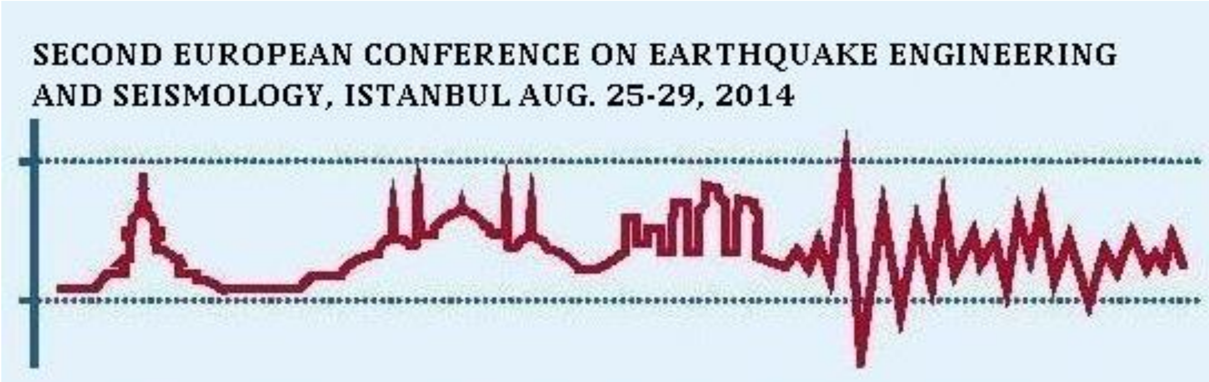

INVESTIGATING THE FUNCTION OF BASEMENT FOR PREVENTING LIQUEFACTION IN SANDY SOIL

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ABSTRACT

On March 11, 2011, Tohoku-Pacific Ocean earthquake occurred, a lot of personal house were destroyed by liquefaction caused by the huge earthquake. The phenomenon of liquefaction is the urgent problem that needs further study. Simultaneously, the expenditure in the engineering for preventing liquefaction should be taken into account. On the principle of higher safety and lower cost, a new structure form, Three-Union house with basement, is introduced in this study. Aiming at liquefaction inhibition and the stability of foundation, the function of basement for preventing liquefaction is evaluated by shaking table tests. This test considered the following factors that the substructure existing and not, individual or union forms, the weights of different model. The test result showed that higher stability can be achieved by Three-Union house with basement.

INTRODUCTION

Japan is the handful of earthquake-prone countries in the world. Liquefaction occurred in a wide range from Tohoku to Kanto in Tohoku-Pacific Ocean earthquake, which took place on March 11, 2011 (Mw 9.0). As a result, thousands of houses were destroyed and more than 15,000 people lost their lives in this huge disaster. Since many countermeasures of liquefaction have been developed and applied in the construction of large buildings, there was relatively less damage to large buildings. On the other hand, the slower development of protection countermeasures for personal house led to more damages in this earthquake.

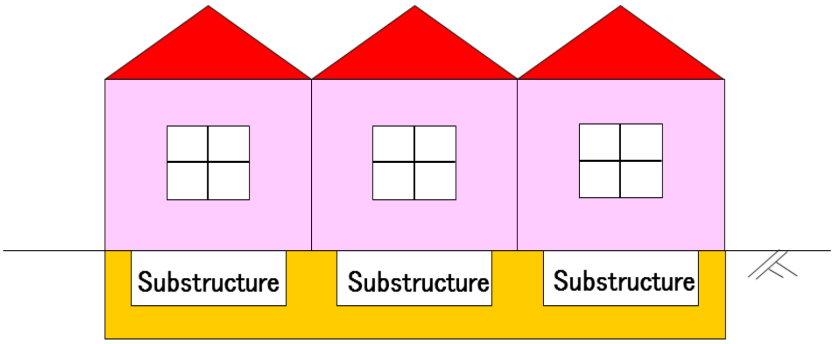

Figure 1. Three-Union house with substructure model.

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After that Tohoku-Pacific Ocean earthquake, a lot of researches on solving liquefaction problem were conducted to help the disaster victims re-constructing their homeland, which is an extremely urgent problem. Focusing on Three-Union house with basement, a new structure form is proposed in this study as shown in Figure 1. In order to look for a structure form with most effective function of preventing liquefaction, a series of tests were conducted. Furthermore, the factors were evaluated to analyse the damage of liquefaction, which includes the excess pore pressure on the ground, seismic responding on acceleration, settlement and incidence of house model. The substructure existing and not, individual or union forms, the weights of different model are considered when implementing the shaking table tests. The seismic wave was input in sinusoidal with frequency f = 3 Hz, and the maximum acceleration was set to 400 Gal in 10 s for testing.

TEST CONDITONS

Ground condition and each sensor setting were depicted in Figure 2, all tests were operated in earth's gravity field. The container is 1800 mm in length and 400 mm in width. Toyoura sand was adopted as the test material. By water falling method, the ground could nearly reach full saturation that was the initial condition. Adjusting the height of the sandy ground in the container up to 500 mm, the relative density (Dr) got to around 35%. The pore pressure transducers were set inside the ground, at the same time, the top of house model was installed. The accelerometer was used to measure the acceleration in horizontal direction, while linear variable differential transformer was used to record the history of settlement.

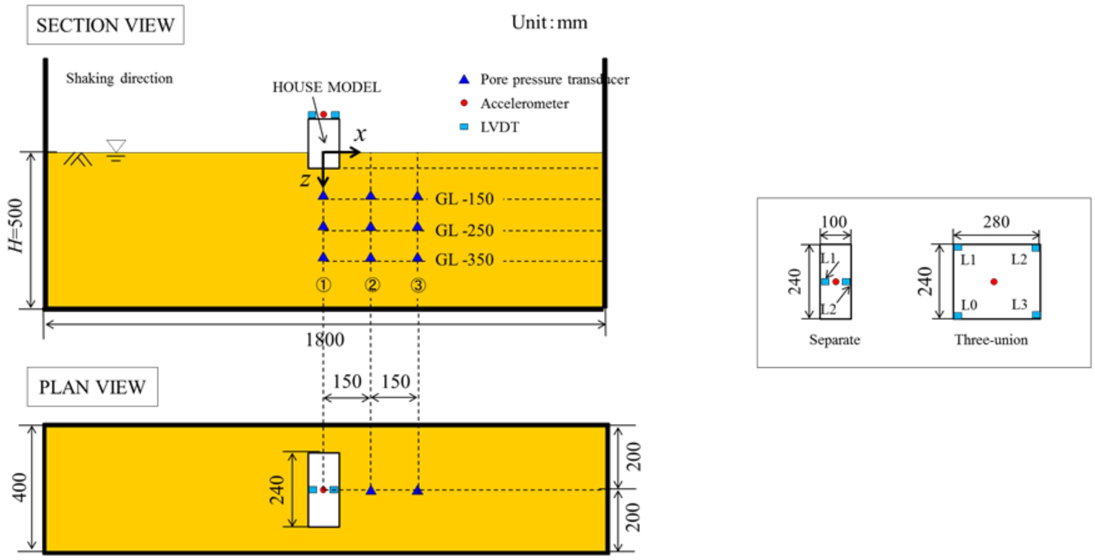


Figure 2. Schematic diagram of the container.

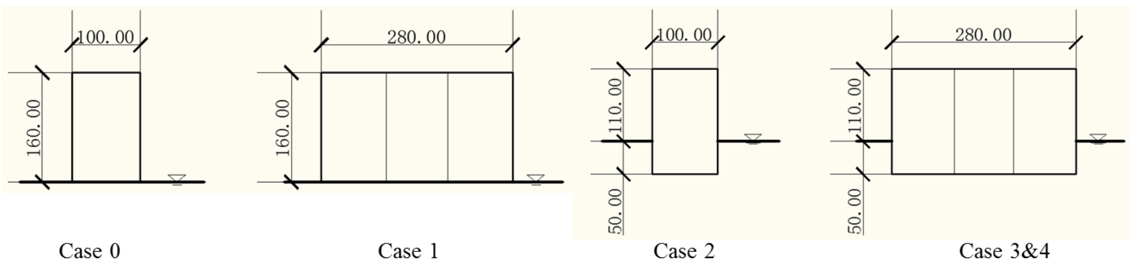


Figure 3. Model size, all sizes are in mm.

House model were made of acrylic fibre by scale of 1/50 to actual size of specified house. Depending on the substructure existence or not, individual or union forms and different weights of models, five patterns was considered in the testing, and the details are shown in Table 1 and Figure 3.

Table 1. Test conditions

	GROUND CONDITION (Relative Density)	STRUCTURE	SUBSTRUCTURE EXIST OR NOT	MODEL WEIGHT (KG)
Case 0	38%	Separate	No(z = 0 mm)	1.8
Case 1	39%	Three-Union	No(z = 0 mm)	3.6
Case 2	30%	Separate	Yes(z = 50 mm)	1.8
Case 3	33%	Three-Union	Yes(z = 50 mm)	3.6
Case 4	38%	Three-Union	Yes(z = 50 mm)	7.2

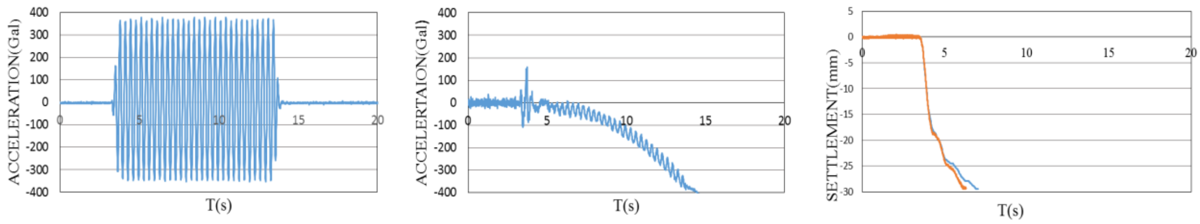
THE PERFORMANCE OF THE PATTERNS WITHOUT SUBSTRUCTURE

The response of Case 0 is analysed in first. Figure 4(a) shows the seismic wave input to the container, which was recorded by an additional accelerometer from the table. Figure 4(b) depicts the acceleration varying with time on the top of house. It reaches the maximum magnitude around 150 Gal rapidly when the shaking started, then decreased and finally changed in a limited extent. Note that the acceleration curve deviated from X-axis, which indicates that the house over turned in final situation. Figure 4(c) reveals that the settlement occurred at 2-3 s after shaking, then kept down 30 mm. After that, the house started to incline. While a high angle lean does not appear in Case 1, and final settlement is about 21 mm.

The magnitude of pore water pressure (Excess pore pressure ratio) is used to estimate the extent of the liquefaction, which is defined as:

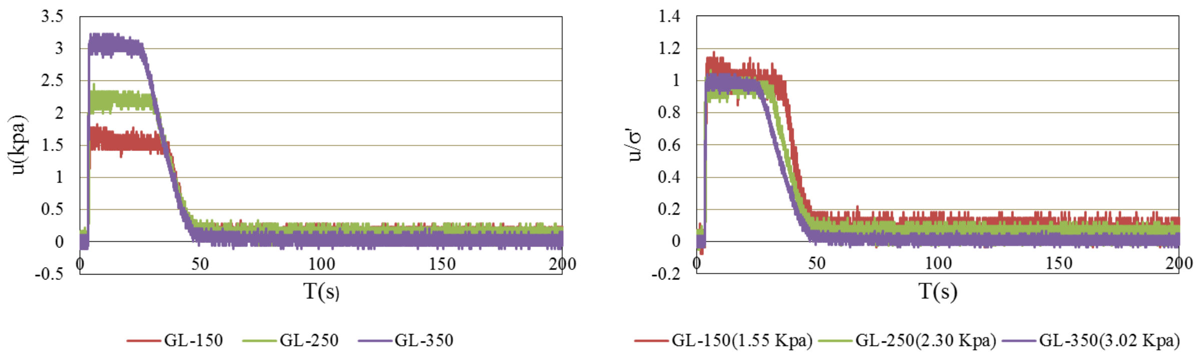
$$\text{Excess pore pressure ratio} = \frac{u}{\sigma'_z} \tag{1}$$

In which, σ'_z is effective stress, determined by the upper load, u is the pore water pressure.



(a) Seismic Wave Input (b) Acceleration on House Top (c) Settlement

Figure 4. Responses on shaking test in Case 0.

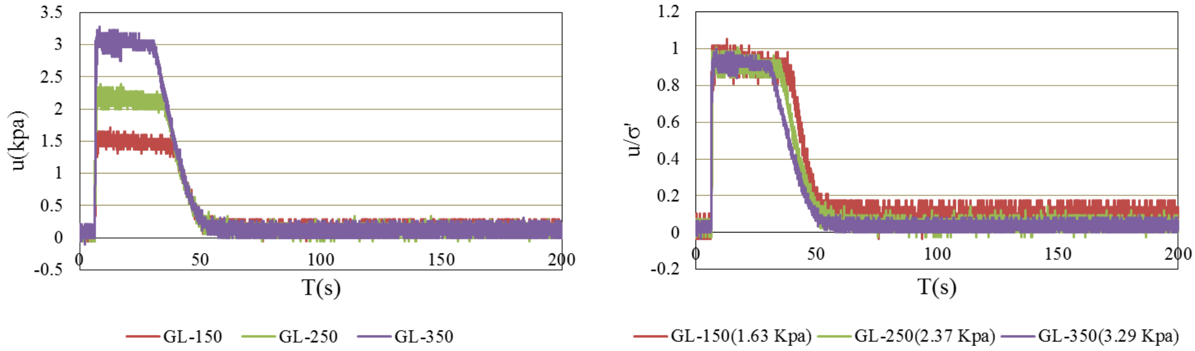


(a) Excess Pore Pressure (b) Excess pore pressure Ratio

Figure 5. The pore water pressure versus time in Case 0.

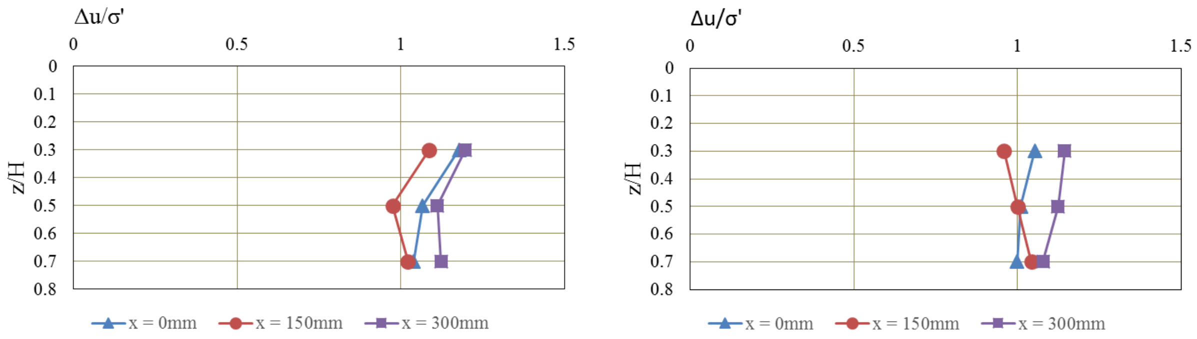
Figure 5 shows the pore water pressure of Case 0 versus time. Figure 5 (a) reveals that the pore water pressure raised promptly following shaking start, and then kept in a constant level in spite of the shaking ending at 15s. The deeper the soil, the higher the pore water pressure performed. Moreover, it is noted that, the pore pressure decreased slowly with time, meanwhile, the beginning of dissipating presents sequential order by depth. Similar phenomenon can be observed in Case 1 as shown in Figure

6 (a). It can be found from Figure 5 (b) and Figure 6 (b) that the excess pore pressure ratio of Case 0 and Case 1 almost achieved 1.0 in each depth, that is to say, liquefaction occurred in entire ground. Since the most maximum excess pore pressure ratio reach 1.0, a relation between the depth and distance from house can be drawn as Figure 7.



(a) Excess Pore Pressure (b) Excess pore pressure Ratio

Figure 6. Case 1 the pore water pressure versus time.

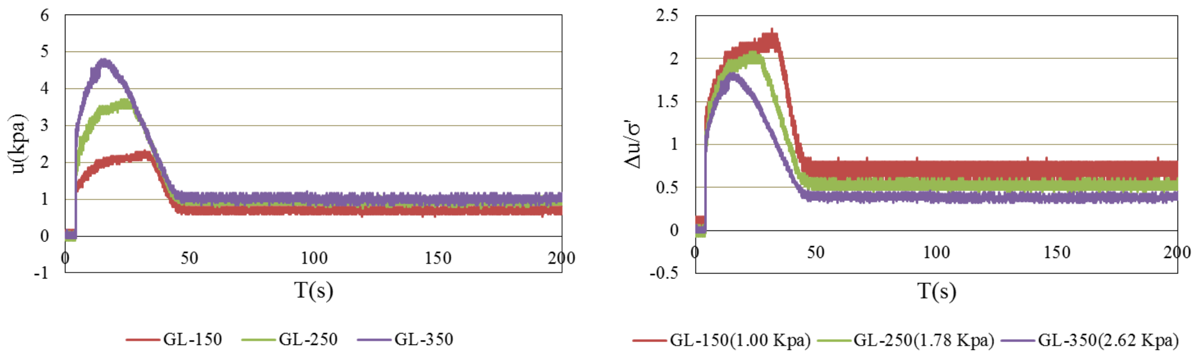


Case 0 Case 1

Figure 7. Maximum excess pore water pressure ratio distribution by depth.

THE PERFORMANCE OF THE PATTERNS WITH SUBSTRUCTURE

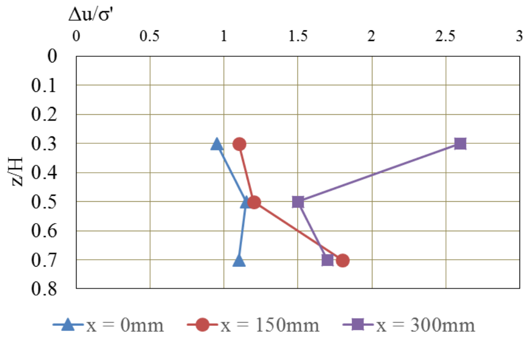
In Case 2, Figure 8 shows that the pore water pressure of each depth versus time, it kept increasing instead of holding a steady level when the shaking stop at 15s, thereafter, the pore pressure dissipated slowly. Furthermore, note that the pore pressure *u* dose not returned back to zero but kept at a constant value. It is considered that pore pressure transducers were not fixed result in declining during the ground liquefaction, as a result, hydrostatic pressure went on increasing, so the pore pressure *u* still kept increasing with these transducers dropping down. The result of Case 3 and Case 4 is similar to that of Case 2.



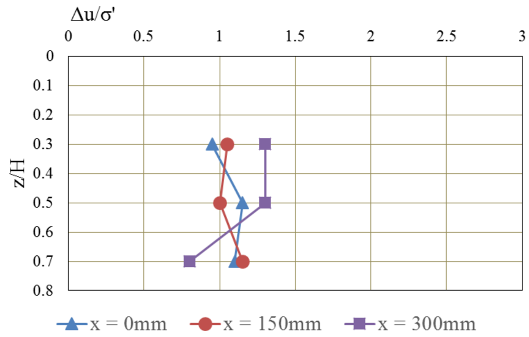
(a) Excess Pore Pressure (b) Excess pore pressure Ratio

Figure 8. The pore water pressure versus time in Case 2.

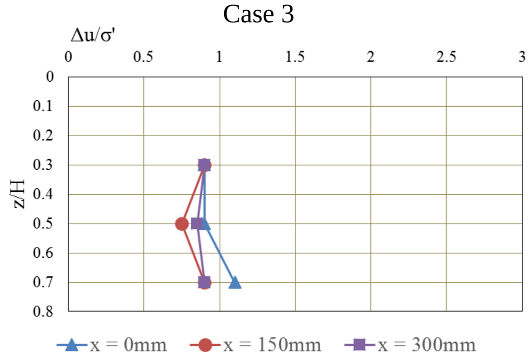
To solve this problem in Figure 9, a new equation form is adopted as $u' = u - \Delta u$, here u is the original maximum pore pressure, Δu is the residual pore pressure, u' the modified maximum pore pressure. The results are rearranged as shown in Figure 10. Considering the Case 2, Case 3 and Case 4, most maximum pore water pressure ratio reached 1.0, which indicates that the ground was completely liquefied after inputting the seismic load. The comparison of the three cases reveals that the preventing effect become more and more effective in turn of Case 2, Case 3 and Case 4. This provides the evidence that Three-Union form have a better performance than Separate structure form.



Case 2



Case 3



Case 4

Figure 10. Maximum Excess Pore Pressure Ratio Distribution.

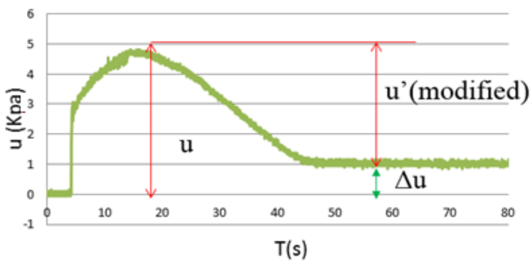


Figure 9. Modification Method.

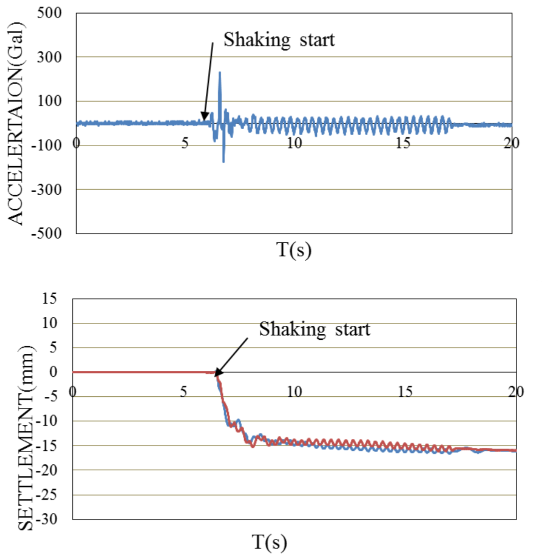


Figure 11. Case 1 Acceleration and Settlement varies with time.

WEIGHT EFFECT

Focusing on acceleration on top of house together with the settlement, Case 1, Case 3, and Case 4 will be discussed in this section. The weight of the house model in Case 4 was changed from 3.6 Kg to 7.2 Kg for clarify the weight effects.

As shown in Figure 11, the settlement increased sharply as shaking started and attained to 15 mm, and then the settlement increased gradually with time. Final settlement was stabilized at 20.9 mm, meanwhile uneven settlement of house was less than 1.5 mm in Case 1 (Three-Union house without basement). On the contrary, if the substructure exists, the height was 50 mm, such as Case 3 (Three-Union house with basement), the buoyant force can be calculated to around 3.6 equal to the weight of house. As a result, the house was uplifted about 10 mm in maximum and stabilized at 2.85

mm higher than original position, it was around 3.05 mm of uneven settlement as shown in Figure 12. For limiting the uplift problem, Case 4 was set by adding weight to 7.2 Kg which was 2 times greater than the former Cases. As is expected, the position of house mostly remained during the test, and settled about 4.67 mm finally, whereas the non-uniform settlement was up to 9.5 mm as shown in Figure 13. Larger leaning happened compared with Case 1 and Case 3.

The comparison among the accelerations is depicted in Figure 14. Case 1 shows a lowest response that only half of the input wave. Both Case 3 and Case 4 exceed 400 Gal result of that the substructure was embed into ground foundation. Substructure weight and height will be discussed in future to decrease the settlement and acceleration response.

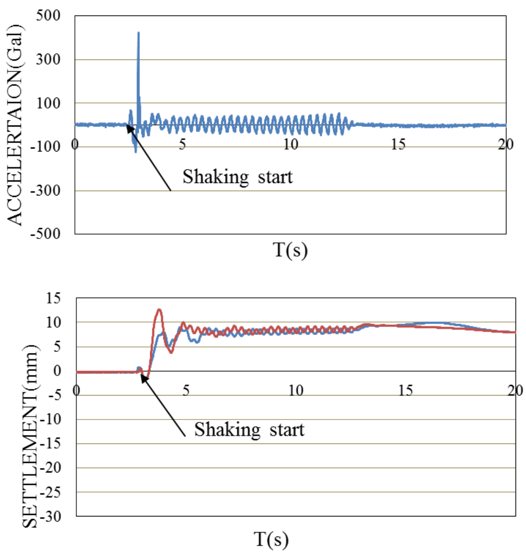


Figure 12. Acceleration and settlement versus time in Case 3

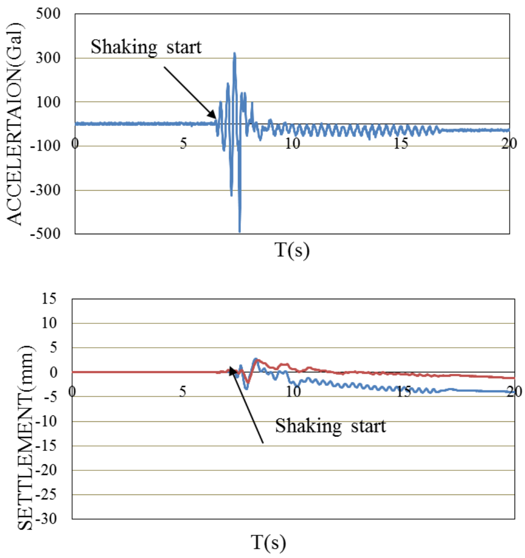


Figure 13. Acceleration and settlement versus time in Case 4.

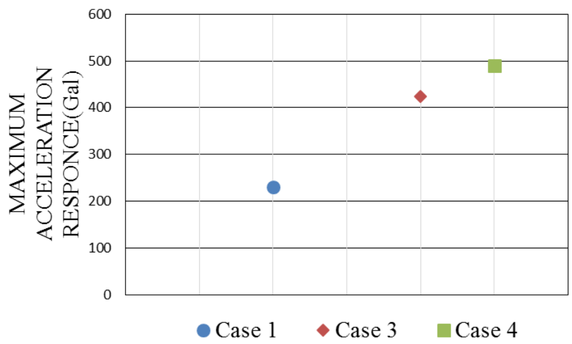


Figure 14. Maximum acceleration response.

CONCLUSIONS

Five different structural performances have been investigated by shaking table test in gravity field. Several primary results are summarized as follow:

1. Comparing with separate house, three-union form shows higher stability and lower settlement on liquefied ground condition during earthquakes.
2. Settlement is reduced greatly with the help of substructure. However, the uneven settlement occurred in this case produced by the buoyancy uplifting the house during liquefaction. So that water level and model weight become significant factors to balance the vertical force, which will be considered in the future study.
3. Liquefaction occurred on all patterns in this test condition. It could not indicate a clear function of basement to restrict the pore water pressure increasing on sandy ground. In order

to detect the advantage of Three-Union house with basement, the lower seismic load condition will be carried out in further study.

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