acceleration.

Relationships between input acceleration and axial strain are shown in Fig.6 for Case 0 and Case 2. In Case 2, axial strain deceased with input acceleration, because soil was compacted due to shaking. In contrast, axial strain in Case 0 increased with input acceleration. Iron rods must be stretched due to sliding of soil.

Figure 7 compares bending strain in Case 2 and Case 4. In Case 4, bending strain at lower iron rods decreased with input acceleration up to about 600 Gals. Then, the bending strain increased. The bending strain of middle iron rods also increased with input acceleration up to about 600 Gals. Then, the bending strain decreased. As partial failure occurred in untreated zone when input acceleration reached to about 600 Gals, the bending resistance at lower iron rods must be decreased in higher acceleration.

Figure 8 compares bending strain in Case 2 and Case 3. Tendency of bending strains with input acceleration was similar in both cases. However, changes of strain with input acceleration in Case 3, were smaller than those in Case 2. This means resistance to sliding could be shared by iron rods and wire ropes in Case 3.

Figure5.Relationships between input acceleration and bending moment of iron rod (Case0, Case2)



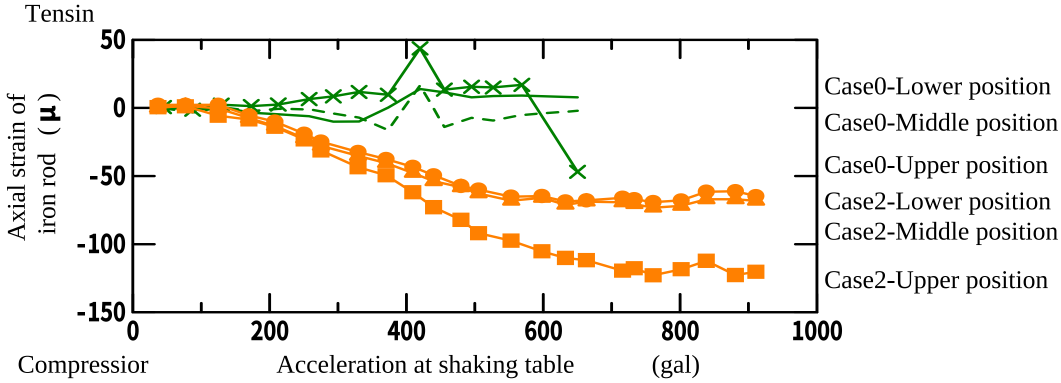


Figure6.Relationships between input acceleration and axial strain of iron rod (Case0, Case2)

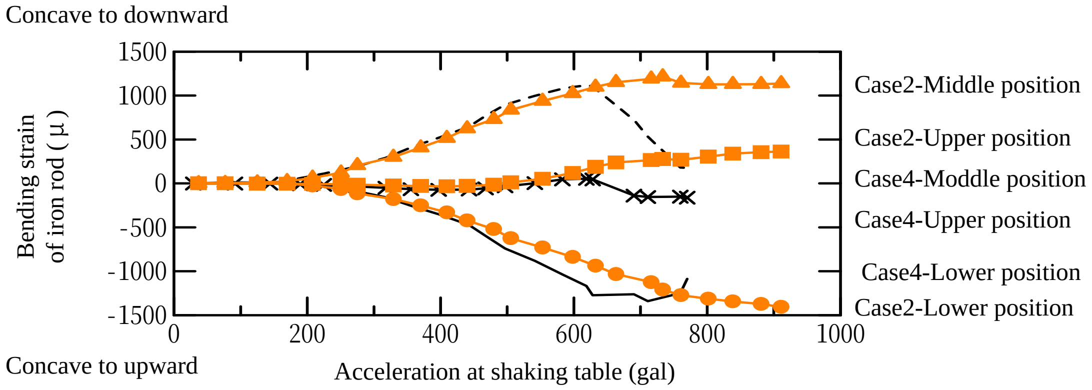


Figure7.Relationships between input acceleration and bending moment of iron rod (Case2, Case4)

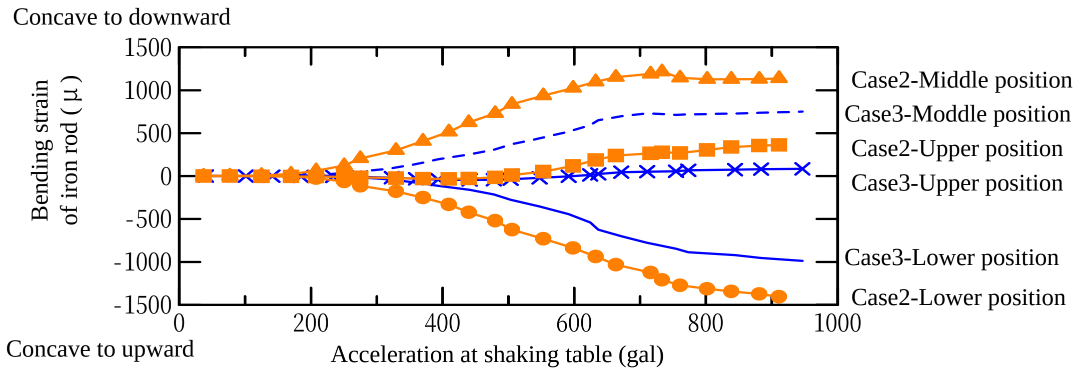


Figure8.Relationships between input acceleration and bending moment of iron rod (Case2, Case3)

SETTLEMENT OF SLOPE SURFACE

Figure 9 shows relationships between input acceleration and settlement measured at the middle of slope surface. In Case 2, settlement at the center of the slope surface increased with input acceleration. In contrast, slope surface heaved in Case 1 and Case 4. The heaving occurred when input acceleration reached to about 400 Gals and 600 Gals for Case 1 and Case 4, respectively. In Case 3, ground surface did neither settle nor heave. Wire ropes must prevent the settlement or heaving.

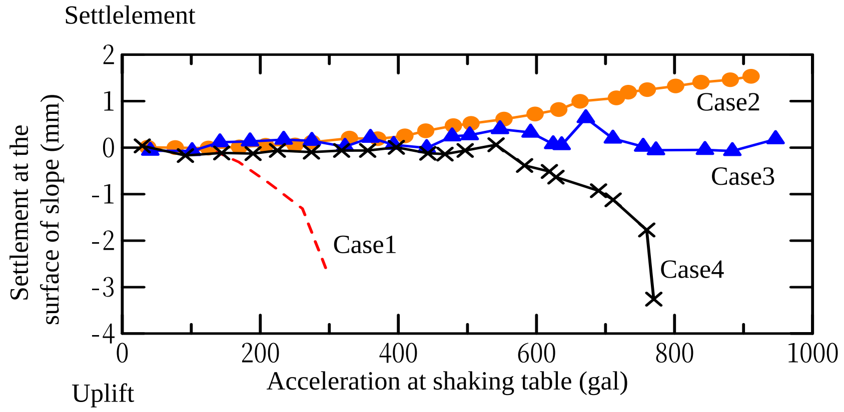
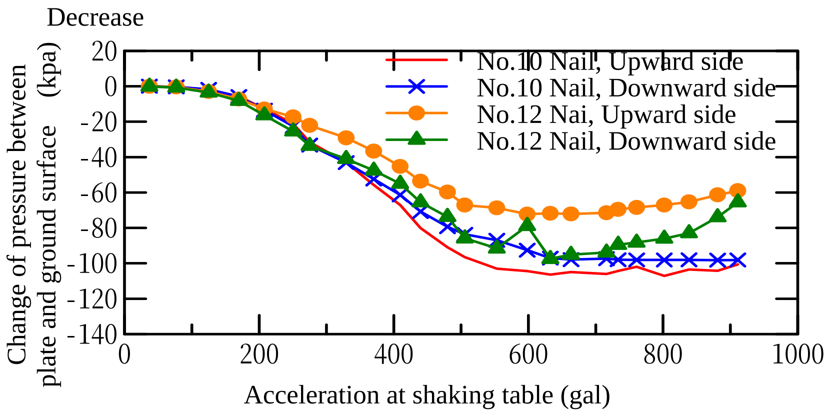


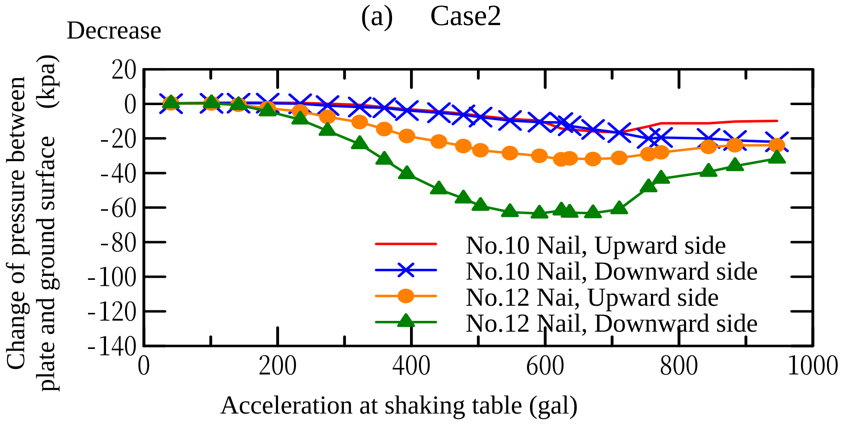
Figure9. Relationships between input acceleration and settlement at the surface of slope

PRESSURE ACTED ON PLATES

Figure 10 (a) and (b) show relationships between input acceleration and pressure acted between plates and slope surface for Case 2 and Case 3, respectively. All pressure decreased with input acceleration due to compaction of soil. The pressures in Case 2 decreased more than those in Case 3.



(a) Case2



(b) Case3

Figure10. Relationships between input acceleration and change of pressure between plate and ground surface

CONCLUSIONS

Several 1G shaking tests were conducted to study the mechanism of the Non-frame method during earthquakes. The following conclusions were derived through the tests:
(1) Non-frame method is effective to prevent slope failure during earthquake.
(2) Iron rods must be fixed to stable bottom layer.
(3) Large plates are effective than small plates.
(4) Wire ropes can increase resistance to failure.

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