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AN EXPERIMENTAL RESEARCH ON A REDUCTION METHOD FOR LIQUEFACTION DAMAGE TO HOUSE USING THIN STEEL SHEET PILES

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ABSTRACT

The Great East Japan Earthquake of March 11, 2011 induced liquefaction damage to detached houses in the area along Tokyo Bay where was far from the epicenter of the earthquake. While the countermeasures against liquefaction for large structures have been carried out so far, those for small structures have not been sufficiently done. Therefore, we have developed a new method of a countermeasure that thin sheet piles are set by every detached house so as to surround the ground under the foundation of such a house. This method can be carried out even in narrow space and applied to build new houses or already built one. This method can suppress the unequal settlement of detached house by confining the movement of the subsurface soil mass under the foundation of detached house even if it may fail to prevent occurrence of liquefaction itself.

The results of the shaking table experiment with 1/4 scale model of the house and ground conducted to examine the reduction effect for liquefaction damage, exhibit the reduction effects for liquefaction damage in terms of the settlement sunk into ground and inclination of house floor and foundation.

INTRODUCTION

The Great East Japan Earthquake of March 11, 2011 induced liquefaction damage to detached house in the area along Tokyo Bay where was far from the epicenter of the earthquake. Out of about 27000 houses all over Japan which suffered from liquefaction damage due to this earthquake, 8700 were in Urayasu City, Chiba Prefecture. While the countermeasures against liquefaction for large structures have been carried out so far, those for small structures such as detached house have not been sufficiently done.

The method of liquefaction damage reduction for detached house changes according to the range for countermeasures to be carried out and the target of countermeasures, that is, for new build house or for already built one. As for the range within which the countermeasure for detached house is carried out, there are two cases, one is for the whole housing lots in wide space and the other is for every detached house in narrow space. Moreover, the methods of the countermeasures for liquefaction damage reduction are generally classified into two groups. One group of methods permits the occurrence of liquefaction, and the other group does not permit it. Considering countermeasures for liquefaction damage reduction from the viewpoint of construction engineer, various problems occurs, such as small space for countermeasures, impossibility of use of heavy construction machinery in high

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efficiency, and difficulty of house owners' acceptance of its expense for countermeasures and so on. The authors have developed a new method of countermeasure for liquefaction damage reduction in order to solve these problems. The method uses thin sheet piles which are set so as to surround the ground under the foundation of every detached house, and can be executed even in narrow space. We expect that this method could suppress the unequal settlement of detached house by confining the movement of the surface soil mass under the foundation of detached houses and preventing the soil from flowing out, even if allowing the occurrence of liquefaction.

We have conducted the shaking table experiments with 1/4 scale model of house and ground which is considered to be real house and ground to examine the effect for liquefaction damage reduction. The outline and results are as follows.

OUTLINE OF METHOD

Figure.1 shows the sheet piles which we used in the experiments. This sheet pile is made of hot-dip zinc coated steel with high corrosion resistivity which is also environmentally friendly. Though general sheet pile has a thickness of more than 10mm, this sheet pile has a thickness of 2.3mm, so is lighter and more economical compared to general one. We standardize the parts into two types, standard type and corner type to communize them for convenience.

Figure.2 shows the outline of this method. We use small construction machinery to carry out this method. We show here the case of a new house build after having carried out the countermeasure for liquefaction damage reduction in narrow space. The execution sequence of the method is as follows.

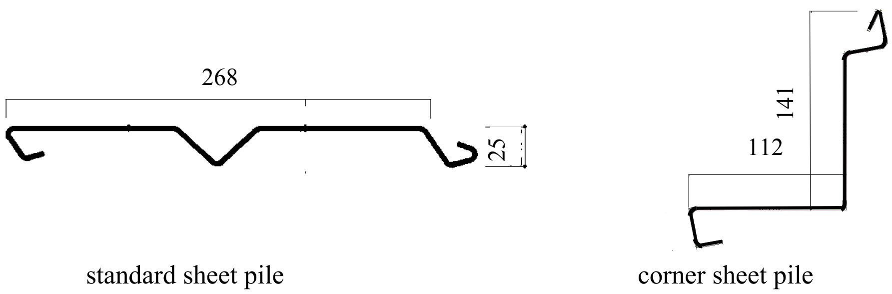


Figure 1 Shape of sheet pile

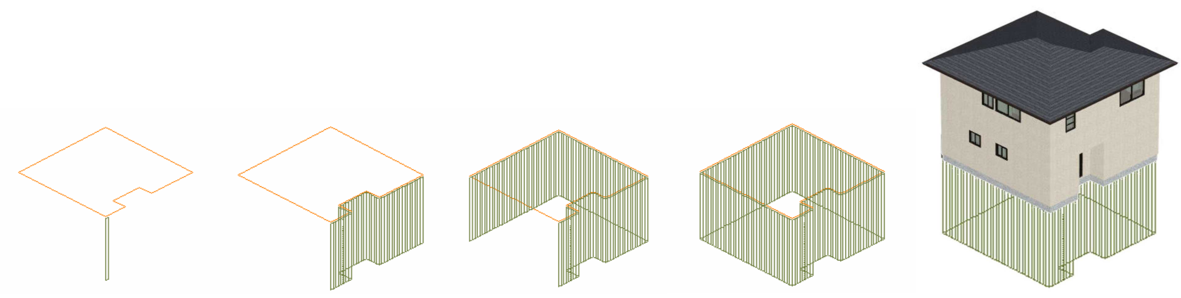


Figure 2 Outline of the method

First, drive standard or corner sheet pile under the foundation of the house supposed to be constructed. Next, drive the second sheet pile fitting together with the first one at the junction, and repeat this operation so as to surround the subsurface soil mass under the foundation of detached house. Third, after completion of the sheet pile work, make the mat foundation of reinforced concrete. Then, construct the upper structure of detached house.

EXPERIMENT METHOD

EXPERIMENT EQUIPMENT

Figure.3 shows the experiment equipment used. It is a large shear box, one of facilities in Building Research Institute, which is composed of shear frames, hydraulic actuators, automatic soil and earth transport device, and measurement system. This equipment can reproduce the vibration of ground in earthquake by making the artificial ground of 10m long (in direction of shaking), 5m deep, and 3.6m wide in shear frames. This large shear box is placed on a shaking table, and can realize relative displacement of ±50mm and total displacement up to maximum ±800mm to total height of 5m because the unit frame of 300mm in height is piled up in 17 stages to form the whole shear frames. Hydraulic actuators have a shaking performance of maximum 20kine to the inertial load of total weight of 4410kN in loading the shear box. It can accept fundamental or real earthquake waveform as input waveform by automatic hydraulic control system. Measurement system can obtain data of 100 points at the same time by using high speed digital strain measurement device.

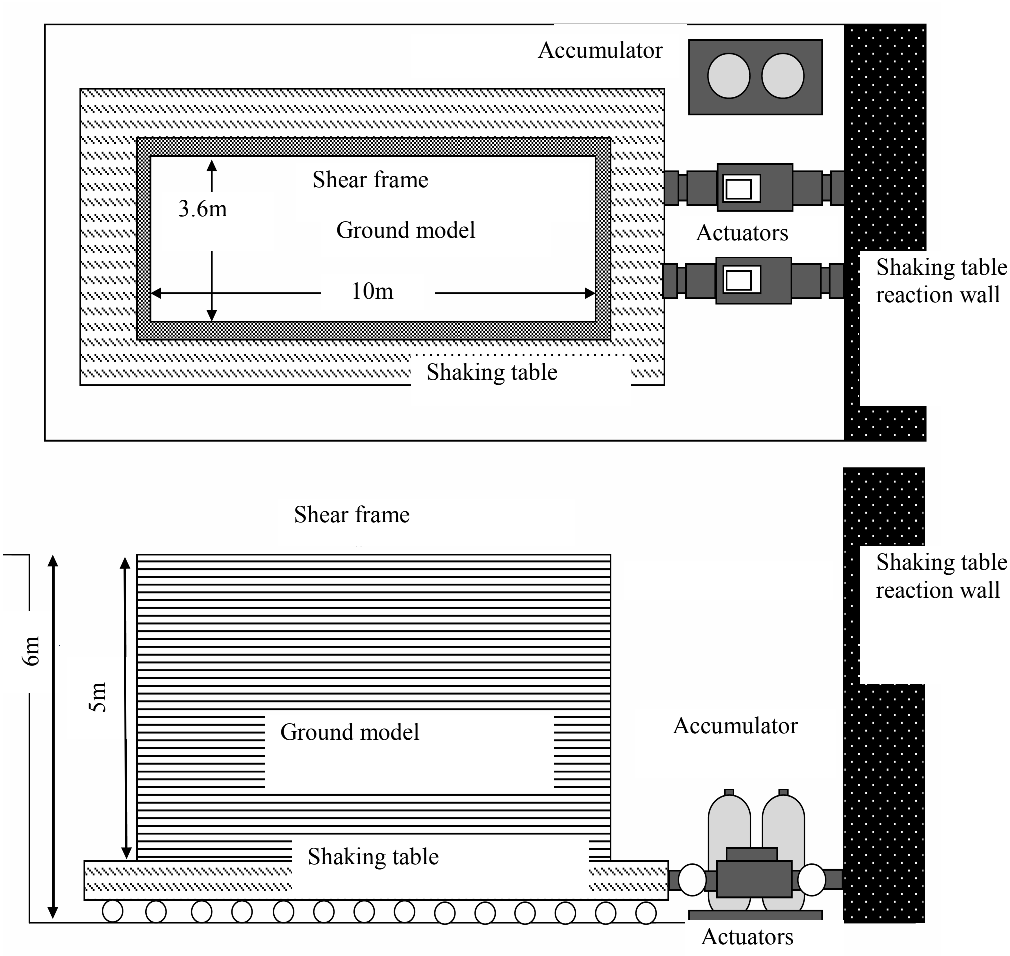


Figure 3 Experiment equipment

EXPERIMENT MODEL

We planned Type1 and Type2 models in the experiments. Figure 4 shows the arrangement of houses and sheet piles of Type 1. In Type1 model, southern house has sheet piles of 2500mm in length and northern house has none of countermeasures. Figure 5 shows the arrangement of houses and sheet piles of Type 2. In Type2 model, both houses have sheet piles of 1250mm in length and are set into up to the middle point of liquefaction layer (upper layer) ,and in addition to that, southern house has four supports at four corners, of which tips are embedded into non liquefaction layer (lower layer).

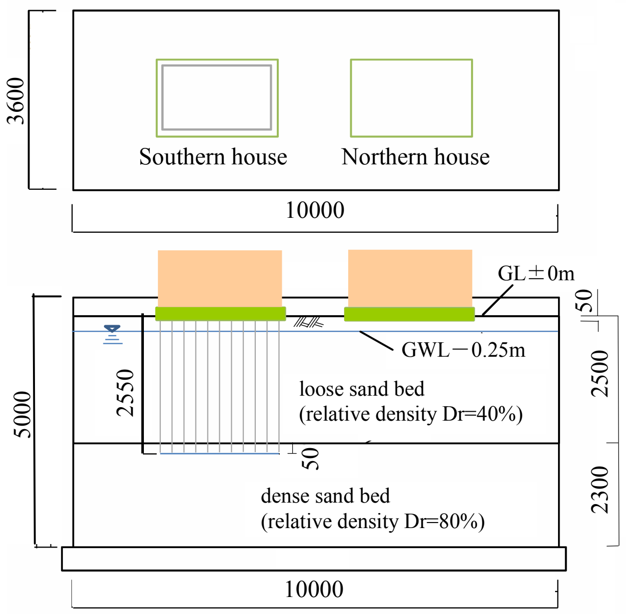


Figure 4 Experiment Type 1

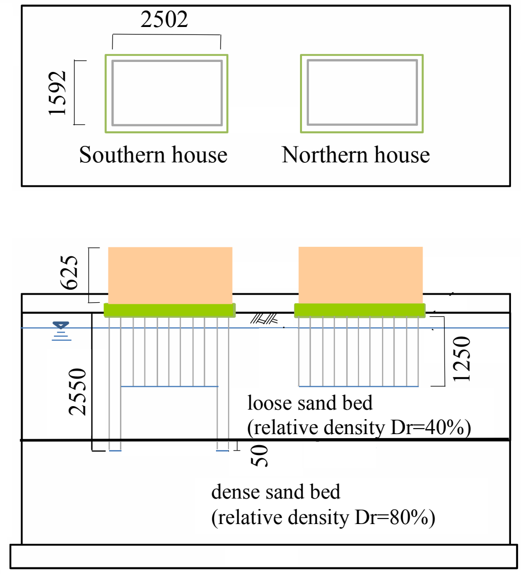


Figure 5 Experiment Type 2

METHOD OF GROUND MAKING

Nikko Silica Sand No.6 was used as the ground material. Table 1 shows the properties and mechanical characteristics. Figure 6 shows the dynamic characteristics. The ground for the experiment is composed of two layers. The lower layer has a thickness of 2300mm on the basement of the shear box, and has a relative density of 80% (Dr=80%). The upper layer has a thickness 2500mm over the lower layer, and has a relative density of (Dr=40%). The ground was made by air pluviation method. After having levelled the surface of the spread soil in a spreading depth of 25cm homogeneously, the ground was compacted using small tamping machine with managing to keep the soil density a specified value. The control of density of each layer was carried out through the density measurement by core cutter method.

Table 1 Physical and mechanical characteristics

Item	Property	Remarks
Density of soil grain ρs g/cm^3	2.648	
Maximum dry density $\rho dmax$ g/cm^3	1.701	
Minimum dry density $\rho dmin$ g/cm^3	1.339	
Maximum grain size mm	0.85	Sand {S}
Gravel fraction 2～75mm %	0	
Sand fraction 75μm～2mm %	96.4	
Fine particle fraction ＜75μm %	3.6	
Uniformity coefficient Uc	2.13	
Adhesive force (Cohesion) c_d kN/m^2	2.6	Dr=30%
Internal friction angle φ_d deg.	31.9	Consolidated-Drained condition

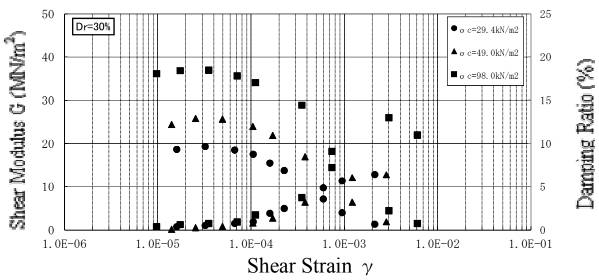


Figure 6 Dynamic deformation characteristics of ground materials

HOUSE MODEL MAKING

The foundation of house model is made of concrete and its upper structure is made of wood. The dimensions of the house model are 1592mm in width, 2502mm in length, 625mm in height and its weight is 59.78kN. The dimensions and weight of the house model are set in homothetic ratio of 1/4 to standard wooden 2 storied house.

MEASUREMENT

Figure 7 and figure 8 show the arrangement of sensors.

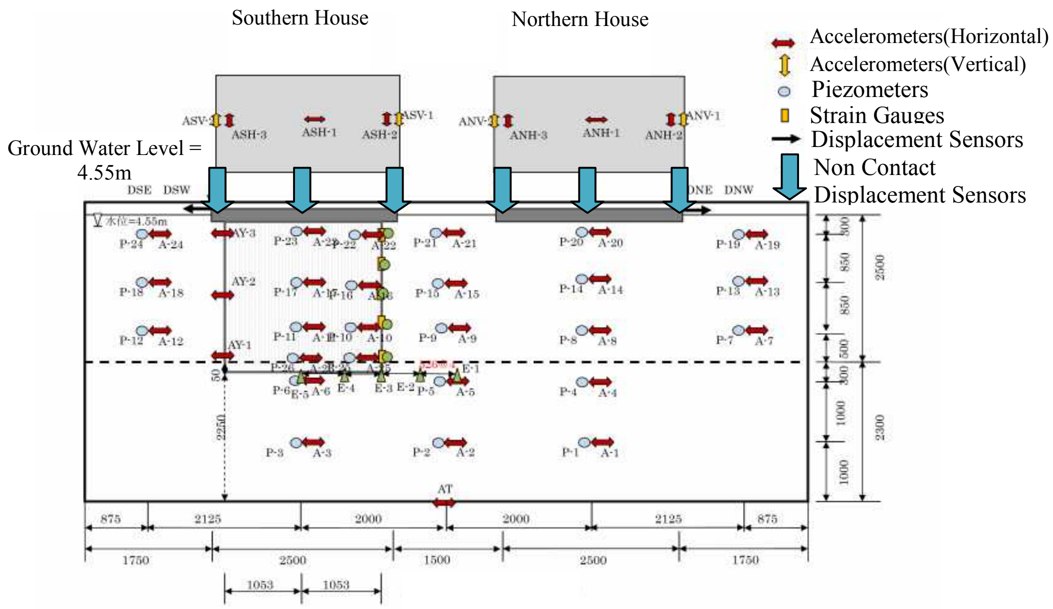


Figure 7 Type1 Experiment models and sensor arrangement

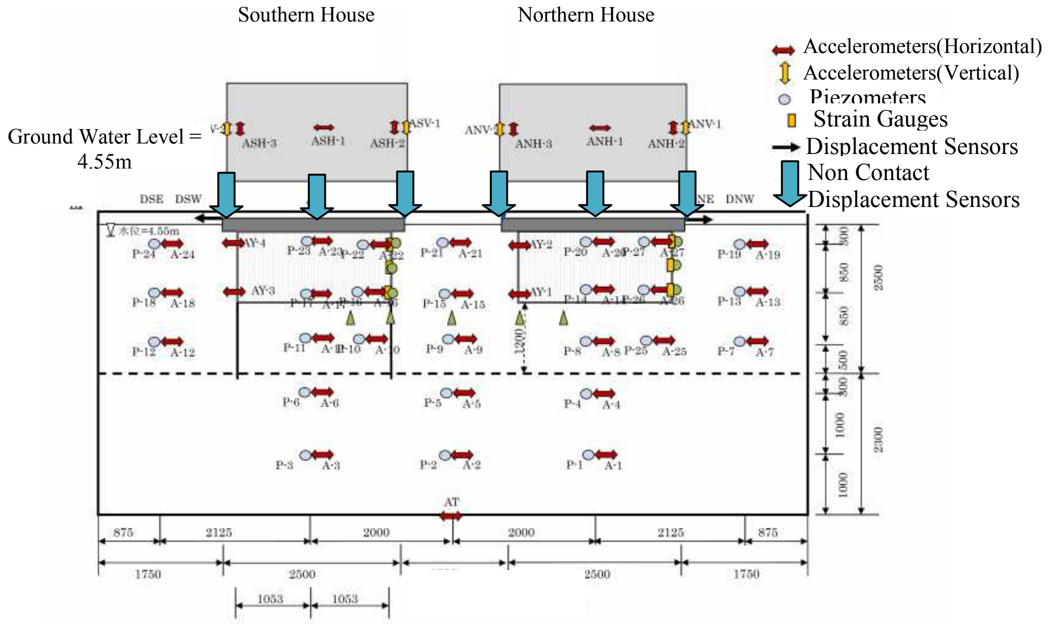


Figure 8 Type2 Experiment models and sensor arrangement

Displacement sensors, piezometer accelerometers, strain gauges and several other sensors were set in order to obtain displacements and water pressure change required in numerical analysis. Noncontact displacement sensors set outside of shear box were mainly used to measure the absolute settlement of house model. Piezometers and accelerometers were arranged and measured in order to be able to grasp the difference between the behaviors of the free ground and the confined ground by thin sheet piles

INPUT WAVE

Frequency, amplitude of acceleration and number of waves during shaking duration are 2Hz, 120gal, 120, respectively. This was determined by obtaining the cyclic shear wave equivalent to Tokyo Bay seismic motion of the Great East Japan Earthquake and considering the shaking ability of shaking table. The simple waveform was selected in order to utilize the parameters obtained in this experiment in numerical analysis.

EXPERIMENT RESULTS

SETTLEMENT OF FOUNDATION AND SETTLEMENT SUNK INTO THE GROUND

Figure 9 shows the time history of average settlements of Type1 and Type2. The average settlement is an average of vertical displacements measured by displacement sensors at three points (north, middle, south) on the foundation of each house model. The average settlements at about 90sec after the beginning of shaking were 16.7mm at southern house model with countermeasure and 139.7mm northern house model without countermeasure in Type1. This means that the average settlement in the case of house model with countermeasure was suppressed compared to that of house model without countermeasure. In Type2, the average settlements were 62.7mm at southern house model with supports at four corners and 62.6mm at northern house model. This means that there is no big difference in settlement between house model with supports at four corners and that without supports at four corners. Comparing the case of house model without countermeasure in Type1 with that with countermeasure in Type2 which had thin sheet piles set up to the middle point of liquefaction layer, we could confirm the latter had the suppression effect of about 45% in terms of average settlement.

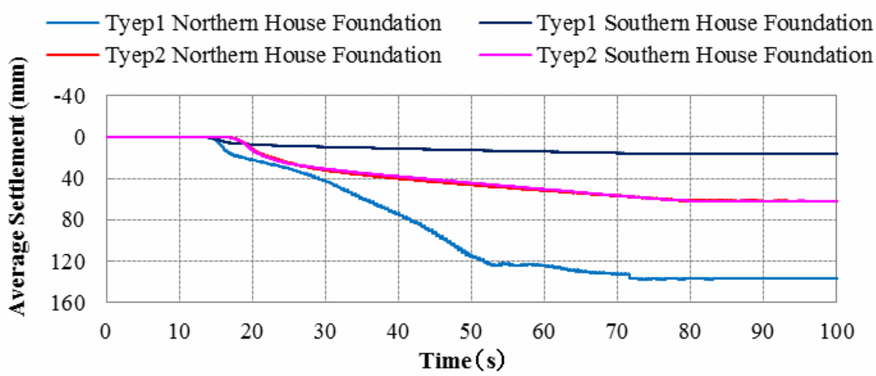
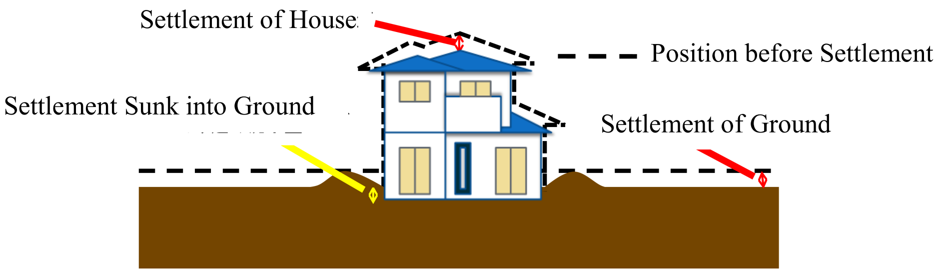


Figure 9 Time history of foundation average settlement

We calculated settlement sunk into the ground in the way shown in Figure 10. Table 2 shows average settlement of ground surface and foundation measured with leveling instrument after 3 hours from the completion of shaking. The average ground settlement is an average of that of 9points which are the total of 3points at southern part, 3points at central part and 3points at northern part of the free ground that house model doesn't exist. The average settlement of foundation with dissipation of excess pore water pressure increases by 58.4mm to the foundation average settlement of 137.9mm at about 90sec after the beginning of shaking experiment at northern house foundation in Type1. On the contrary, southern house foundation in Type1 and both southern and northern house foundations in type 2 almost remained unchanged within ±2mm to the values of the foundation average settlement measured at about 90sec after the beginning of shaking. We could confirm the suppression effect after dissipation of excess pore water pressure. The settlement sunk into ground of both the foundations in

Type 2 were about -35mm, which were smaller by about one fourth than that in Type1. One of the reasons could be the restriction of the flow of liquefied ground by sheet piles.



Settlement Sunk into Ground =
Settlement of House – Settlement of Ground

Figure 10 Settlement sunk into ground

Table 2 Absolute settlement and settlement sunk into ground
(3hours after completion of shaking, level measurement)

	Average Ground Settlement (mm)	Southern House Foundation (mm)		Northern House Foundation (mm)	
		Average Settlement	Settlement Sunk into Ground	Average Settlement	Settlement Sunk into Ground
Tyep1	55.2	14.7	-40.5	196.3	141.1
Type2	26.9	63.5	36.6	61.8	34.9

INCLINATION

Figure 11 shows time histories of inclination in the type1 and type2 experiments.

Inclination is defined as relative vertical displacement between ends of foundation of each house model divided by width of the foundation (2500mm), is revealed in the form x/1000, and the sign of inclination takes positive value when house or foundation inclines rightward down. The maximum values of inclination in the type 1 are 1.6/1000 in the southern house with countermeasure and 11.1/1000 in the northern house with no countermeasure. We could confirm the suppression effect is confirmed in the southern house with countermeasure. The maximum values of inclination in Type 2 are -1.4/1000 in the southern house with supports at four corners, and 4.6/1000 in the northern house with no supports. We could confirm that inclination was smaller in the southern house with supports at four corners than in the northern house with no supports. Comparing the case of the northern house with no countermeasure in Type 1 with the cases of which have the sheet piles set up to the middle point of upper layer in Type 2, we could confirm the suppression effect of about 49% concerning inclination.

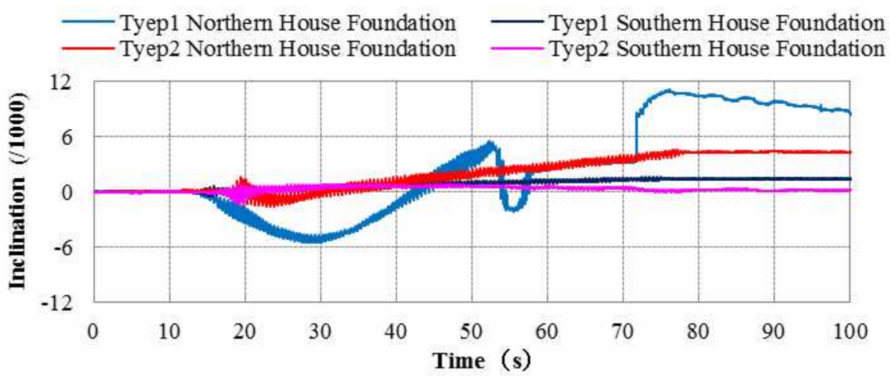


Figure 11 Time history of inclination

CONCLUSION

To evaluate the performance of a new reduction method using thin sheet piles for liquefaction damage to detached house, 1/4 scale shaking table experiment has been conducted. The shaking response behaviors of the ground and house with and without countermeasure of thin sheet piles and supports were compared. The results exhibits that the new reduction method using thin sheet piles has the suppression effect of liquefaction damage, in terms of settlement sunk into ground and inclination. This suppression effect of liquefaction damage may be attributed to the restriction of the flow of liquefied ground by thin sheet piles.

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