Particle Image Velocimetry (PIV) Analysis to Delineate Mechanism of Rainfall Induced Landslides

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Introduction

Rainfall-induced landslides (RIL) are a type of slope disaster and are characterized by widespread damage. Recently, heavy rainfall has increased around the world due to climate change, and many RIL have occurred in various parts of the world, including Japan, and caused a lot of damage to human lives and property. Currently, there are a variety of countermeasures against RIL.

There are many landslides for which the failure mechanism was not identified. For example, in July 2018, the slope formed by rocks with a lot of natural vertical cracks failed in Fukuoka Prefecture. It was presumed that the cracks caused the slope to fail, but the true mechanism of this failure is not identified [1].

It is considered that applying PIV analysis to model tests of RIL can contribute to understanding the detailed mechanism of RIL. PIV analysis is a method of image analysis and can detect the velocities of soil particles from the image data of model tests on slopes. It can obtain detailed and large amounts of data that cannot be obtained from observation by human eyes or sensors. However, PIV analysis is a technique developed in the field of fluid mechanics, and there are very few studies applying PIV analysis to rainfall induced landslides.

The objective of this research was to analyze the model tests of RIL considering the difference in vertical cracks using PIV analysis. This research also aims to verify the usefulness of PIV analysis in the model tests of RIL and their mechanism.

Method

Two model tests of RIL considering the difference in vertical cracks in slopes were carried out. Fig 1 shows the setup of the tests. The slope model was made inside a rectangular box. Two cameras were placed on the side and front of the slope model. They captured the side and front images of the slope model every 10 seconds until the entire slope failed. The initial soil moisture content was set to 10%, and the rainfall intensity was set to 70 mm/h. Two model tests, Test 1 and Test 2, were carried out. Test 1 was for normal slope without any cracks and Test 2 was for a slope with eight vertical cracks.

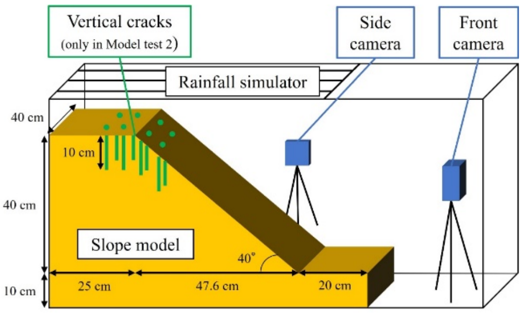
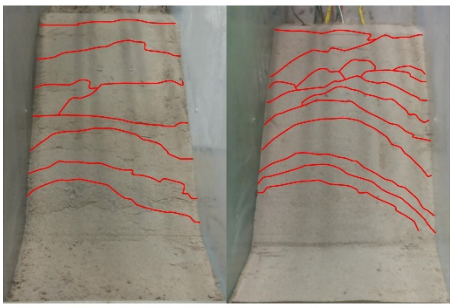


Fig 1 Setup of the tests

To analyze the image data recorded in the model tests, PIV analysis was used. It obtains the displacement vectors of particles in successively captured images using the luminance of the images. To carry out PIV analysis effectively, it is very important to set the optimal size of the “test patch” according to the image to be used. The larger the test patch, the more accurate analysis results can be obtained, while the smaller the test patch, the more detailed analysis results can be obtained [3]. In this research, the test patch sizes of 16 pixels square, 32 pixels square, 64 pixels square, and 96 pixels square were tested using the image data from the tests. It was found that the optimal size was 32 pixels square, and therefore, the size of the test patch was set to 32 pixels square.

Results

Fig 2 shows the locations, where the landslides occurred in each test. In both the tests, multiple shallow landslides were observed. Landslides occurred continuously from the bottom to the top of the slope. In Test 2, more landslides occurred than in Test 1, and a series of small landslides were observed, especially on the upper part of the



a. Test 1 b. Test 2

Fig 2 Location of the landslides

slope where the vertical cracks were created. It is considered that they occurred by the effect of the cracks.

The data of velocity vector and strain rate in the tests were obtained using PIV analysis. Fig 3 shows the velocity vectors of the soil particles for the representative landslides in Test 1. The elapsed time from the beginning of the tests when each velocity vector was captured is shown in the figures. As in the previous research [2], the velocity and soil volume of the landslides increased as the number of landslides increased, especially in Test 1. This tendency was observed in both the side and front of the slope model. However, in test 2, some smaller landslides occurred on the upper part of the slope after larger landslides, and their velocities were smaller than those of the larger landslides. This indicates that landslide velocity depends on the soil volume of landslides, not on the number of landslides.

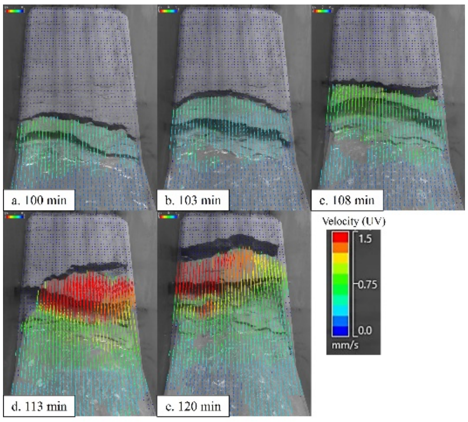


Fig 3 Velocity vectors at the front in Test 1

In Test 2, the velocity vectors tended to be smaller, and the landslide tended to be shallower than those in Test 1. It is considered that the cracks saturated the soil in the slope faster and caused smaller and shallower landslides. The velocity vectors were smaller because the soil volume of the landslides was smaller.

Fig 4 shows the shear strain rates at the side of the slope model for the representative landslides in Test 1. The shear strain rates at the side of the slope model indicated the location of the sliding surface of landslides. There was a tendency that the larger the velocity of the landslide, the larger the shear strain rate. As a result, the shear strain rate in Test 2 tended to be smaller than those in Test 1.

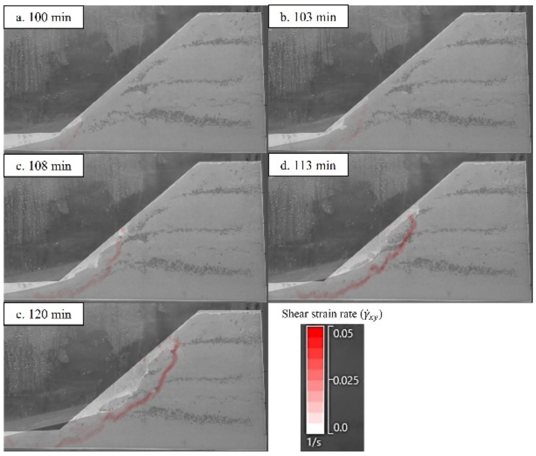


Fig 4 Shear strain rates at the side in Test 1

Fig 5 shows the vertical strain rates in Test 1 from before the landslide cracks were visible until the landslides occur. The elapsed time when each vertical strain rate of the landslide was first captured is shown in the figures. These small strain rates were observed for most landslides in both the tests. Even just before the landslide cracks were visible on the slope, the strain rates were captured. This strongly supports that the accumulated strain rates caused the cracks in the slopes, which led to the landslides.

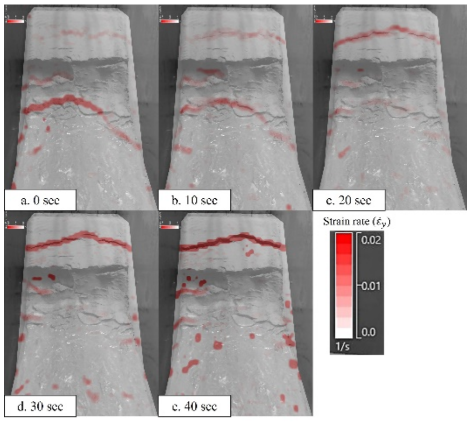


Fig 5 Vertical strain rates at the front in Test

Conclusion

Vertical cracks in slopes induce multiple RIL, but the velocity of the RIL becomes small. PIV analysis can capture the velocity vector and strain rate of RIL in detail and is useful for clarifying the mechanism of RIL.

Acknowledgment

This research was funded by Kyushu Regional Management Service Association, Fukuoka.

References

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