17th World Conference on Earthquake Engineering, 17WCEE
Sendai, Japan - September 13th to 18th 2020

Seismic stability of masonry retaining wall in centrifuge tilting tests

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Abstract

Recent years, a lot of housing retaining walls have been damaged or even collapsed by earthquakes in Japan. Particularly, more than 4000 retaining walls were damaged during the Kumamoto earthquake in 2016.

Most of the damaged retaining walls were air masonry retaining walls unfilled with mortar, which are not allowed by the current Japanese building standards law.

Today, although there are reinforcement methods for retaining walls, such as a lock bolt method or an anchor method, they have limit in the application of housing retaining walls due to workability or cost problems.

The purpose of this study is to understand the seismic behavior of an air masonry retaining wall, which is not satisfied with the current Japanese building standards law and eventually to examine the reinforcement for such a masonry retaining wall.

In this report, in order to confirm the effect of the reinforcement method on a masonry retaining wall, we modeled an air masonry retaining wall and conducted a centrifuge tilting experiment.

In the experiment, the model retaining wall ground was tilted using a tilting table which is called Centrifugal seismic force simulator under 20G generated in a small centrifugal model experiment device (owned by Tokyo City University), horizontal seismic force during an earthquake was reproduced and the deformation behavior of the masonry retaining wall during an earthquake was confirmed.

Sponge tape was attached to the retaining wall block surface in contact with the soil tank for reducing the friction between the soil tank and the retaining wall block.

A plaster block was used for the model air masonry retaining wall, which was made with a 3D printer on 1/20 scale and silica sand No. 7 of air-dried state was used for the ground behind the wall.

Measuring devices were installed during this experiment to record the state at the time of tilting with HDV and to grasp the ground surface displacement, etc. In addition, the image analysis was performed using an image analysis software called SKIP (Surface Kinematometry by Image Processing) and the shear strain, etc. were grasped.

From the result of image analysis, it was confirmed that the maximum shear strain was significant on the straight line in the ground after the tilt.

Keywords: masonry retaining walls, centrifugal model experiment, horizontal seismic force

1. Introduction

Recent years, a lot of housing retaining walls have been damaged or even collapsed by earthquakes in Japan. Particularly, more than 4000 retaining walls were damaged during the Kumamoto earthquake in 2016. Most of the damaged retaining walls were air masonry retaining walls unfilled with mortar, which are not allowed by the current Japanese building standards law. Today, although there are reinforcement methods for retaining walls, such as a lock bolt method or an anchor method, they have limit in the application of housing retaining walls due to workability or cost problems. The purpose of this study is to understand the seismic behavior of an air masonry retaining wall, which is not satisfied with the current Japanese building standards law and eventually to examine the reinforcement for such a masonry retaining wall. In this report, in order to confirm the effect of the reinforcement method on masonry retaining wall, we modeled an air masonry retaining wall and conducted a centrifuge tilting experiment using small centrifugal model experiment device and tilting table under 20G.

2. Experimental Equipment

2-1 Geotechnical Centrifuge facility

In this experiment, a geotechnical centrifuge device owned by Tokyo City University, was used. The photo of the device and performance values are shown in Fig.1, and Table 1, respectively.


1) Outside of device


2) Platform inside of device

Fig.1, Small centrifugal experimental device

Table1.Performance values of small cetrifugal device

Radius of rotation	350
Revolution per minute	100～510rpm
Maximum acceleration	100G
mass	100kg
External dimensions	1500×1450mm

2-2 Tilting table device

A tilting table device used for the experiment is shown in Fig.2. We can tilt the table from 0 to 30 degree and load horizontal seismic force $k_h=\tan\theta$ (k_h=horizontal seismic force, θ=tilting angle) on the modelled retaining wall.


Fig.2, Tilting table device

3. Outline Of Experiment

3-1 Method of modelling retaining wall

A soil container with 300mm in width, 200mm in height, and 120mm in depth was used for this experiment. All the sides of the container are made of aluminium except for one side, which is made of acrylic to observe the inside through it. In order to model an air masonry retaining wall, retaining wall blocks and base were reproduced with plaster on 1/20 scale by a 3D printer. Two types of retaining wall blocks with 20mm in height and 19mm or 38mm in width and a retaining wall base with 20mm in height and 114mm in width were used for this experiment. Sponge tape was attached between the retaining wall surface and the soil container for reducing the friction. The retaining wall blocks and the base used for this experiment are shown in Fig.3. Blocks were subsequently stacked in five layers on the base to make the retaining wall with 110mm in height and then the retaining wall was tilted with 75 degree. as shown in Fig.4. The backfill was made with silica No. 7 by air pluviation to achieve a relative density of 60%. The schematic diagram of the modelling retaining wall ground is shown in Fig.5. In order to make conditions similar to actual conditions, modelled micropiles with rough surface made of MC nylon were used for the reinforcement as shown in Fig.6. As a reinforcement method, seven micropiles were put in the backfill at the point of 47mm away from the top of slope, and four micropiles were tilted 5 degree toward the wall and three were tilted 15° degree backward. In addition, the bottom of the micropiles were fixed in a zigzag with a intervals of 15mm to the bottom of the soil container with 120mm in width, and the top of the micropiles were integrated by PVC footing. The schematic diagram of the modelling reinforced retaining wall is shown in Fig.7. In addition, the photos of modelled air retaining wall (Case1) and modelled reinforced retaining wall (Case2) are shown in Fig8 and Fig9, respectively.

Fig.3, Retaining wall blocks on base

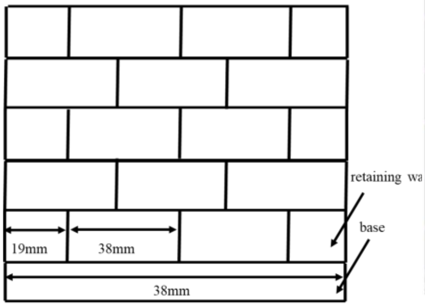


Fig.4, Image diagram of retaining wall

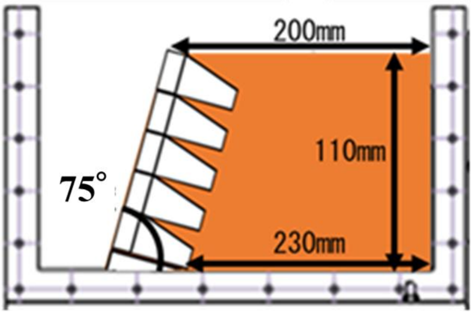
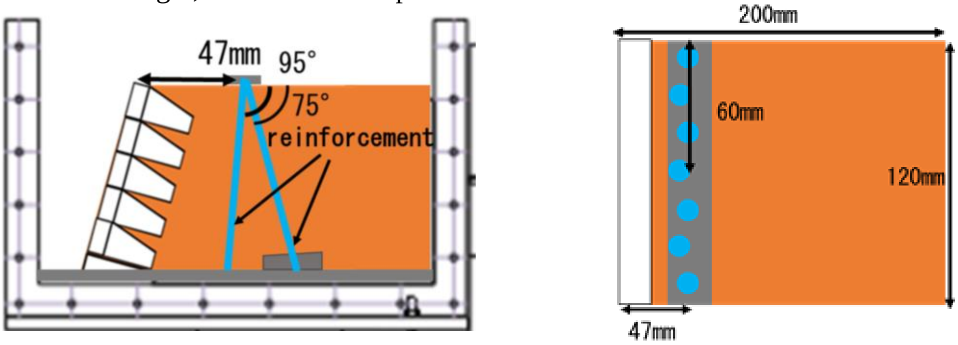


Fig.5, Schematic diagram of modelled retainig wall

Fig.6, Modelled micropile for reinforcement



Sectional diagram

Top diagram

Fig.7,schematic diagram of modelled micropile

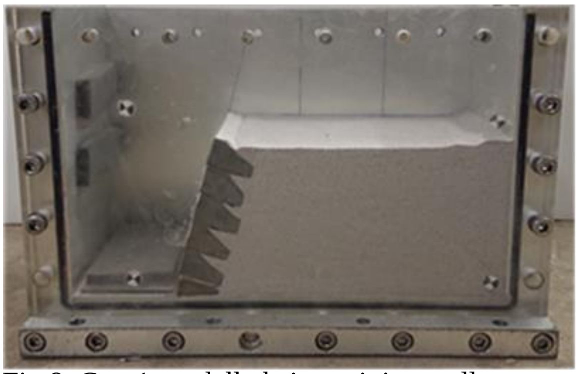


Fig.8, Case1-modelled air retaining wall

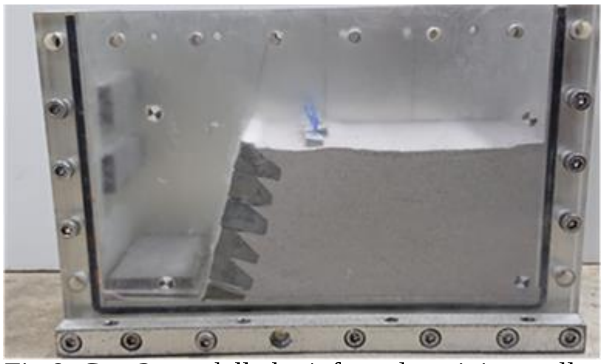


Fig.9, Case2 -modelled reinforced retaining wall

3-2 Experimental Procedure

The modelling retaining wall was placed on the tilting table device, where a HDV camera (GoproHEROsession5) was installed out of the soil container for image analysis, and displacement sensors were attached at two points; one was near the slope and the other was far from the slope for measuring vertical displacement. In this experiment, a 20G centrifugal force was applied and 3 minute after the force reached 20G, a tilting experiment was conducted with changing the tilting angle from 0 to 26.7 degree under the condition of 0.16° /sec in tilting speed. Since a collapse didn't occur when the tilting angle reached 26.7 degree, a horizontal seismic force was attempted to be continually applied for 1 minute. The State before the experiment is shown in Fig.10.

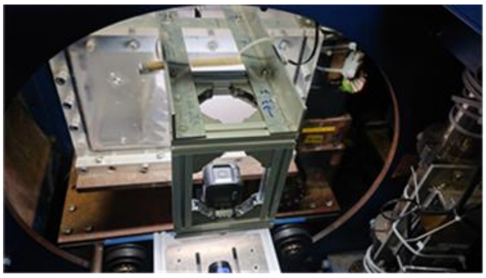


Fig.10, State before tilting experiment

4. Results of Experiment

The relationship between tilting angle and displacement amount obtained from displacement sensors located at two measuring points are shown in Fig.11 and 12. As for Case1 both in Fig.11 and 12, after the displacement amount gradually increased according as the tilting angle increased, sudden rise was observed when the tilting angle turned to approximately 25 degree and which means the collapse of the retaining wall. As for Case2, on the other hand, the displacement amount was smaller than Case1 as the tilting angle increased, and the displacement amount had increased more significantly since the tilting angle became 18 degree, however, a collapse didn't occur when the tilting angle turned to 25 degree. From the results, the reinforcement effect in Case2 was confirmed.

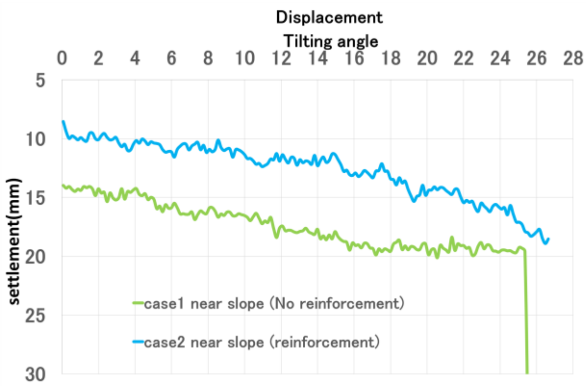


Fig.13, Relationship between tilting angle and settlement near slope

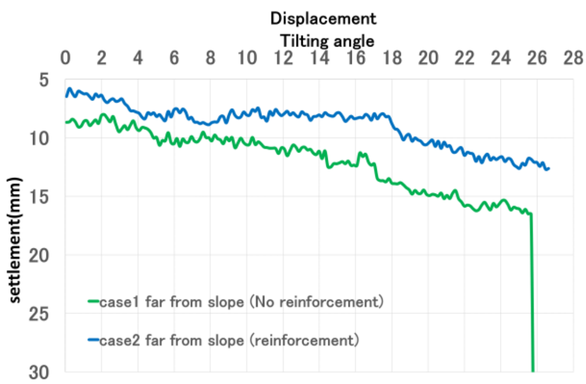


Fig.14, Relationship between tilting angle and settlement far from slope

In addition, we also conducted image analysis using the data obtained from the HDV camera for confirming the collapse behavior of backfill. For image analysis, image analysis software, "TN-SKIP" was used, which can analyze deformation, strain and etc from the difference between the shade of the color of the image before and after the deformation. Image analysis was categorized in three patterns; from 22 to 23, 22 to 25, and 22 to 25.45 degree of tilting angle in Case1 and Case2. The results of image analysis are shown in Table2, where an increase in the maximum shear strain is shown by the change from cold color to warm color. In Case1, since the change of color was not observed from 22 to 23 degree, deformation didn't occur then. While from 22 to 25 degree, faintly and linear change of color was confirmed from the first layer of the retaining wall blocks to the center of top of slope, and the change became more standing out from 22 to 25.45 degree which indicates an increase in shear strain. In Case2, on the other hand, the change of color, that is, an increase in shear strain was not confirmed in all patterns. From the results, it was confirmed that slip collapse in Case2 was suppressed by the effect of the reinforcement. In addition, since collapse didn't occur in the reinforced retaining wall when the tilting angle reached 26.7 degree, horizontal seismic force was attempted to be continually loaded for 1 minute. As a result, collapse occured after 20 seconds. The image analysis of 2-second and three phases; 1.4, 1, and 0.8-seconds before the collapse is shown in Table 3. From the result, linear shear strain was observed in the area between the wall and the reinforced area. When comparing the image analysis of Cases1 and Case2, the effect of reinforcement was confirmed in Case2 because the sliding mass area and the collapse area in Case2 were smaller than those in Case1.

Table2. Image analysis in Case1 and Case2

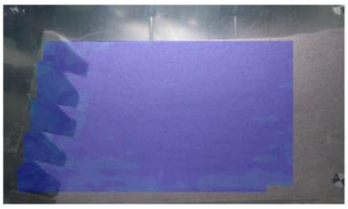
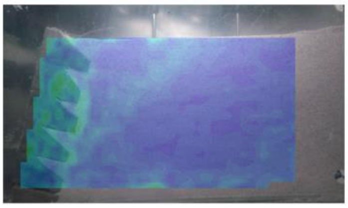
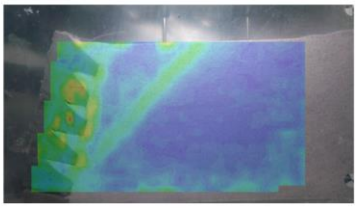
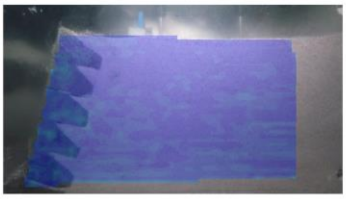
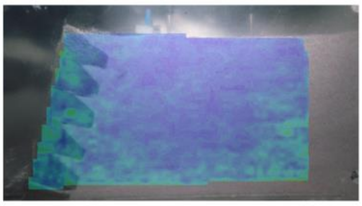
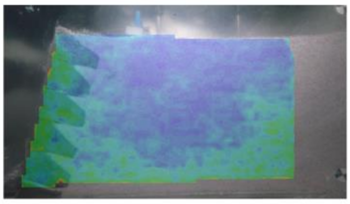
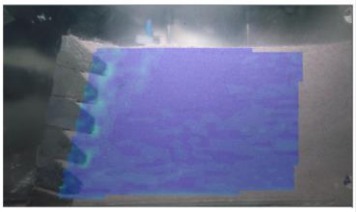
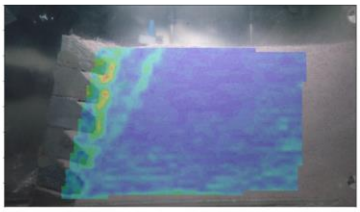
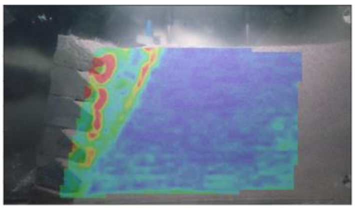
Degree(°)	22→23°	22→25°	22→25.45°
kh	0.42	0.47	0.48
Case1			
Case2			

Table3. Image analysis of 2-sec (collapse time) and three phases in Case2

Seconds before of collapsing	Between 2 seconds and 1,4seconds before collapse	Between 2 seconds and 1seconds before collapse	Between 2 seconds and 0.8seconds before collapse
Case2			

5 Conclusions

In this report, we focused on a masonry retaining wall, which is so vulnerable to natural disasters that it is not allowed by the current Japanese building standards law. In order to confirm the effect of a reinforcement method on the masonry retaining wall, we modeled an air retaining wall and a reinforced retaining wall, and conducted centrifuge tilting experiments with using them. As a result, the reinforcement effect was confirmed because the settlement amount of reinforced retaining wall was lower than that of no reinforced retaining wall, and the reinforced retaining wall did not collapse during the tilting experiments. In addition, it was also confirmed from the result of image analysis that the liner shear strains in reinforced and no reinforced retaining walls were differently generated and the area of the sliding mass of reinforced retaining wall was smaller than that of no reinforced retaining wall.

6 References

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