# Countermeasure for slope failure by wooden pile 

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#### Abstract

SUMMARY: There exists many places where soil-structure disaster are likely to occur in Japan. Because of the necessity to take a measure at very many points, a countermeasure method is required to be cheap and to be easy to construct. The authors proposed the measure against slope failure by wooden pile not only as a technique to disaster mitigation, but also as a method for global environment load reduction. This plan is put into practice by using effectively of the forest resources which exist abundantly in Japan. Fundamental experiments about the effect of wooden pile for countermeasure for slope failure were conducted by using small shaking table. Also, numerical analyses were conducted. Then, it is revealed that wooden piles are effective as a countermeasure for slope failure.


Keywords: Slope failure, Countermeasure, Wooden pile

## 1. INTRODUCTION

Many ground disasters were occurred in eastern Japan during the 2011 Tohoku-chiho Tiaheiyo-oki earthquake. Like this, a lot of soil-structure disasters arise in an earthquake. There exists many places where soil-structure disaster are likely to occur in Japan. For instance, there is an complicated geographical feature in the eastern Kanto district in Japan that long and slender valleys like a wooden branch enter into plateau deeply. These valleys are called Yachi and soft ground has deposited thickly on these Valleys. A steep slope exists at the boundary of a plateau and lowlands like Yachi in many cases, and there is a high possibility that the serious damage will occur in case of an earthquake in such an area. Because of the necessity to take a measure at very many points, a countermeasure method is required to be cheap and to be easy to construct.

The authors have been proposing to use wood in civil engineering field not only for enlarging the application of wood to civil engineering structures, but also for presenting the solution to global warming by storing CO2 (Numata et al., 2006, 2009, Kayo et al., 2011). As one of these activities, the authors proposed the measure against slope failure by wooden pile not only as a technique to disaster mitigation, but also as a method for global environment load reduction. This plan can be put into practice by using effectively of the forest resources which exist abundantly in Japan. In this research, fundamental experiments about the effect of wooden pile for countermeasure for slope failure were conducted by using small shaking table. Also, numerical analyses were conducted to express the experimental results (Miwa et al., 2011, 2012).

## 2. PROCEDURE OF THE EXPERIMENT

In this research, the authors tried to use wooden piles as a countermeasure for slope failure. In order to reveal the behavior of wooden piles and slope during an earthquake, and the effect of wooden pile as a countermeasure, small shaking table tests were conducted. Slope model and arrangement of wooden
piles as a countermeasure for slope failure are shown in Figure 1. The experiments were conducted in $1 / 20$ scale. The soil container which has 780 mm in width, 278 mm in length, and 400 mm in depth respectively was used. A slope model with 45 degrees and 200 mm in height was made by fine silica sand in the soil container. The grain size of silica sand used in the experiment distributes almost between 0.075 mm and 0.212 mm . Silica sand was compacted to about $74 \%$ degree of compaction with $2 \%$ water contents of partial saturation. In order to measure the displacement of slope by shaking, marks for measurement were set on the slope with 50 mm intervals as shown in Figure 1. Accelerometers were set on the bottom of the soil container, at the top of the slope and at the toe of the slope.


Figure 1. Slope model and arrangement of wooden piles
6 cases with different pile arrangements were prepared. One is the case of no measure, only the slope was made. 5 models were with wooden piles as a countermeasure in different arrangements with each other. Wooden piles used in experiments have diameter of 9 mm and length of 250 mm . Interval between piles is 3D. D expresses the diameter of wooden pile. Wooden piles were nailed into soils at the top of the slope, the toe of the slope and the hillside respectively. Piles were penetrated into soils with the depth of 150 mm . It correspond to 3 m in real scale. Cases of experiment were shown in Table 1. Case 1 is no measure, only the slope. Case 2 is with wooden piles at the hillside penetrated vertically as a countermeasure. Case 3 is with wooden piles at the top of the slope penetrated vertically, case 4 is with wooden piles at the toe of the slope penetrated vertically, case 5 is with wooden piles both at the toe of the slope and the hillside penetrated vertically. Case 6 is with wooden piles at the hillside penetrated with the angle of 45 degrees.

Table 1. Case of experiments

| No. | Case | Diameter <br> $(\mathrm{mm})$ | Interval <br> of pile | Place <br> of piles | Angle for <br> penetration | Slope <br> angle <br> $($ degree $)$ | Water <br> contents <br> $(\%)$ | Degree of <br> compaction <br> $(\%)$ |
| :---: | :--- | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 1 | No measure | - | - | - | - | 45 | 2 | 73.9 |
| 2 | Piles at the hillside <br> (Vertical) | 9 | $3 D$ | hillside | Vertical | 45 | 2 | 73.6 |
| 3 | Piles at <br> the top of the slope | 9 | $3 D$ | top of <br> the slope | Vertical | 45 | 2 | 73.6 |
| 4 | Piles at <br> the toe of the slope | 9 | $3 D$ | toe of <br> the slope | Vertical | 45 | 2 | 73.9 |
| 5 | Piles at the hillside <br> and <br> the toe of the slope | 9 | $3 D$ | hillside <br> and toe of <br> the slope | Vertical | 45 | 2 | 73.7 |
| 6 | Piles at the hillside <br> (45 degrees) | 9 | 3D | hillside | 45 degrees | 45 | 2 | 73.7 |

The small shaking table system is shown in Figure 2. Vibration system consists of geared motor, cam, rod with turnbuckle, linear rail, soil container and stand for soil container. The cam is rotated by geared motor with a generating capacity of 0.75 kw and a reduction ratio of $1 / 5$. A rod of about 1.1 m length connected a cam and a soil container, horizontal vibration was generated and transferred to the soil container by them. One dimensional sine waves can be generated by this vibration system. An amplitude was variable by changing the eccentricity of the cam. The slope models were excited horizontally by sine wave of 5 Hz . Then the effects were compared. Input motion is shown in Figure 3. Input motion is consist of 22 sin waves of 5 Hz with 5 tapered sin waves before and after the main vibration. Amplitude is increased step by step, as $150 \mathrm{~cm} / \mathrm{s}^{2}, 200 \mathrm{~cm} / \mathrm{s}^{2}, 300 \mathrm{~cm} / \mathrm{s}^{2}$ and $400 \mathrm{~cm} / \mathrm{s}^{2}$ in each cases. Accompanied vibration in the other directions of back and forth, up and down, were very small and ignorable.


Figure 2. Small shaking table for experiment


Figure 3. Input motion for the experiment

## 3. RESULT OF THE EXPERIMENT

Displacement of the slopes were measured by marks on the slope surface and shown in Figure 4. Indicated displacements are the averaged value of 5 marks of the same height. Solid line indicates the planned initial shape of the slope. However, the initial shape of the slope have a little unevenness, so, the initial shape was also indicated by in dotted line in the figure. The shape after shaking were indicated by solid line with points, which indicate the place of marks after the shaking. During the vibrations with the amplitude of $150 \mathrm{~cm} / \mathrm{s}^{2}$ and $200 \mathrm{~cm} / \mathrm{s}^{2}$, no obvious displacement were appeared even in the case of no measure, so, displacement in such cases are not described in the figure.

(a) Case 1 No measure

(b) Case 2 Pile at the hillside (Vertical)

(c) Case 3 Pile at the top of the slope (Vertical)


Figure 4. Results of experiment

In the case of no measure with $300 \mathrm{~cm} / \mathrm{s}^{2}$, slope was largely deformed, about 50 mm in horizontal direction and 25 mm in vertical direction, respectively. Displacement could not be measured in larger amplitude shaking, because very large displacement appeared and the slope almost collapsed. In the cases of measured by wooden piles, the displacements were restrained compared with the displacements in the case of no measure. The soil did not bypass between piles during the excitation. It is thought that if viscosity can be expected to some extent in the soil, wooden piles is effective even in the case that piles have the interval of 3D. The effect of the case with wooden piles at the hillside (case 2) is same as that of the case with wooden piles at the toe of the slope (case 4). In the case with wooden piles at the top of the slope (case 3), displacement was relatively larger because the restrain effect is small on the lower part of the slope. In the case with wooden piles at the toe of the slope (case 4), horizontal displacement reduced to between 25 cm and 30 cm , vertical displacement reduced less than 10 mm during the vibration of $300 \mathrm{~cm} / \mathrm{s}^{2}$ by the effect of piles.

Displacement was mostly restrained in the case with wooden piles both at the hillside and the toe of the slope (case 5). In this case, the displacement during the vibration of $400 \mathrm{~cm} / \mathrm{s}^{2}$ was same as the displacement during the vibration of $300 \mathrm{~cm} / \mathrm{s}^{2}$ in the case of no measure. The result showed that displacement did not increase even in the larger ground motion in this case. In the case with wooden piles at the hillside with the angle of 45 degrees, displacement was smaller than that of the case with wooden piles at the hillside with vertical direction, and the displacement did not increased even in the $400 \mathrm{~cm} / \mathrm{s}^{2}$ vibration.

## 4. NUMERICAL ANALYSIS

In order to enable to examine the effect of many type of countermeasures by wooden piles in the nest step of the research, numerical analyses were conducted to express the experimental results. FLIP, which is the numerical analysis code name (Iai et al., 1992), was used in this research. Only the case 1 and 5 were simulated by the analysis. The experimental models of case 1 and case 5 is shown again in Figure 5. Model for the numerical analysis is shown in Figure 6. Soil was modeled by multi-spring element, wooden pile and the frame of soil container were modeled by linear beam element. Side boundary condition was rigid, but soil container can move left and right freely, and lower boundary condition was rigid and fixed. Table 2 shows properties of soil and wooden piles in the analysis model. Shear wave velocity of soil is $30 \mathrm{~m} / \mathrm{s}$ at the middle depth of the container $(0.2 \mathrm{~m})$, which indicates very loose condition. It correspond with about $81 \mathrm{~m} / \mathrm{s}$ in 98 K pa of effective confining pressure.


Figure 5. Slope model and arrangement of wooden piles for numerical analysis


Figure 6. Slope model and arrangement of wooden piles for numerical analysis

Table 2. Properties of soil and wooden pile for analysis

| Material | Height |  | Thickness | Unit weight | Effective confining pressure | Poisson's ratio | Porosity |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Top | Toe | H | $\gamma \mathrm{t}$ | $\sigma \mathrm{v}$ ' | v | n |
|  | (m) | (m) | (m) | (kN/m ${ }^{3}$ ) | (kPa) |  |  |
| Soil | 0.4 | 0.2 | 0.4 | 12.2 | 2.44 | 0.33 | 0.45 |
| Material | Cohesion | Angle of internal friction | Shear wave velocity |  | Initial normalized shear wave velocity | Maximum damping factor |  |
|  | c | $\phi_{\mathrm{f}}$ | Vs |  | $\mathrm{Vs}_{\text {ma }}$ | $\mathrm{h}_{\text {max }}$ |  |
|  | (kPa) | (degree) | ( $\mathrm{m} / \mathrm{sec}$ ) |  | (m/sec) |  |  |
| Soil | 0 | 37.92 | 30 |  | 81 | 0.24 |  |
| Material | Diameter |  | Unit weight |  | Poisson's ratio | Shear rigidity |  |
|  | (m) |  | $\left(\mathrm{kN} / \mathrm{m}^{3}\right)$ |  |  | (kPa) |  |
| Wooden pile | 0.09 |  | 3.3 |  | 0.4 | $6.37 * 10^{5}$ |  |

The results of analysis were shown in Figure 7 with the results of the experiments. In the case of no measure, displacement of analysis was slightly smaller than that of experiment during the vibration of $300 \mathrm{~cm} / \mathrm{s}^{2}$, and increased largely during the vibration of $400 \mathrm{~cm} / \mathrm{s}^{2}$. In the case with wooden pile (case 5), displacement of analysis was almost the same as that of experiment during the vibration of $300 \mathrm{~cm} / \mathrm{s}^{2}$, and increased larger than that of experiment during the vibration of $400 \mathrm{~cm} / \mathrm{s}^{2}$, but clearly smaller than that of the no measure case. It is thought that because the experiment were implemented in the very loose soil condition, the influence of the difference of soil condition between one case and the other cases might be larger, soil condition might be changed largely step by step in each amplitude, it is difficult to express the results of experiments by the analysis using uniform material properties. Increase of displacement in accordance with amplitude of vibration, reducing the displacement by the countermeasure can be expressed qualitatively by the analysis.

(b) Measured by wooden pile (Case 5; piles at the hillside and the toe of the slope)

Figure 7. Results of numerical analysis

## 5. CONCLUSIONS

The conclusions obtained from this research are summarized as follows,

1) Wooden piles are effective as a countermeasure for slope failure.
2) The effect is different by the arrangement of wooden pile.

The authors would like to enlarge the usage of wood in civil engineering field in order to restrain the global warming and save the Earth.

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