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STUDY ON LIQUEFACTION COUNTERMEASURE TECHNIQUE FOR EXISTING RESIDENTIAL HOUSES

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Abstract

During the 2011 Great East Japan Earthquake in Japan, extreme liquefaction caused extensive damage to residential houses in the Kanto Plain region and resulted settlements and tilts larger than that was observed during the past earthquakes. This paper deals with a proposal of ground improvement technique by installing logs into loose sand layer as a soil liquefaction countermeasure for existing residential houses. First, a demand for countermeasure of residential houses and reasonable cost of construction were shown by questionnaire surveys. Next, small-scale shaking table tests were carried out to propose how to apply the technique of log pilling around existing residential house. As a result, the magnitude of settlements of the house which was improved by log piling with an inclination and the fixed top of logs became quite small.

Keywords: earthquake, liquefaction, countermeasure, log, shaking table test, residential house

1. Introduction

During the 2011 Great East Japan Earthquake, enormous liquefaction damage occurred in Tokyo Bay coastal areas and the Tone River basin. Damage of settlements and tilts of the residential house amounted to 27,000 buildings. In response to this, the Ministry of Land, Infrastructure and Transport has published a "technical guidelines relating to the liquefaction damage possible judgment of residential land draft" in March 2013. Currently, many companies and research institutions, are working on the development of liquefaction countermeasure technique for residential houses ex [1], [2], [3].

In this paper, the authors propose the use of the log to countermeasure for liquefaction. The following findings have already obtained.

1. By installing the log directly under the foundation of the structure, it is possible to reduce the subsidence due to liquefaction [4].

2. For existing structures, subsidence mitigation effect can be obtained by piling the log into the ground around the structure [5].

If the wood can be used as a log construction material, the material degradation must be considered. It is generally known that the water level in the liquefiable soil usually very high. However, we do not need to concern too much about the material deterioration in the liquefiable ground, because material deterioration, for example, decay, does not occur below the ground water level. In addition, the use of the wood contributes as well to global warming mitigation and forest business activation. Ground reinforcement using the log was subjected to “Wood Utilization Point Business” of the Forestry Agency in Japan that started from April 2013. Therefore, the technology improvement and cost reduction need to be established immediately.

In this study, a questionnaire survey of the general public was conducted firstly. The survey asked a demand and construction cost of the liquefaction measures. Next, a shaking table test of piling logs was conducted to compare a lattice-like improved method [6] which is proposed as one of the liquefaction countermeasure methods for existing structures. We examined the effectiveness of a method of piling logs to ground around a structure. In addition, we proposed a method for fixing the head of the inclined logs of installing and examined its effectiveness through shaking table tests.

2. Questionnaire survey

2.1 Summary of questionnaire

To investigate the awareness of earthquake disaster prevention and liquefaction measures of people who live in detached houses. This questionnaire is aimed to clarify a demand and construction costs of future liquefaction countermeasures. 973 guardians of students of National Institute of Technology, Fukui College in Fukui Prefecture were the respondents. The number of collected questionnaires was 467, so the collection rate was 48%.

2.1 Results of questionnaire

The awareness about liquefaction is shown in Fig. 1. Most of the respondents know liquefaction occurrence conditions, such as “Occur in the soft sand ground”, “Muddy water spout to the surface of the ground”, “Subsidence of the structure”. In contrary, about 80% of respondents do not know that liquefaction occurs in a deeper ground than the groundwater level. These results show that the phenomenon of liquefaction was known by almost everyone but they do not know that the important factor to cause liquefaction is underground water. In addition, it should be noted that in the question of a different item, for the question of "Have you ever heard the term of liquefaction phenomenon that occurs during an earthquake", everyone had answered yes.

Furthermore, percentage of recognition of the damage caused by the liquefaction was also high as shown in Fig. 1. These results seem to base on the fact that the media has widely reported the liquefaction damage caused in the 2011 Great East Japan Earthquake. In addition, liquefaction also occurred in the 1948 Fukui earthquake. Contrary, percentage of people who know that liquefaction has occurred in Fukui is only 10%. Currently, more than 60 years has passed from the Fukui earthquake. 90% of the respondents did not know about it because they were not born yet at that time. Although the people knew about the Fukui earthquake, percentage of awareness of the damage by the Fukui earthquake may be very low. On the other hand, about 80% of the respondents increased interest in anti-earthquake measures after the 2011 Great East Japan Earthquake.

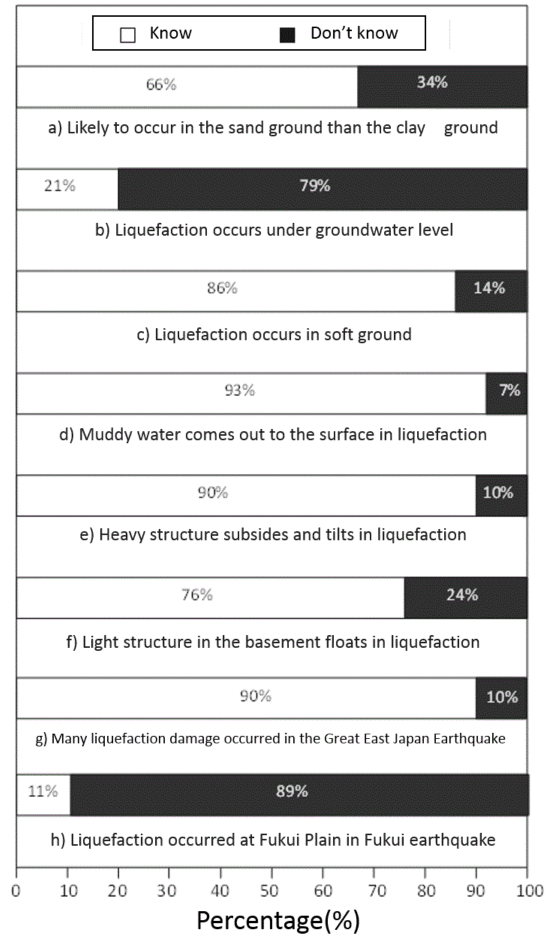

Fig. 1 – Awareness about liquefaction

The findings on liquefaction measures are shown in Fig.2. Currently, about half of the respondents did not make a ground improvement. About 20% of the respondents had done the ground improvement and about 40% of them chose a shallow layer mixing method. The adoption rate of the small-diameter pile construction method that uses the wood pile was low. The positive opinion was about 60% about the need to carry out the liquefaction measures for house in preparation for the future earthquake. The majority of the respondents answered that cost is the main reason for countermeasure. For the question of "How much do you spend money to liquefaction measures", 80% of the respondents answered that less than 2 million Japanese yen. Therefore, it is necessary to be within 2 million yen of the construction cost.

A cross-tabulation was carried in the construction cost, the age and the floor area of house. The average amount of the construction cost was turned into 850,000 yen regardless of the floor area. Next, the relation of the average amount of the construction cost and the age of house is shown in Fig. 3. In the new houses and the houses aged 61 years or more, there is a tendency not to pay the money to the measures. The use of the log could be a good option to countermeasure of liquefaction for economic reasons. As a result, about 70% of the respondents adopt the countermeasure using the log. On the other hand, the reason of no use of the log is anxiety of strength of wood.

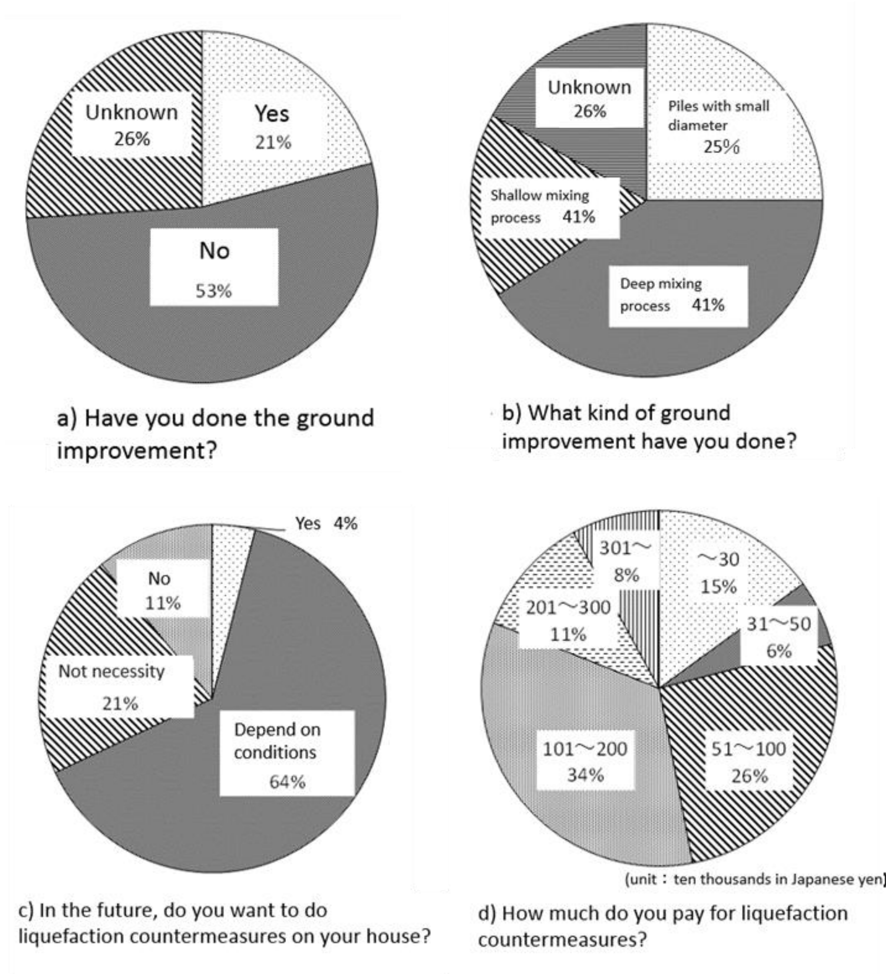

Fig. 2 – Questionnaire on liquefaction measures

Fig. 3 – The average amount of the construction cost for each Age of the building

The awareness of the characteristics of wood is shown in Fig. 4. For the question of "wood does not rot under groundwater level," 70% of the respondents did not know about it. The biggest concern in the wood utilization was rotting. Therefore, it is necessary to spread the fact that deterioration due to rot can be prevented by use in water. Awareness on the use of wood in the construction business is low. Therefore, it is necessary to carry out active enlightenment related to use of wood in construction projects. For the question of "wood is stronger than the iron and the concrete if the weight is same," 80% of the respondents did not know. It is necessary to know the fact that there is sufficient strength to the wood because the problem of the strength had become the biggest reason not to adopt the log.

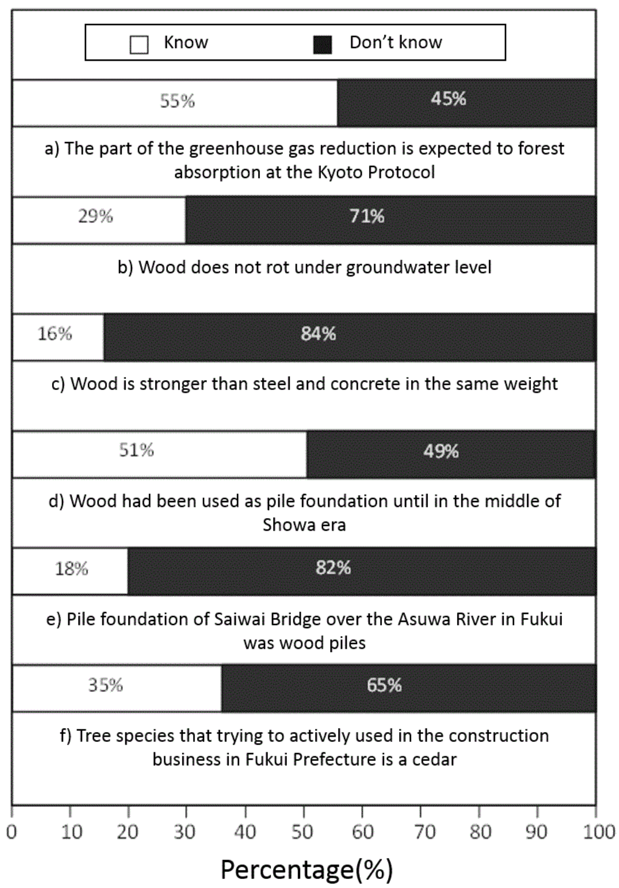

Fig. 4 – Awareness about the nature of a timber

2.3 Discussion

From the above results, it was found that there has been a growing interest in anti-earthquake measures since the 2011 Great East Japan Earthquake. Furthermore, an interest in liquefaction countermeasure against liquefaction became high after the earthquake. However, liquefaction measures cannot be decided to be implemented because it is high construction cost. From these points of views, there is a need to continue the technical development of the liquefaction countermeasures method using the log.

3. Shaking table tests of log piling method in comparison with lattice wall improvement method

3.1 Outline of tests

We performed shaking table tests to examine the effectiveness of the technique of log piling around existing residential house in comparison with the lattice wall improvement method [6].

Fig. 5 shows an overview of the model ground. Soil tank of acrylic (width 800 mm × depth 400 mm × height 500 mm) was placed on a shaking table. Model ground consists of loose and saturated sand layers of about 40% relative density using silica sand No. 7 (the density 2.63 g / cm^3, average particle diameter 0.17 mm). The sand layer was made by water dropping method. Groundwater level sets at ground surface.

Log model is a cylindrical shape with 12mm diameter and 300mm length. Lattice wall model is 222mm square and 300mm height. These models were made from cedar lumber. 28 pieces of log model are statically penetrated at 30 mm intervals around a structure model after ground fabrication, and not fixed to the bottom of the soil tank. On the other hand, the lattice wall model was fixed to the bottom of the soil tank before ground fabrication. Therefore, there is no effect of disturbing the surrounding ground. These models and logs had been stored in water. The density of the wood was about 1.1 g/cm^3. A model of house is a wooden box treated waterproof and 150mm square bottom, 112mm height, 3.45kg weight, and 1.5kN/m^2 of ground pressure. This value is supposed to be one-tenth of the ground pressure of two-storey wooden house on the mat foundation. Input wave is a sine wave with frequency of 5Hz, the maximum acceleration of 120gal and duration of 20 seconds. We measured input acceleration (A1), response acceleration of the model of house (A2), response acceleration of ground (A3), excess pore water pressure in the ground (P1~P4), and vertical displacement of the model of house. In measuring of excess pore water pressure in the ground, steel plate for the water pressure gauge shown in Fig. 6 mounted at the bottom of the soil tank, and water pressure gauge is fixed at a measuring point.

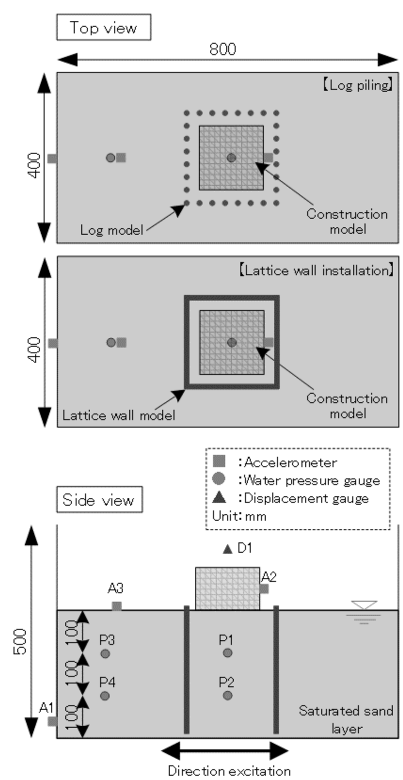

Fig. 5– Overview of test apparatus of log piling and lattice wall

Fig. 6 – Steel mounting plate for the water pressure gauge

3.2 Experimental result and discussion

Fig. 7 shows the time histories of excess pore water pressure ratio of ground in G.L.-100mm in cases of log piling and lattice wall installation. The free ground means no structure and no countermeasure in the model ground. The water pressures measured at P1 point and P3 point shown in Fig. 5 are indicated in Fig.7. Excess pore water pressure ratio of free ground means the ratio of the effective vertical stress due to the weight of the ground and excess pore water pressure. Excess pore water pressure ratio of countermeasure ground means the ratio of the sum of the effective vertical stress due to the weight of the ground and contact pressure of the structure, and excess pore water pressure. The excess pore water pressure ratio of free ground reached to 1.0 in both cases of log piling and lattice wall installation from the time histories, therefore the ground was completely liquefied. On the other hand, the maximum value of the water pressure in the countermeasure ground has decreased. The maximum water pressure in case of log piling was smaller than that of lattice wall installation. In the case of lattice wall installation, it is considered that density of the ground had not changed in making model ground because ground prepared by using water drop method in a state that lattice wall fixed to the soil tank in advance. On the other hand, the density of the surrounding ground increased due to the log piling and therefore shearing rigidity as the composite ground of logs and sand increased [7].

Fig. 8 shows time histories of settlement of the model of house measured by using a laser displacement meter in cases of countermeasure and non-countermeasure grounds. This figure indicates that subsidence of the non-countermeasure ground reached 73mm at about 18 seconds from the start of excitation, finally, subsidence amount reached 78mm with increasing gradually. On the other hand, the final ground subsidence with log piling was 61mm and that with lattice wall installation was 57mm. Therefore, we have confirmed that these ground improvement methods are effective to reduce subsidence. However, these results seem to be influenced by not only mitigating effect of countermeasure but also an increase in the effective confining pressure due to the installation of the model of house.

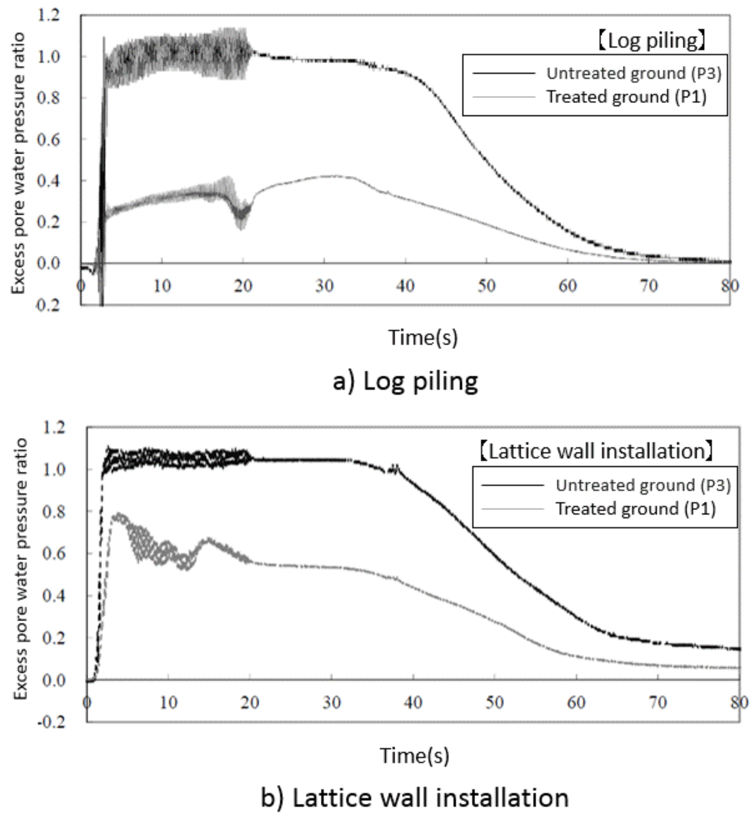

Fig. 7 – Time histories of excess pore water pressure ratio

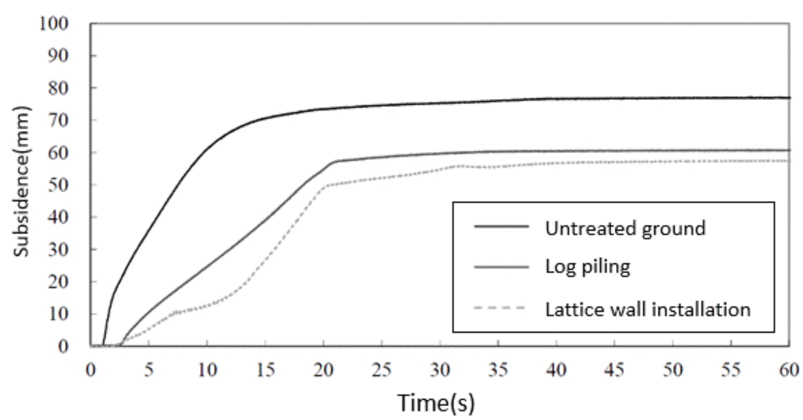

Fig. 8 – Time histories of subsidence of the structure model

Mitigating effect of excess pore water pressure in log piling ground was greater than that in lattice wall installation, but the difference between the amounts of final subsidence of both cases was not large. This result was caused by the reduction of subsidence mitigating effect because logs were not fixed to the bottom of the soil tank and moved to the side along with the subsidence of the model of house. On the other hand, the lattice wall was fixed at the bottom of the soil tank and did not move irrespective of a gap between the lattice walls and the bottom of soil tank.

4. Shaking table tests on the effectiveness of log piling with an inclination and the fixed top of logs

4.1 Outline of tests

The results show the shaking table tests of the vertical logs piled in the ground around the structures as a countermeasure against liquefaction method of the existing structures in Chapter 3. The logs piling with an inclination were tested in this chapter. Furthermore, a method of fixed top of the logs was proposed and compared the effectiveness in the case of fixing the top and no fixing.

An outline of the model ground is shown in Fig. 9. Log model is diameter of 12mm and length of 300 mm. The interval of two rows in the piling is 30 mm. Total number of logs is 64 and only 24 logs of shaded portion in Fig. 9 are tilted 15 degrees. The log was not fixed at the bottom of the soil tank and a space existed between logs and the bottom a little bit. The log heads were fixed by using an acrylic plate with holes shown in Fig. 10 in the method of the top fixation. This plate restrained the horizontal movement of the head of logs. Other experimental conditions are the same as Chapter 3.

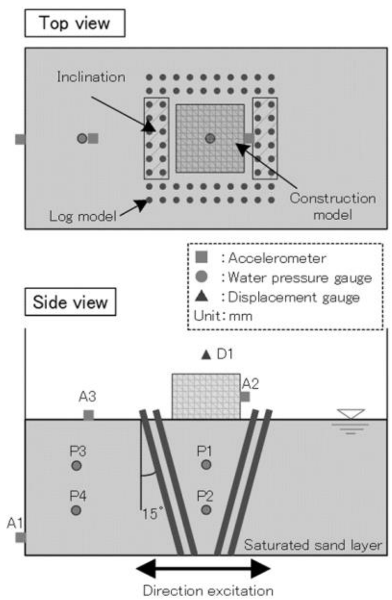

Fig. 9 – Overview of test apparatus of inclined piles

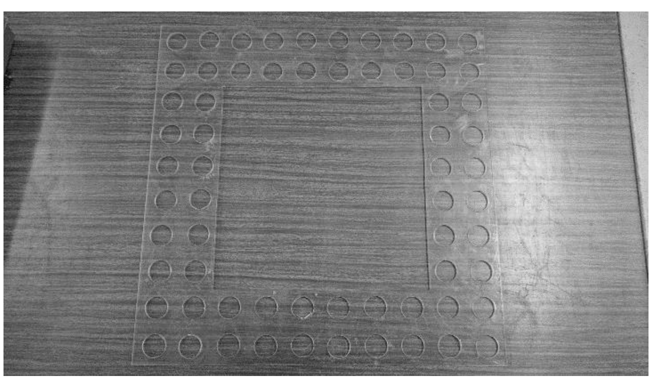

Fig. 10 – Top fixed plate

4.2 Experimental Results and Discussion

The time histories of excess pore water pressure ratios in G.L.-100mm are shown in Fig. 11. This figure shows the results of vertical piling and inclined piling with free top and fixed top. This figure indicates that the rapid rise of excess water pressure was mitigated and the excess water pressure after the end of excitation rapidly decreased in case of fixed top with inclined likewise other countermeasure method. The excess water pressure waveforms in each case with free top and fixed top show almost the same. From the results, it is clarified that fixation of the top of logs did not affect the rise and dissipation of excess pore water pressure. It seemed that strength against liquefaction of the ground just below the structure increased because of compaction effect of the surrounding ground by the log pilling. The maximum excess water pressure ratio decreased in two cases of inclined piling. It is considered as a reason that the area of ground that shear deformation occurs just below the structure decreased because logs piled diagonally.

Fig. 12 shows time histories of settlements of the model of house in each case. Most of the subsidence occurred during vibration and subsidence stopped at the same time that vibration stopped in each case. The final settlement was 45mm at vertical pilling with free top, 40mm at vertical pilling with fixed top, 27mm at inclined piling with free top, 20mm at inclined piling with fixed top, respectively. Subsidence mitigating effect in case of inclined piling with fixed is the largest. In the case of inclined piling, it is assumed that subsidence has been reduced because deformed region of the ground just below the model of house is small. The reduction rate of the final settlement by fixed top is 11% at vertical pilling, 26 % at inclined piling. The ground below the model of house was compressed and deformed to the side along with the logs when the model of house settled during liquefaction. But the subsidence seems to be reduced because lateral movement of the log is constrained in case of top fixed.

As a result, we confirmed that inclined piling could reduce the volume of ground which deformation occurs at just below the structure, and top fixation of logs could reduce the lateral deformation of logs due to lateral movement of the ground. The reinforcement of the pile head seems to be necessary because the fixed part of pile head might be damaged in case of a larger earthquake motion.

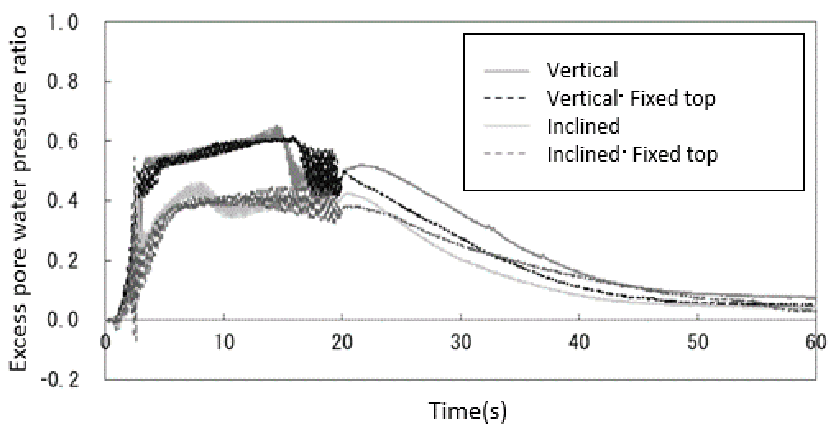

Fig. 11 – Time histories of excess pore water pressure ratio

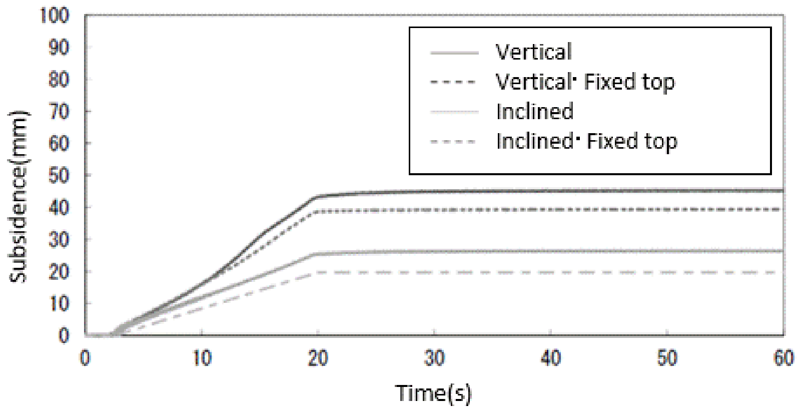

Fig. 12 – Time histories of subsidence of the structure model

5. Conclusions

A questionnaire survey was firstly conducted in order to examine the demand and construction costs of liquefaction measures. Afterwards, as a countermeasure against liquefaction of the existing structures, we propose a method of pouring the log into the ground around the structure. In addition, it is proposed as well a method of inclined piling of log to the ground, it was examined its effectiveness by shaking table tests. Following conclusions can be noted :

(1) An interest in countermeasure against liquefaction became high after the earthquake. However, liquefaction measures can't be decided to be implemented because it is high construction cost. For the question of "How much do you spend money to liquefaction measures", 80% of the respondents answered that less than 2 million Japanese yen. Therefore, it is necessary to be within 2 million yen of the construction cost.

(2) The final ground subsidence with log piling was 61mm and that with lattice wall installation was 57mm according to the results of the shaking table tests. That of the non-countermeasure ground reached 78mm. Therefore, we have confirmed that these ground improvement methods are effective to reduce subsidence.

(3) Inclined piling could reduce the volume of ground which deformation occurs just under the structure, and top fixation of logs could reduce the lateral deformation of logs due to lateral movement of the ground. Both methods seem to be effective for liquefaction countermeasure.

Acknowledgements

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