Experimental Study on Liquefaction Countermeasure Technique by Log Piling for Residential Houses

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SUMMARY:
During the 2011 Great East Japan Earthquake in Japan, extreme liquefaction caused extensive damage to residential houses in the Kanto Plain region with the magnitudes of the settlements and tilts larger than that was observed during past earthquakes. This paper deals with a proposal of technique of ground improvement by installing logs into loose sand layer as a countermeasure against soil liquefaction for the residential houses. Small scale shaking table tests in a 1-g gravity field were carried out using some model grounds. It was clarified that the wooden pile could increase the resistance of ground against liquefaction due to the increase of ground density by piling and the dissipation of excess pore water pressure along the surface of piles. As a result, the magnitude of settlements of the house which was set on the improved ground by piling logs became quite small.

Keywords: Liquefaction, countermeasure, shaking table test, log, residential house

1. INTRODUCTION

Global warming is one of the most serious problems in this century. Because a tree can store carbon within itself, the utilization of wood in the engineering field for the carbon stock may contribute to the mitigation of global warming. As a way of extending and increasing the usage of wood, the authors consider that wood should be used in the construction project, because a huge amount of materials are used and soft ground scattered in many different locations. However, modern civil engineering constructions seem to be using lesser amount of wood compared to those in the previous times. Therefore the authors consider that one of the most effective ways to utilize wood is installing the wood into the soft ground as a material for ground reinforcement. Generally, one of the major reasons that affect the reliability of wood is decay and insect damage. However, it is reported that decay and insect damage of wood do not occur below the ground water level (Numata et al., 2008). Since the water level in the soft ground is very high, logs can act as a pile or material for ground improvement without having to concern for decay or insect damage of wood.

The Great East Japan Earthquake of March 11, 2011, caused severe damages and loss of life. Damages observed in the Kanto Plain region, which includes the Tokyo Bay and Tone River areas were dominated by the effects of liquefaction-induced ground failures. Liquefaction-induced damages were observed around the northern shorelines of Tokyo Bay and at communities along the Tone River. Liquefaction caused extensive damage to light residential structures in many of these areas with the magnitudes of the settlements and tilts larger than that was observed during past earthquakes as shown in Photograph 1.1. The authors proposed a technique of ground reinforcement by piling logs into loose saturated sand layer as a countermeasure against liquefaction. This technique has advantage to apply for the residential house which has narrow space around structure because this technique does not need large construction equipment.

In this paper, a series of small scale shaking table tests was conducted in a 1-g gravity field in order to evaluate the performance of this technique in liquefiable sand layers during an earthquake. From the test results, it was confirmed that the ground improvement by piling logs could be treated as one of the countermeasures to restrain the magnitude of settlements and tilts for the residential houses.

Photograph 1.1. Differential settlement of residential house in Chiba city

2. EFFECTIVENESS OF INSTALLING LOGS INTO LIQUESIABLE GROUND

To evaluate effectiveness of installing logs into liquefiable sand layers during earthquakes, shaking table tests were conducted using the model ground (Yoshida et al., 2010). Figure 2.1 illustrates cross sections of top and side view of a model ground with locations of transducers. The model ground was set up in a rigid acrylic container that measured 800 mm long, 400 mm wide and 540 mm high. The tests were conducted by using a composite ground which consists of two parts. One was improved ground that model of logs made of Japanese cedar got by thinning in Fukui prefecture were installed in loose sand layer which was shown in left side of Figure 2.1, the other was unimproved ground without log pilling. The loose liquefiable sand layer was made of silica sand No.7 and the relative density was about 35%. The physical properties of sand are listed in Table 2.1. The model of log measured 12 mm diameter and 220 mm long.   The log was saturated with water and its density was 1.1 g/cm^3.

The shaking table tests were conducted as follows: 1) Pore water pressure transducers were installed at the locations as shown in Figure 2.1. 2) The container was first filled with water to 300 mm high from the bottom. Then a sieve with a 2 mm mesh was moved back and forth below water surface, pouring wet sand through water to form a uniform sand layer with 300 mm in thickness. 3) Excess water above the sand layer was soaked up so that the water surface was level with the surface of the sand layer. 4) Accelerometers were installed at the locations as shown in Figure 2.1. 5) Thirty six logs were installed into the loose sand layer slowly with an interval 30mm, except the top of log with a length 20mm. 6) No. 5 gravels were laid over the loose sand layer with a thickness 20mm. 7) The model ground was shaken in the horizontal direction with the sinusoidal wave of 100 gal in peak amplitude, 5 Hz in frequency and 4 seconds in duration time as shown in Figure 2.2. The pore water pressures and the response accelerations were recorded simultaneously on the data recorder. 8) After the excess pore water pressure had completely dissipated, the vertical displacements of logs and ground surface were measured by a point gauge. 9) The processes of 7) to 8) repeated five times with different amplitude which was from 100 gal to 180 gal at intervals of 20 gal.

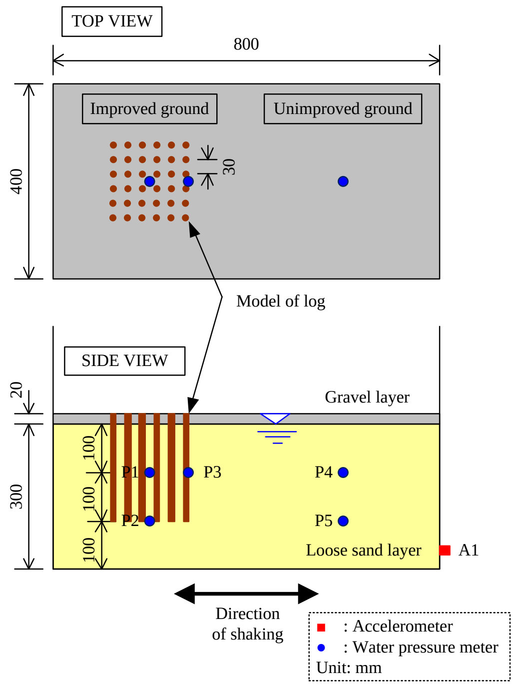

Figure 2.1. General view of model ground and transducers

Table 2.1. Physical properties of sand

Density (g/cm^3)	Average diameter (mm)	Coefficient of permeability (cm)
2.63	0.17	4.79x10^{-3}

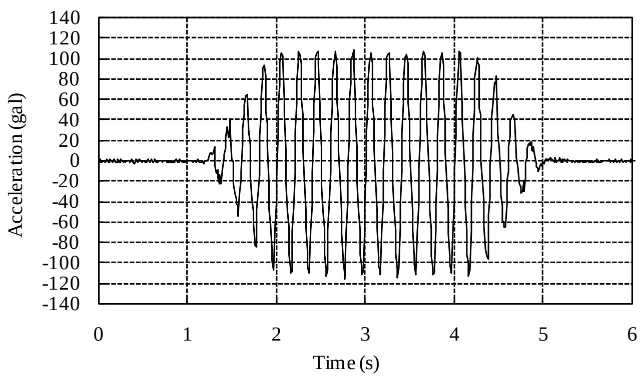

Figure 2.2. Time history of input acceleration

Figure 2.3 shows time histories of excess pore water pressure ratios located at 100 mm in depth from ground surface after undergoing shaking of 120 gal. In case of unimproved ground, the excess pore water pressure ratio reached 1.0 and the ground completely liquefied. However, in case of improved ground, the maximum value of excess pore water pressure ratio decreased and the velocity of dissipation was extremely fast.

It is clarified that the resistance against soil liquefaction increased by installing the logs into the loose sand layer. It is considered that the resistance was caused by the following four effects; 1) replacing the loose sand with logs, 2) densifying the loose sand by installing the log, 3) restraining the shear deformation by fixing the top of logs into gravel layer 4) dissipating the water pressure along the periphery of logs (Yoshida et al., 2010).

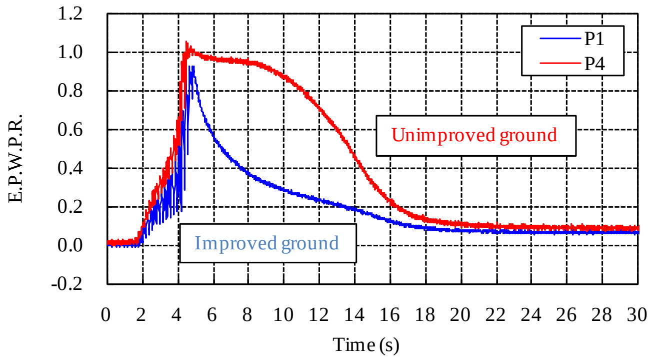

Figure 2.3. Time histories of excess pore water pressure ratio

3. EFFECTIVENESS AGAINST LOMG DURATION OF SHAKING

To investigate relation between duration time of shaking and settlement of house, shaking table tests were conducted using the model ground. Figure 3.1 illustrates cross sections of top and side view of a model ground with locations of transducers. The container, materials and way to make model ground were similar as shown in chapter 2. The tests were conducted by using a composite ground which consists of two parts. One was improved ground where thirty six logs were installed which was shown in left side of Figure 3.1, the other was unimproved ground. The density of loose liquefiable sand layer was controlled from 40 % to 60% by preliminary shaking using 300 sinusoidal waves with a frequency of 5 Hz, whose amplitude was 100gal. A model of log measured 12 mm diameter and 200 mm long. A model of house was made by water-resistant wood that measured 150 mm square and 112 mm high. The ground contact pressure of house was 1.5kN/m^2 which was scaled down one tenth of two-story wooden house with a mat foundation. Input wave used in the tests was sinusoidal wave with a frequency of 5 Hz and a peak magnitude of 120 gal. The duration time of shaking was 10, 30 and 60 second.

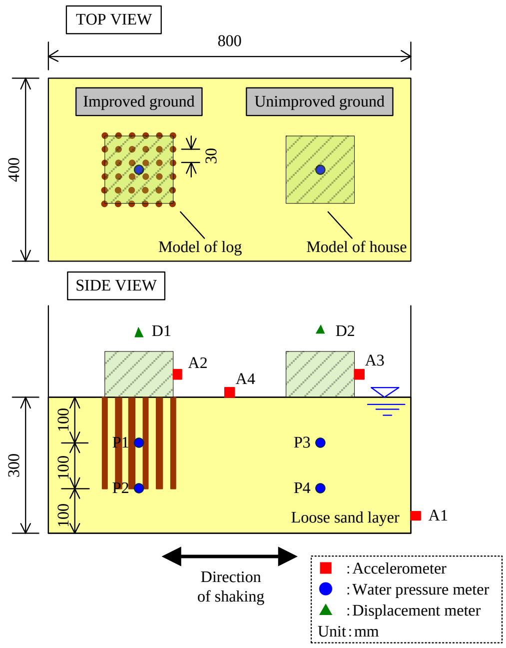

Figure 3.1. General view of model ground and transducers

Figure 3.2 shows residual settlement of house in relation to the duration time of shaking. It is obvious that the settlement of house increased with increase of shaking time in case of unimproved ground, but the settlement was reduced about one twentieth in case of the improved ground though the duration time was 60 second. In the previous study (Yoshida et al., 2010), it is clear that bearing capacity of ground where logs were installed could be improved due to densifying the loose sand around logs, dissipating the water pressure along the periphery of logs and restraining the shear deformation by composite ground with soil and wood in addition to skin friction of log. According to the results as mentioned above, it is considered that these effects would be expected even if the duration time of shaking might increase.

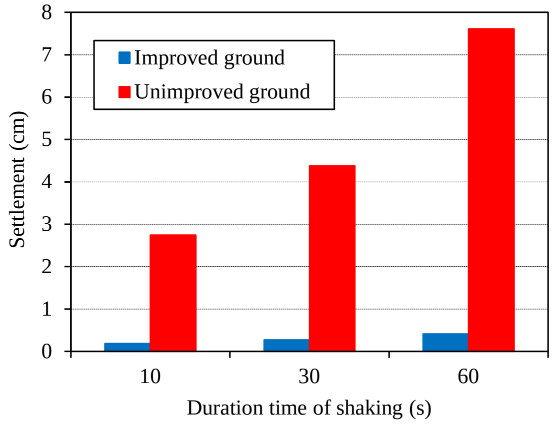

Figure 3.2. Relationship between duration time of shaking and settlement of house

4. HOW TO APPLY LOG PILLING FOR EXISTING HOUSE

To propose how to apply the technique of log pilling for existing house, shaking table tests were conducted using the model ground. Figure 4.1 illustrates cross sections of top and side view of a model ground with locations of transducers. The container, materials, model of house and way to make model ground were similar as shown in chapter 3. A model of log measured 12 mm diameter and 300 mm long. Four types of way to install logs were adopted in this study. Case 1 was the ground without installing logs. In Case 2, the logs were installed around foundation of house. The top and bottom of log did not be fixed. In Case 3, the top of logs were fixed. In Case 4, the logs were installed into the ground with an inclination of 15 degree. The relative density of loose sand layer was about 40%. Input wave used in the tests was sinusoidal wave with a frequency of 5 Hz and a peak magnitude of 120 gal. The duration time of shaking was 20 second.

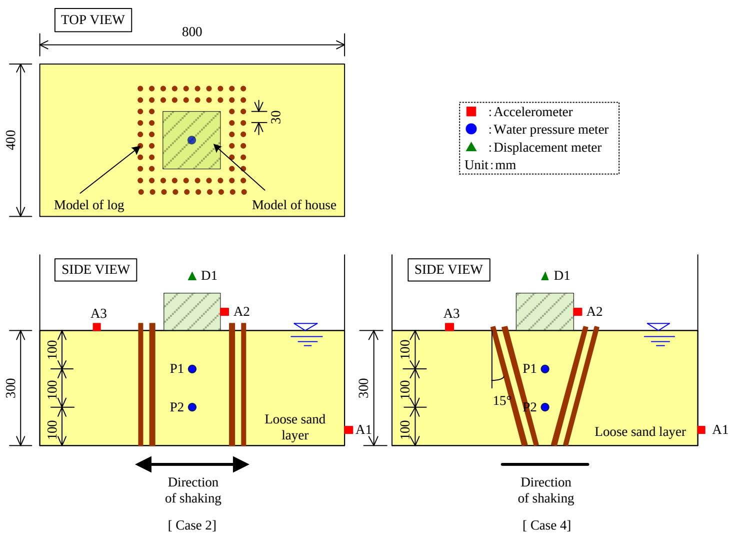

Figure 4.1. General view of model ground and transducers

Figure 4.2 shows the time histories of settlement of house. It is clear that the log pilling around the foundation of house (Case 2, 3, 4) was effective to reduce the settlement of house as compared with unimproved ground (Case 1). Though most settlement in all cases occurred during shaking, the settlement stopped with the end of shaking in case of improved ground. The most effective way was Case 4 and the settlement was reduced about one third of unimproved ground. If the ground liquefies below the base of house, the house settles and the liquefied soil moves laterally. Therefore the logs around the foundation of house can prevent the lateral movement of soil. This function was more effective by fixing the top of logs in Case 3. Furthermore it is confirmed that the most effective way to install logs was Case 4 because the deformed area could be smaller by installing logs with the inclination.

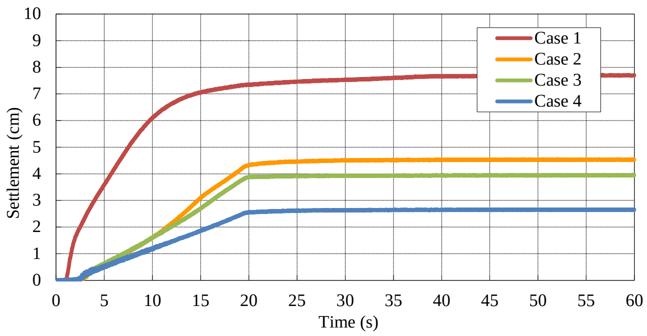

Figure 4.2. Time histories of settlement of house

5. CONCLUSIONS

The three kinds of shaking table test in a 1-g gravity field were conducted in order to propose the liquefaction countermeasure technique by log piling for residential houses. The following conclusions may be made on the basis of the experimental study:

(1) The logs installed in the liquefiable soil layer could increase the resistance of ground against liquefaction. This effect was caused by the following four effects; 1) replacing the loose sand with logs, 2) densifying the loose sand by installing the log, 3) restraining the shear deformation by fixing the top of logs into gravel layer 4) dissipating the water pressure along the periphery of logs.

(2) The bearing capacity of ground where logs were installed would be expected due to the skin friction of logs and above effects even if the duration time of shaking might increase.

(3) The log pilling around the foundation of house was effective to reduce the settlement of house. The most effective way was to install logs with the inclination because the deformed area below the house could be smaller.

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