STUDY ON LIQUEFACTION COUNTERMEASURE TECHNIQUE BY USING LOGS WITH DRAINAGE FUNCTION FOR RESIDENTIAL HOUSES

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Abstract

A technique of ground reinforcement by installing logs into loose saturated sand layer was proposed as a countermeasure against soil liquefaction. The principle of this method is based on compaction of soil. Because a target performance of the method is set against the Level 1 earthquake ground motions, it is necessary to improve the method by using other technique together or adding a new function in order to guarantee the seismic performance against Level 2 earthquake ground motions. The log with drainage function based on a water pressure dissipation method was proposed in this study. This log was made by opening holes in a core and on the surface. The principle of the method is to dissipate water pressure when an excess pore water pressure increases by Level 2. Small scale shaking table tests were conducted to evaluate the effectiveness of the piling log with drainage for a new and existing residential house. As a result, the log with drainage could reduce the rate of accumulation of excess pore water pressure and increase the velocity of its dissipation. Furthermore, the settlement of house could be mitigated because the effect of log with drainage improved liquefaction resistance and seismic performance.

Keywords: liquefaction; log; drainage; residential house; shaking table test

1. Introduction

Extensive damage of residential houses was caused during the 2011 Great East Japan Earthquake because extreme soil liquefaction occurred in a reclaimed land along bay area and in river basin. Similar damage was also observed in alluvial deposit along rivers and in a reclaimed land from former rivers during 2016 Kumamoto Earthquakes in Japan. The inclination and settlement of residential houses caused by these earthquakes were especially serious as shown Fig. 1. The Ministry of Land, Infrastructure, Transport and Tourism in Japan released a technical guideline in March, 2013, expected to provide safe land of housing and lowered the cost of liquefaction countermeasure. As a liquefaction countermeasure technique for a lightweight structure like residential house, a deep soil stabilization with column, a pile foundation, a sheet pile wall, a mat foundation, a shallow soil stabilization, etc. have been proposed. However, since there is no regulation which imposes a duty of the liquefaction countermeasure, and its expense becomes so high, the countermeasure is not performed in many cases. Moreover, the countermeasure for an existing house is a developing step. On the other hand, the government of Japan established a guideline for a technical development of construction method using woods which were produced regionally in the positive utilization of public works in December, 2013.

(a) 2011 Great East Japan Earthquake (b) 2016 Kumamoto Earthquake

Fig. 1 Inclination and settlement of residential house during 2011 and 2016 earthquakes.

A liquefaction countermeasure technique for the purpose of wood utilization promotion in public work has been developed with these points as background. It was clarified that the settlement of structure was mitigated by installing logs under the foundation [1], and also reported that decay and insect damage of wood did not occur below the ground water level [2]. "Log Piling Method for Liquefaction Mitigation and Carbon Stock (LP-LiC) [3]" was developed as one of liquefaction countermeasure technique by conducting a series of above studies. The principle of this method is based on compaction by piling logs into loose saturated sand layer. Furthermore, a strong point of this method is the burden on the environment is small because a lot of logs containing carbon can be stocked in the ground for a long term without a biodeterioration. A target performance of this method is set that a factor of safety against liquefaction F_L must be more than 1 at all liquefiable layer against the Level 1 earthquake ground motions. However, this method allows the F_L may be less or equal than 1 at the layer partially against Level 2 earthquake ground motions. The "Level 1" used above is likely to strike a structure once or twice while it is in service. On the other hand, the "Level 2" is very unlikely to strike a structure during the structure's life time, but when it does, it is extremely strong. Therefore, it is necessary to improve this method by using other method together or adding a new function in order to guarantee the seismic performance against Level 2 earthquake ground motions.

The log with drainage function based on a water pressure dissipation method was proposed to ensure the seismic performance against Level 2 earthquake ground motions in this study. This log was made by opening holes in a core and on the surface because the wood had advantage that processing was easier than reinforced concrete and steel. The principle of this method is to mitigate liquefaction as a soil compaction technique by installing logs into loose saturated sand against Level 1 earthquake ground motions, and if an excess pore water pressure increase by Level 2 earthquake ground motions, the log with drainage can dissipate water pressure rapidly.

Small scale shaking table tests in a 1-g gravity field were carried out in this study to investigate effectiveness of the log with drainage function as the countermeasure against soil liquefaction for residential house. This countermeasure was applied to a new house which logs were installed under the foundation and an existing house which logs were installed around the foundation of house. The difference of method between new and existing house is shown in Fig.2. Tests used logs without drainage function were also carried out to comparing with logs with drainage.

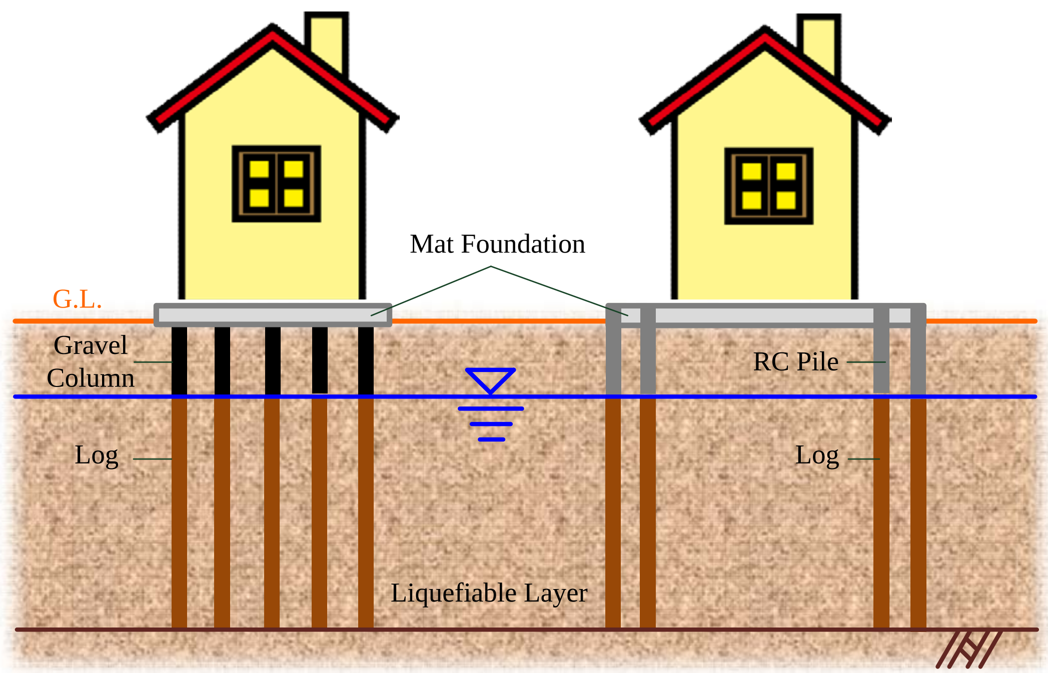


Fig.2 Difference of method between new and existing house

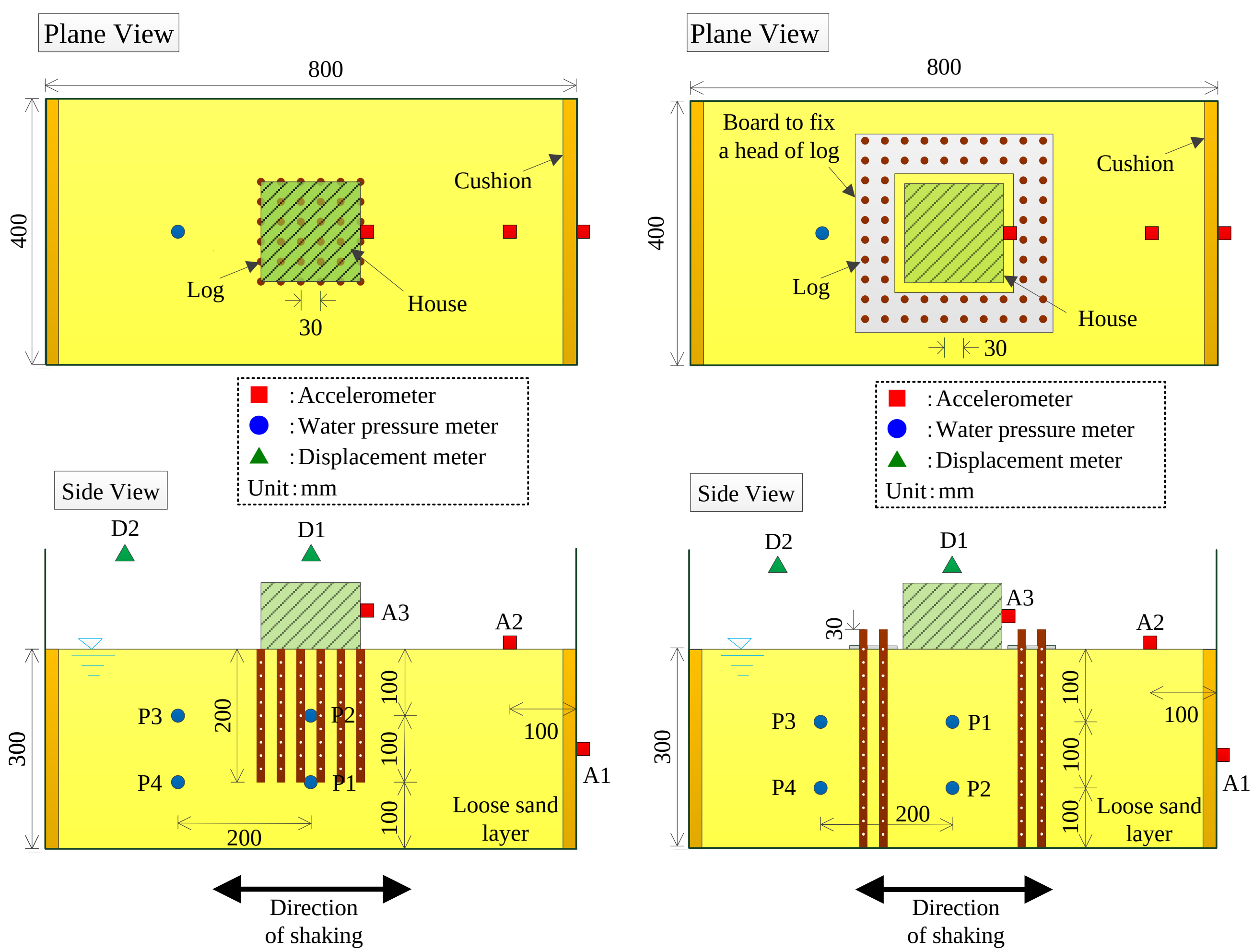
2. Test Procedure

Fig.3 illustrates cross sections of top and side view of model ground. Fig.3a shows the case of log piling under foundation for a new house, Fig3b shows the case of log piling around foundation for an existing house. There are no logs in the case of unimproved ground in these figures. The model ground was set up in a rigid acrylic container that measured 800 mm long, 400 mm wide and 540 mm high. The loose saturated sand layer whose relative density was about 50% was made of silica sand No.7 at first. The physical properties of sand are ρ_s=2.63g/cm3, D_{50}=0.17mm and k=4.79x10^{-3}cm. Then the relative density was adjusted to about 60% by preliminary excitation with a sinusoidal wave, 5 Hz, 100 gal, 30 seconds. Water level was set at ground surface. The cushioning made of urethane was installed in the both ends of the wall of the sand box to ensure the shearing deformation of ground easily.

A model of log made of Japanese cedar got by thinning in Fukui prefecture measured 12 mm diameter. The log with drainage function had four openings whose diameter is 2mm horizontally, and these opening were made at 20mm interval vertically as shown in Fig.4. The top of log was drain condition, and bottom was undrained condition. These were installed statically into the loose sand layer at intervals of 30 mm, its replacement ratio was 12.5% and the intervals of log were 2.5 times the diameter. The log was saturated with water and its density was 1.1 g/cm^3. A boundary condition between bottom of house and top of log was not connected in the case of new house as shown in Fig.3a. A top of log was connected by using acrylic board in the case of existing house as shown in Fig.3b. Fig.5 shows relationship between a hydraulic gradient and permeability which were got by a constant head permeability test [4]. D1 in this figure means diameter of the opening is 1mm. The permeability coefficient of D2 used in above-mentioned shaking table test was about 1 m/s, and it exceeded the coefficient of No.5 crushed stone which was used for a gravel drain system, one of the countermeasure against liquefaction.

A model of house was made by water-resistant wood that measured 150 mm square and 112 mm high. The ground contact pressure was 1.5 kN/m^2 which was scaled down one tenth of two-story wooden house with a mat foundation. An input ground motion used in the tests was sinusoidal wave with a frequency of 5 Hz and a peak magnitude of 120, 160 and 200 gal. The duration time of shaking was 10 second. Fig.6 shows a time history of input acceleration of 120gal.

The input acceleration (A1), response acceleration of house (A2), response acceleration of ground (A3), excess pore water pressures in the ground (P1-P4) and vertical displacements of house (D1) and ground (D2) were recorded during shaking as shown in Fig.3.



(a) Log piling under foundation (b) Log piling around foundation

Fig.3 General view of model ground

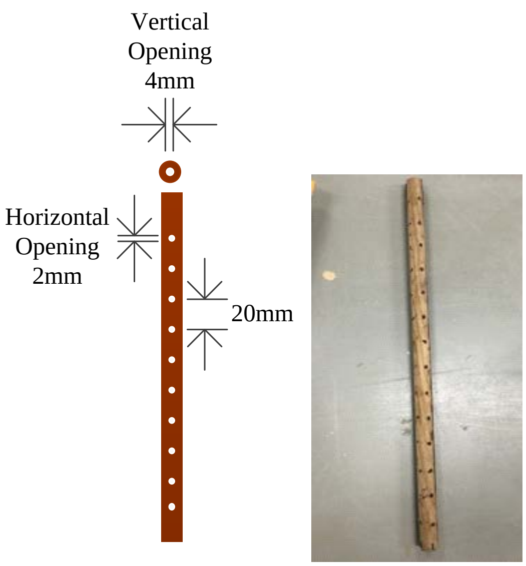


Fig.4 Log with drainage function

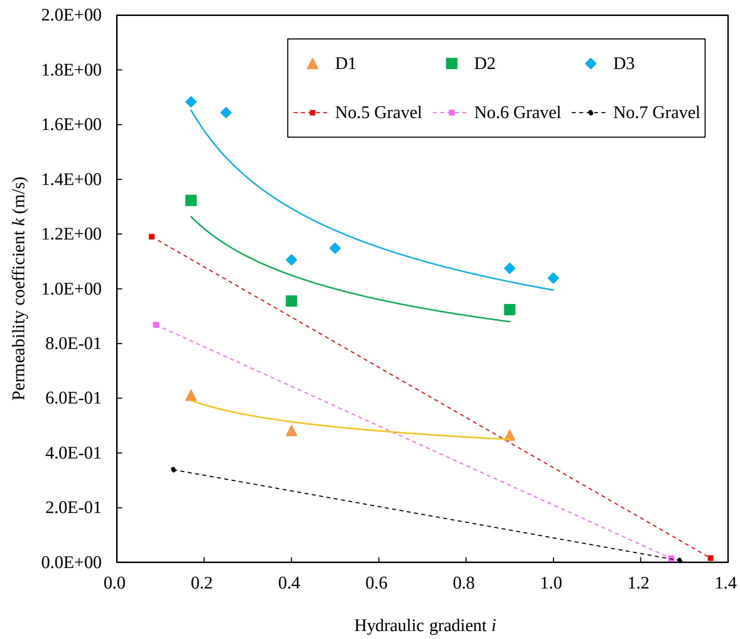


Fig.5 Relation between hydraulic gradient and permeability

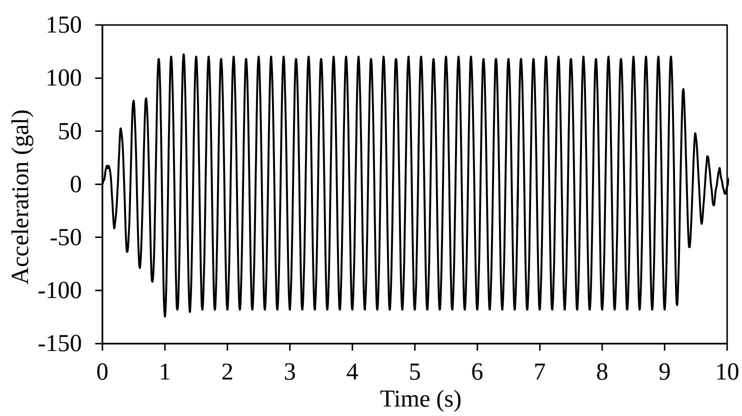


Fig.6 Time history of input acceleration in 120gal

3. Test Results and Discussions

Fig.7 shows the accumulative settlement of house in the case of log piling under foundation for the new house. The settlement in the case of unimproved ground is also shown in this figure. It seems that the accumulative settlement after three shaking was reduced to about 52% in the ground where the logs were installed compared with the unimproved ground. It was about 38% in case of logs with drainage. This effect was remarkable when the magnitude of input acceleration became large.

Fig.8 shows time histories of excess pore water pressure ratios located at 100 mm in depth from ground surface after undergoing shaking in 200 gal. These records were smoothed by using a moving average method. In the case of log with drainage, the maximum value of excess pore water pressure ratio decreased and the velocity of dissipation was extremely fast. The effect of dissipation can also be seen in the case of log because the water pressure was dissipated along the periphery of logs [1].

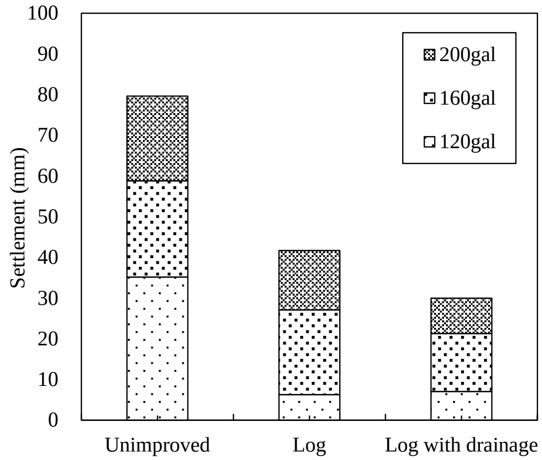


Fig.7 Accumulative settlement of house

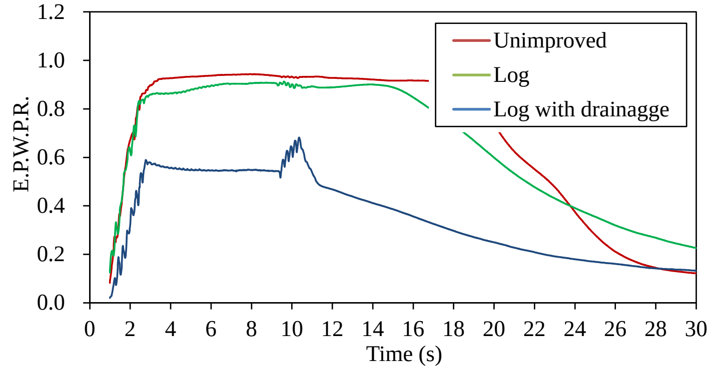


Fig.8 Time history of excess pore water pressure ratio

Fig.9 shows the accumulative settlement of house in the case of log piling around foundation for the existing house. It seems that the accumulative settlement after three shaking was reduced to about 20% in the ground where the logs were installed compared with the unimproved ground. There was no obvious difference whether the log had the drainage or not. The principle of countermeasure against liquefaction in the case of log piling around foundation is considered as follows. The composite ground which consisted of logs and sand performed as rigid wall, and it restrained the lateral displacement of ground under the foundation of house. As a result, resistance against liquefaction increased, and settlement of house decreased.

Fig.10 shows time histories of excess pore water pressure ratios located at 100 mm in depth from ground surface after undergoing shaking in 200 gal. Though the liquefaction did not occurred in the case of 120gal and 160gal, it occurred in the case of 200gal as shown in Fig.9. It can be seen that liquefaction resistance in the case of log piling increased in the accumulation process of excess pore water pressure. The dissipation process of excess pore water pressure in the case of log with drainage started earlier than other cases. It is clear that log with drainage will be able to show additional effect if earthquake ground motion will exceed seismic performance of this method.

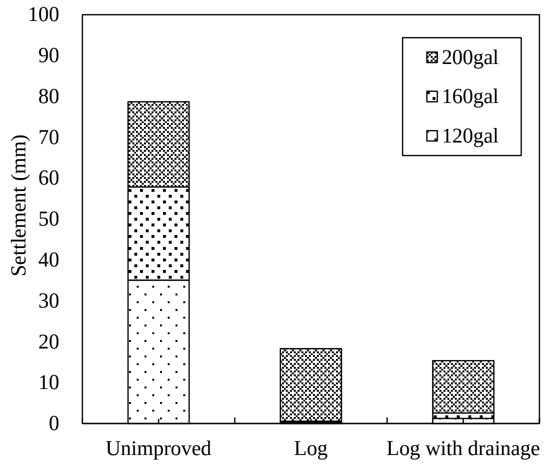


Fig.9 Accumulative settlement of house

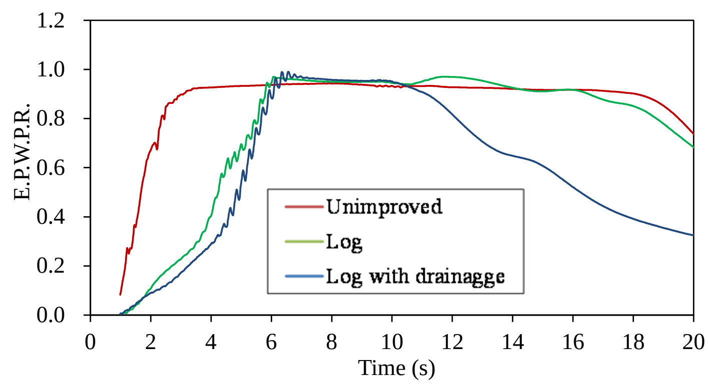


Fig.10 Time history of excess pore water pressure ratio

4. Conclusions

Small scale shaking table tests were conducted in a 1-g gravity field in order to evaluate the effectiveness of the piling log with drainage function for the new and existing residential house.

(1) The permeability coefficient of log with drainage function exceeded No.5 crushed stone which was used for gravel drain system, one of the countermeasures against liquefaction.
(2) The log with drainage could reduce the rate of accumulation of excess pore water pressure and increase the velocity of its dissipation as compared with the log without drainage.
(3) The settlement of house could be mitigated because the effect of log with drainage improved liquefaction resistance and seismic performance.

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