27 May 2010, 4:30 pm - 6:20 pm

Liquefaction Countermeasure Technique by Using Logs for Carbon Storage Against Global Warming

Masaho Yoshida
Fukui National College of Technology, Japan

Masakatsu Miyajima
Kanazawa University, Japan

Atsunori Numata
Tobishima Corporation, Japan

Fifth International Conference on
Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics
and Symposium in Honor of Professor I.M. Idriss
May 24-29, 2010 • San Diego, California

LIQUEFACTION COUNTERMEASURE TECHNIQUE BY USING LOGS FOR CARBON STORAGE AGAINST GLOBAL WARMING

Masaho Yoshida
Fukui National College of Technology
Geshi, Sabae, Fukui, 916-8507, JAPAN

Masakatsu Miyajima
Kanazawa University
Kakuma, Kanazawa, Ishikawa,
920-1192, JAPAN

Atsunori Numata
Tobishima Corporation
5472 Kimagase, Noda,
Chiba, 270-0222, JAPAN

ABSTRACT

Global warming is one of the most serious problems which faced by civil engineers in this century. Because a wood can store carbon within itself, the utilization of wood in the construction projects may contribute to the mitigation of global warming. The technique of ground improvement by installing logs into loose sand layer as a countermeasure against soil liquefaction was proposed in this study. The logs had been used as pile foundation until 1950's in Japan. However, as the wood has high possibility of a decrease in strength by decay, the utilization of wood become minority in the construction projects. First, since a lot of former wooden piles were found at the riverbed of the Asuwa River in Japan in 2005, the soundness of wood was evaluated. From the test results, it was confirmed that the level of decay was extremely low and the compression strength exceeded the allowable stress of wood pile, though they were buried under the riverbed for 59 years. Second, small scale shaking table tests in a 1-g gravity field were carried out using a composite ground which was made of loose saturated sand layer and the improved ground by piling with logs. It was clarified that the logs installed in liquefiable soil layer could increase the resistance of ground against liquefaction and decrease the settlement of structure.

INTRODUCTION

The Intergovernmental Panel on Climate Change (IPCC)'s Fourth Assessment Report states that warming of the climate system is undoubted. Most of the data indicating increase in the global temperature as observed after the mid-20th century are most likely attributed to the increase in anthropogenic greenhouse gases concentrations. Many of the associated impacts can be reduced, delayed or avoided by effective mitigation. Efforts in mitigation and investment over the next two to three decades will impose a large influence on the extent of achieving lower stabilization. In this report, it can be understood that the global warming is currently in a very critical situation and all fields of specialization, including the civil engineering field, must seriously consider its countermeasure.

In terms of global warming mitigation, the use of wood are expected to yield the following three positive effects: 1) storage of carbon in wood products, 2) substituting wood products for more energy intensive materials, 3) reducing fossil fuel use by substituting with woody biomass. In addition, extensive use of wood will result in making the forest active and enhancing the preservation of biodiversity, prevention of debris disasters, and water conservation etc.

A tree absorbs CO_2 from the atmosphere, releases oxygen and generates carbon within the wood tissue by photosynthesis. Hence the quantity of tree is proportional to the amount of CO_2 reduction in the atmosphere. Because a tree is mainly constituted of carbon that was absorbed from the atmosphere, even if the tree is burnt, carbon is just simply released back to the atmosphere as CO_2. The total amount of carbon does not change during this process. The whole phenomenon can be known as carbon neutral. Since wood is a carbon neutral material, if wood is used as a substitute for a more energy intensive material such as aluminum, steel and concrete, or as an energy source substituting fossil fuel, contributions towards mitigation of the global warming can be realized. Furthermore, it is also considered that increasing the amount of living trees helps reducing the concentration of CO_2 in the atmosphere because CO_2 is sequestered in trees.

Although jungles and primeval forests are considered to be absorbing a lot of CO_2 from the atmosphere, it is not essentially true in reality. In an aged, unharvested forest, CO_2

absorption and emission reach equilibrium, and the forest no longer reduces CO_2 in the atmosphere. Aged unharvested forests including jungles and primeval forests, therefore, are not contributing towards reducing CO_2 concentration in the atmosphere. To effectively reduce CO_2 in the atmosphere, it is necessary to increase the amount of trees. Also, extending the service lifespan and increasing the usage of wood products are effective ways to achieve the objective, which are equivalent to the contribution by new afforestation. As a way of extending and increasing the usage of wood, the authors consider that wood should be used in the civil engineering field, with which a huge amount of materials are used and construction sites 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. Realizing the fact, the authors consider that one of the most effective ways to utilize wood is employing wood into the ground as a material for ground improvement.

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. In addition, if a log is adopted as a pile for ground improvement, cost and energy reduction can be achieved because of minimum required processing, and unnecessary concerns for flaming and deformation due to drying. Also, in the case of log being is used only as a material for ground improvement but not as a bearing pile, concerns for strength, shape and variation of quality can also be eliminated.

To utilize the wood as a countermeasure against the global warming, a method for ground improvement by piling logs into the liquefiable ground is supposed in this study. First, three kinds of tests were carried out to evaluate the soundness of wood pile which was used as the bearing pile of old bridge. Second, a series of shaking table tests was conducted in a 1-g gravity field in order to evaluate the effectiveness of the logs installed in liquefiable sand layers during earthquakes.

RETRIEVING WOOD PILES FROM GROUND

Photo 1 shows Kida Bridge across the Asuwa River that flows in Fukui city, Japan. The bridge was completed in December, 2008. It can be seen that there are a lot of head of piles made of wood in the riverbed near piers. These wood piles were used as foundations of the former Kida Bride which was completed in 1949. It is assumed that they were placed underneath the riverbed through 59 years (Yoshida et al., 2009).

Photo 1. Former wood pile foundations near Kida Bridge

Photo 2 shows the wood pile which was retrieved from Kida Bridge. The length of the pile was about 3.5m and the diameter was about 30cm. It is clarified that the species of wood pile was cryptomeria, that is, Japanese cedar as a result of identification by using an optical microscope. According to the visual observation of wood pile, it is assumed that the top of the pile was stuck up out about 1m from the riverbed, because the area between about 1m from the top had a mark that water scraped the surface of the wood pile. The wood pile was in the gravelly sand and clay layer and the bottom of the pile was assumed to reach sandy silt layer or sand layer by referring to a borehole data near this site.

Photo 2. Wood pile retrieved from Kida Bridge

INVESTIGATION FOR SOUNDNESS OF WOOD PILES

Visual Observation Test

Fig. 1 shows a result of visual judging method of decay level according to JIS K 1571:2004 (Yoshida et al., 2007). Three evaluators of A, B and C observed and judged the decay level referring to the standard shown in this Figure. The positions of riverbed and water level presumed by site investigation are also shown in this Figure. Because the decay level was 1 or less under the riverbed, it is confirmed that wood pile can keep soundness in the soil under the water level.

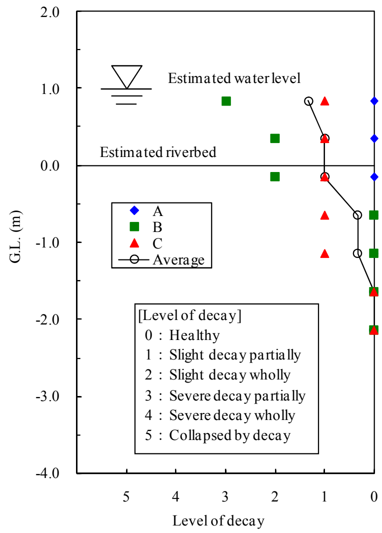

Fig. 1. Results of visual observation test

Pylodin Penetration Test

Fig. 2 shows a result of the penetration test by using a Pylodin which can examine the level of decay (Yoshida et al., 2007). The Pylodin was a device to compare depths of penetration by a pin stricken with a certain force. If the level of decay is high, the surface of wood become soft and the depth of penetration become large. The standards of decay is considered that the depth of penetration is 30mm or over. The shape of test piece was a discoid by cutting out the wood pile and the thickness of the piece was 10cm. The penetration tests were conducted on two sides of wood piles. One was the side of cut end and the other was the orthogonal side of cut end. Although the values vary widely at the same ground level as shown in Fig. 2, it is clarified that the wood piles keep health because the most of average values were less than 30mm.

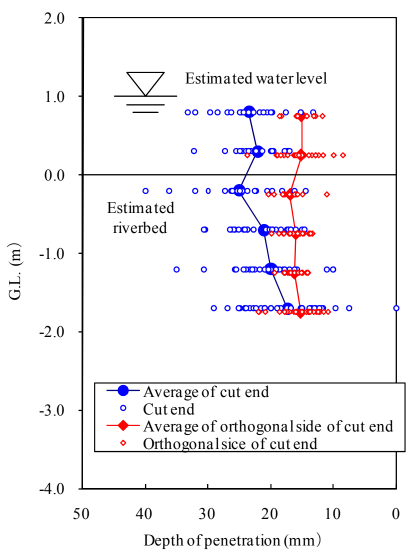

Fig. 2. Results of pylodin penetration test

Compression Test

Fig. 3 shows a result of compression test according to JIS Z 2101:1994 (Yoshida et al., 2008). The size of test piece was 30mm square and 60mm in height, and they were made by cutting out the discoid which was used for the Pylodin penetration test. The standard compression strength of Japanese cedar and allowable stress used for design of wood pile foundation are also shown in this figure. It is considered that the test pieces have three to five times strength of the allowable strength.

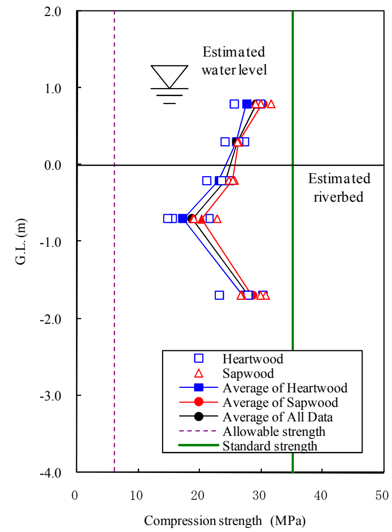

Fig. 3. Results of compression test

Therefore, it is clear that the wood piles made of Japanese cedar that had been buried in soil under the water level through 59 years did not decay and still had enough strength as the pile foundation. In the past, the pine has been often used as a material of the wood pile in Japan. Since civil engineers usually use the pine for pile now, it is very valuable evidence that Japanese cedar used to be used as the pile foundation and existed in the ground with no decay. On the other hand, some physical damage and minor decay were found on the top part of the piles where the pile was stuck up out from the ground. It means that wood including Japanese cedar can be used as a construction material in the ground under the water level for at least over fifty years. Therefore, civil engineers should consider using wood as a construction material instead of steel, concrete or other artificial chemical materials for the future, under the condition that the wood is in the soil under the water level.

SHAKING TABLE TEST TO CLARIFY EFFECTIVENESS OF INSTALLING LOGS INTO LIQUESIABLE GROUND

Fig. 4 illustrates cross sections of top and side view of a model ground with locations of transducers (Yoshida et al., 2008). 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 area 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 Fig. 4, and the other was unimproved area. The loose liquefiable sand layer was made of No.7 silica sand and the relative density was about 35%. The physical properties of sand are listed in Table 1. The model of log made by scaling down 1/25 of the typical wood pile of Kida Bridge and measured 12 mm diameter and 220 mm length.

The shaking table tests were conducted as follows: 1) Pore water pressure transducers were installed at the locations as shown in Fig. 4. 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 a thickness 300 mm. 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 Fig. 4. 5) Thirty six logs were installed into the loose sand layer slowly with a 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 5 seconds in duration time as shown in Fig. 5. The input acceleration and the pore water pressures 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.

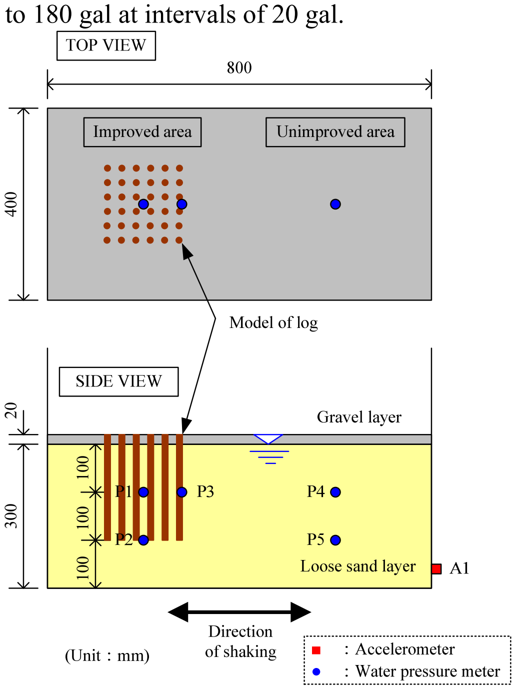

Fig 4. General view of model ground and transducers

Table 1. Physical properties of sand

Density ρ (g/cm^3)	2.63
Average diameter D_{50}(mm)	0.17
Coefficient of permeability k (cm/s)	4.79×10^{-3}

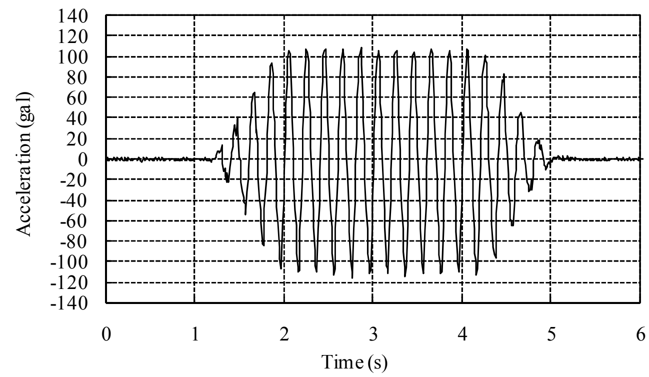

Fig. 5. Time history of input acceleration

Fig. 6 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 aground, the maximum value of excess pore water pressure ratio decreased and the velocity of dissipation was extremely fast.

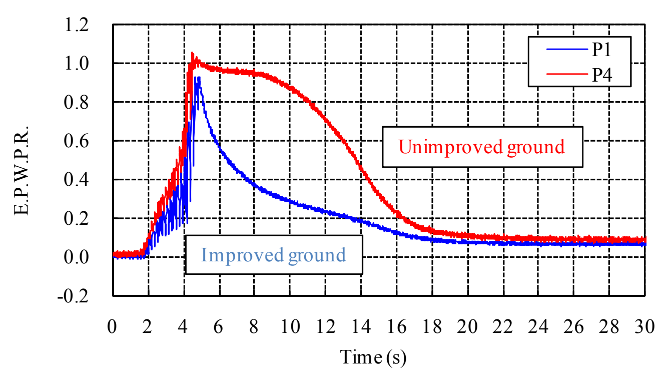

Fig. 6. Time histories of excess pore water pressure ratio

Fig. 7 shows the accumulation of settlement in soil layer. The settlement ratio is defined as a vertical displacement of soil layer divided by initial thickness of the ground, and the residual vertical displacement was accumulated after fifth shaking. The negative value in the figure means upheaval of ground. Though the settlement became about 60cm after fifth shaking in the unimproved ground, the upheaval occurred due to the floatation of logs in the improved ground.

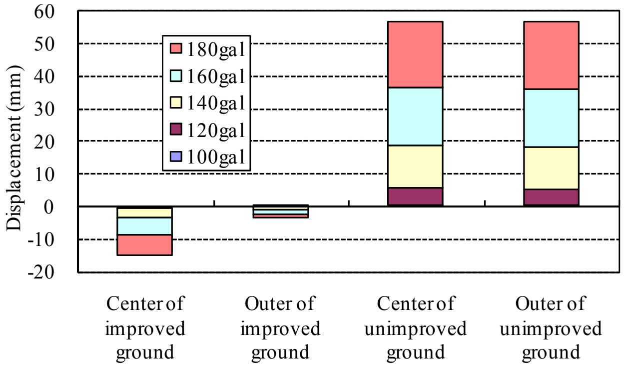

Fig. 7. Vertical displacement of ground surface

Accumulated vertical displacement of logs at the left, center and right part of improved area after fifth shaking is shown in Fig. 8. All of the displacement means flotation of logs. It is clear that the flotation occurred since the input acceleration exceeded 140gal. The flotation of logs in the center part enclosed with a lot of logs was less than that in the outer part of improved ground. It seems that the flotation of logs caused the upheaval of ground in the improved area as mentioned above.

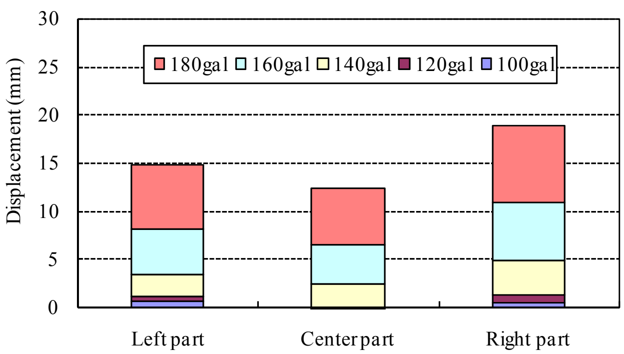

Fig. 8. Vertical displacement of logs

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) restraing the shear deformation by fixing the top of logs into gravel layer, 4) dissipating the water pressure along the periphery of logs.

SHAKING TABLE TEST TO CLARIFY EFFECTIVENESS AS BEARING PILE OF STRUCTURE

Fig. 9 illustrates cross sections of top and side view of a model ground with locations of transducers (Yoshida et al., 2009). The container and sand were same as Fig. 4. The tests were conducted by using a composite ground which consists of three parts. The left part was improved area installed by column type logs, the right part was also improved area installed by cone type logs and the center part was unimproved ground. The shape of cone type log was copied from a typical thinned log in Fukui prefecture. The model of log in case of the column type measured 12mm diameter and 200mm length. The diameter of top was 14mm and that of bottom was 10mm in case of the cone type. The volume of both models was same. The underside of structure model was 150mm square and the weight was 6000g.

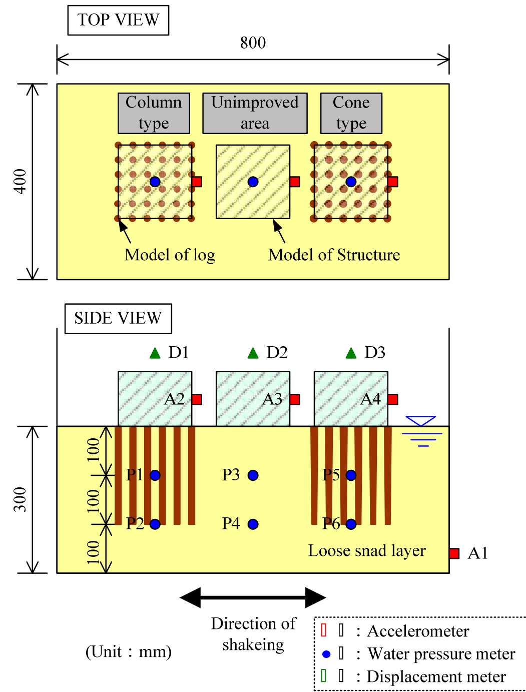

Fig. 9. General view of model ground and transducers

The shaking table tests were conducted as follows: 1) Pore water pressure transducers were installed at the locations as shown in Fig. 9. 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 a thickness 300 mm. 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) Thirty six logs were installed slowly into the loose sand layer with an interval 30mm. 5) The models of structure were placed over the each area. 6) Accelerometers and displacement meters were installed at the locations as shown in Fig. 9. 7) The model ground was shaken in the horizontal direction with the sinusoidal wave of 80 gal in peak amplitude, 5 Hz in frequency and 5 seconds in duration time as shown in Fig. 10. The pore water pressures, the input and response accelerations were recorded simultaneously on the data recorder. A vertical displacement of structures was also measured by a laser displacement meter. 8) After the excess pore water pressure had completely dissipated, the vertical displacement of ground surface was measured by a point gauge. 9) The processes of 7) to 8) repeated three times with different amplitude which was from 60 gal to 100 gal at intervals of 20 gal.

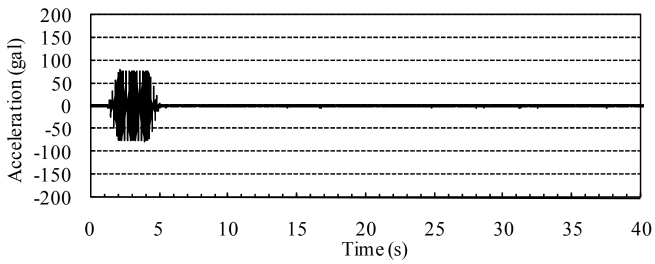

Fig. 10. Time history of input acceleration

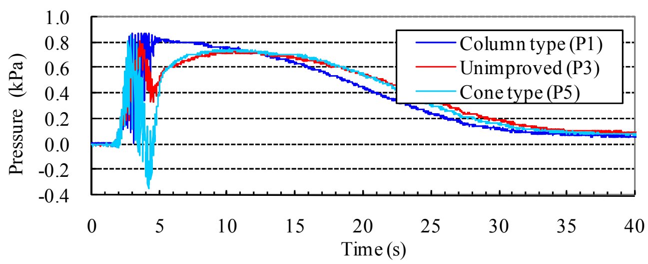

Fig. 11. Time history of excess pore water pressure

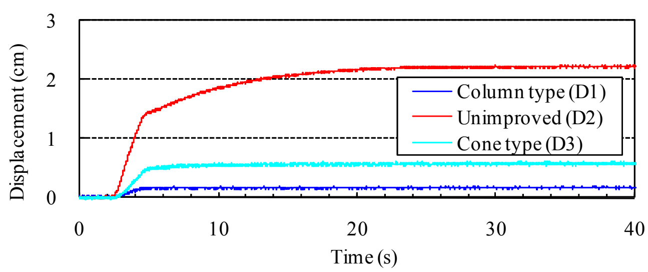

Fig. 12. Time history of settlement of structure model

Fig. 11 shows the time history of excess pore water pressure located at 100mm in depth from ground surface after undergoing shaking of 80gal, and the result of comparing the column type log, unimproved ground and the cone type log. Fig. 12 also shows the time history of settlement of model structures in the same case. The excess pore water pressure reached the maximum value after two seconds when the shaking began. It seems that the ground did not liquefied because the pressure did not reach the effective overburden pressure of 3.4kPa. However, the pressures decreased rapidly after indicating the maximum value and increased again. The time of beginning of this phenomenon correspond to the settlement of structure model as mentioned below. The settlement of structure model started when the excess pore water pressure reached maximum value and it stopped with the end of shaking in the case of improved ground. However, the settlement of the unimproved ground increased continuously until the pressure completely dissipated. It is confirmed that the settlement of structure was mitigated due to the friction of logs eve if the ground softened by generating the excess pore water pressure. Moreover, it seems that the effect of cone type log was relatively low as compared with the column type log. It is considered that the cone type log has the advantage of the area of facing the ground. However, because the excess pore water pressure generated in the ground dissipated from the lower layer of the ground toward the upper layer, the dissipation time of column type log which had small drainage area became longer than the column type.

CONCLUSIONS

The three kinds of test were conducted in order to evaluate the soundness of former wood used as the pile of bridge in the soil under the water level. Furthermore, a series of shaking table tests was conducted in a 1-g gravity field in order to evaluate the effectiveness of the logs installed in liquefiable sand layers during earthquakes. The following conclusions may be made on the basis of the experimental study:

(1) The level of decay of the wood pile made of the Japanese cedar which was retrieved from the riverbed was extremely low and they have kept the soundness as the wood pile even though they were buried in the soil under the water level for 59 years.

(2) The logs installed in the liquefiable soil layer could increase the resistance of ground against liquefaction and decrease the settlement of structure.

ACKNOWLEDGEMENT

The authors would like to acknowledge the valuable suggestion of Messrs. Kubo, H., Gensai, H., Nomura, T. who are researchers of Fukui prefectural office, Messrs. Uesugi, A. and Motoyama, H. who are researches of Tobisima Corporation, and Prof. Hamada of Waseda University. The authors also wish to thank Messrs. Osaka, T., Ogata, Y., Hashimoto, Y., Hirano, F., Kiuchi, T. and Watanabe, Y. who are graduate student of Fukui National College of Technology for his cooperation in experiments. This research was partially supported by the Ministry of Education, Culture, Sports, Science and Technology, Grant-in-Aid for Scientific Research (C), No.19560501 and Scientific Research (A), No.20246078.

REFERENCES

Numata1, A., Uesugi, A., Yoshida, M. and Kubo, H. [2008], "*Investigation of wood piles retrieved from the Asuwa River*", Proc. of 10th World Conference on Timber Engineering No.407, 6p.

Yoshida, M., Numata, A., Uesugi, A., Kubo, H., Gensai, H. and Nomura, T. [2007] "*Investigation of Soundness for Wood Piles Retrieved from Asuwa River*", Proc. of the 62th Annual Meeting of Japan Society of Civil Engineers, pp.183-184 (in Japanese).

Yoshida, M., Numata, A., Uesugi, A., Kubo, H. and Miyajima, M. [2008] "*Experimental Study on Countermeasure against Soil Liquefaction by Using Japanese Cedar Logs*", Proc. of the 63th Annual Meeting of Japan Society of Civil Engineers, pp.43-44 (in Japanese).

Yoshida, M., Numata, A., Motoyama, H., Kubo, H., Miyajima, M. and Nomura, T. [2009] "*Shaking Table Tests on Countermeasure against Soil Liquefaction by Using Japanese Cedar Logs*", Proc. of the 64th Annual Meeting of Japan Society of Civil Engineers, pp.533-534 (in Japanese).