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Topographical characteristics and model test behaviour for occurrence region of debris flow at Hiroshima in August 2014

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ABSTRACT

One of major concerns in geotechnical engineering is a prevention to debris flow disaster caused by Heavy rainfall. Then, the occurrence region of the debris flow should be focused on the research because of the origin and source place for the disaster. The topographical analysis was conducted to understand statistically the topographic condition for occurrence region. The model slope tests by rainfall were carried out to capture the detail collapsed behaviour. Then the characteristics of collapsed occurrence region were discussed in terms of slope angle, catchment area and the cross-sectional pattern.

Keywords: Debris flow; slope angle; catchment area; topographical analysis; model test

1 INTRODUCTION

In August 2014, Hiroshima city experienced the heavy rainfall which recorded the highest value of 1, 3 and 24 hours-precipitation in the observed data. The record heavy rainfall caused many debris flows in residential area (JSCE and JGS, 2014). So, it is an important subject to develop a prevention to probable debris flow disasters. Many of the debris flows were identified as the type which occur along mountain stream. So far, various research on debris flow have been performed (Takahashi, 2014). However, there is no research for understanding the topographical characteristic for the region of occurrence of debris flow (described as "occurrence region or O.R." in below).

Since the occurrence region is one origin and source of a debris flow, the collapsed time at O.R. is related directly to ther happening time of debris flow disaster. The flow volume from the O.R. would influence the run-out area of debris flow because of the highest potential energy. So, it is important to investigate the characteristics of O.R. from the view point of disaster prevention. The paper describes a series of examinations for understanding the topographical characteristics of the O.R. of the debris flow generated at Hiroshima city in August 2014.

2 TOPOGRAPHICAL ANALSYS FOR OCCURRENCE REGION OF DEBRIS FLOW

2.1 Debris flow and occurrence region

A dangerous mountain stream would bring any damages to residences and/or public facilities by occurrence of debris flow. About 10,000 dangerous mountain streams have been specified in Hiroshima Prefecture (Hiroshima Prefecture HP). In the disaster happening, debris flows occurred in some of the dangerous mountain stream specified. The interesting thing is that all dangerous mountain stream did not have any debris flow. A topographical analysis was conducted for 29 mountain streams. The analysis was treated for all of dangerous mountain streams including uncollapsed streams.

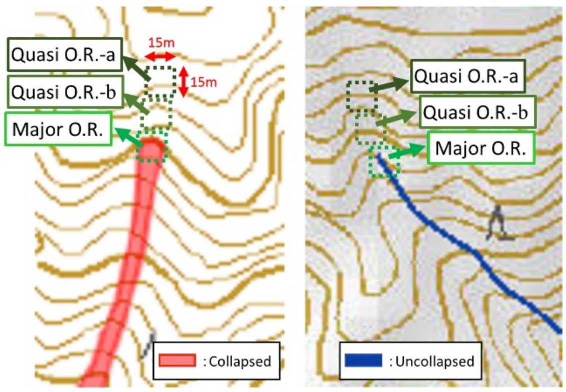

Fig. 1. Occurrence region for collapsed and uncollapsed stream.

In the collapsed mountain stream, O.R. was defined by 15x15m mesh of the highest altitude point, as shown in Fig. 1. In the uncollapsed mountain stream, A possible O.R. was defined as the same size mesh of the highest altitude point of the specified mountain stream. Henceforth, it was described as major occurrence region. For detailed analysis, the quasi occurrence region "a" and "b" were specified as the points where the altitude is higher than the major O.R., as shown in Fig. 1. The major O.R. of collapsed mountain stream is collapsed O.R. The other O.R. such as two quasi O.R.s and major

O.R. of an uncollapsed mountain stream is uncollapsed O.R. The topographical analysis investigated 123 occurrence-regions which are 42 collapsed O.R. and 81 uncollapsed O.R.

2.2 Topographical analysis using GIS

Topographical analysis was conducted using the geographic information system (GIS). The altitude data of 5 x 5 m mesh provided by the Geographical Survey Institute was utilised. The analysis produced the distribution maps for slope angle and catchment area. The slope angle is the maximum among 6 slope angles around a object mesh. Catchment area for rainfall is defined as total area of the place where the water which flows into the object mesh fell.

Fig. 2 shows the frequency distribution of slope angle on the collapsed and uncollapsed O.R.s. The slope angle varies the range of 23-44 degrees. The average slope angle is 33.4 deg., and standard deviation is 5 deg. The collapsed O.R. has the slope angle of 33 deg. or more. The some of uncollapsed O.R. also has the slope angle more than 33 deg.

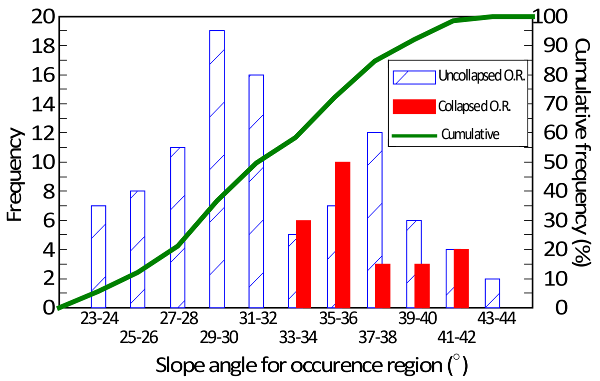

Fig. 2. Distribution of slope angle for O.R.

Fig. 3 shows the relationship of the slope angle and catchment area for the collapsed O.R. Moreover, the same relationship for the uncollapsed O.R. is shown in Fig. 4 The collapsed O.R. were the slope angle of 33 degrees or more, and the catchment area of about 2000 m^2 or more. Since the O.R. with larger catchment area collects much more rainfall water, it is thought that the groundwater level goes up more. The boundary line indicating both conditions is drawn in Figs. 3 and 4. The major O.R. with the condition exceeding the boundary line were 26. The quasi O.R.s at were 5 in Fig. 4. It means that 84 % of the area with the condition mentioned above had collapsed.

The influence of the pattern of cross-sectional slope is analyzed as the 3rd factor. In order to understand the slope pattern, the slope angle variation is defined as a value which subtracted the slope angle of the major region from the slope angle of the lower region. So, the pattern with a negative variation is the combination of steep upper slope and the gentle lower slope. Conversely, the slope of a positive value is a gentle upper and steep lower slope. Fig. 5 shows distribution of slope angle variation. The frequency distribution of the variation takes -9 to 11 degrees. The slope angle variation for 26 collapsed O.R. is distributed from 2.6 deg. to -9 deg., and the average is -3.1 deg. 21 O.R.s among 26 were negative variation. So, it means that 81% of collapsed occurrence region has a gentle lower slope.

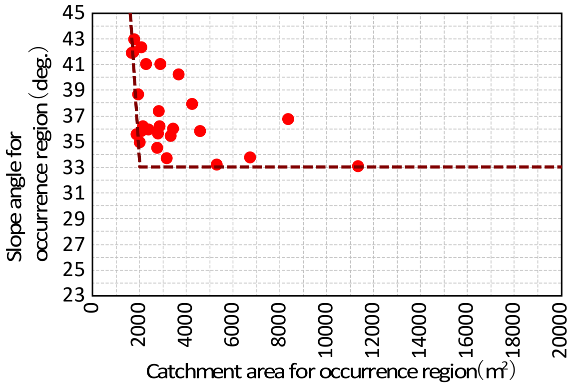

Fig. 3. Slope angle and catchment area for collapsed O.R.

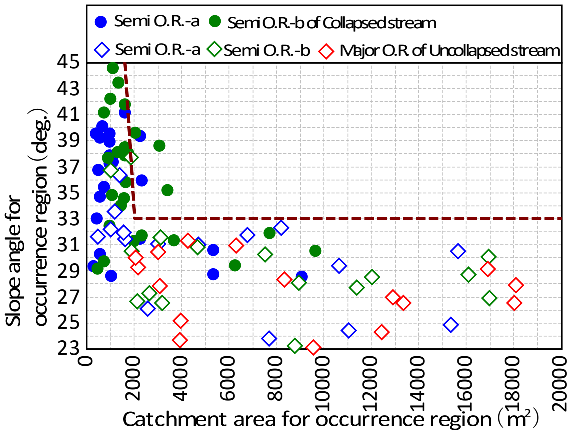

Fig. 4. Slope angle and catchment area for uncollapsed O.R.

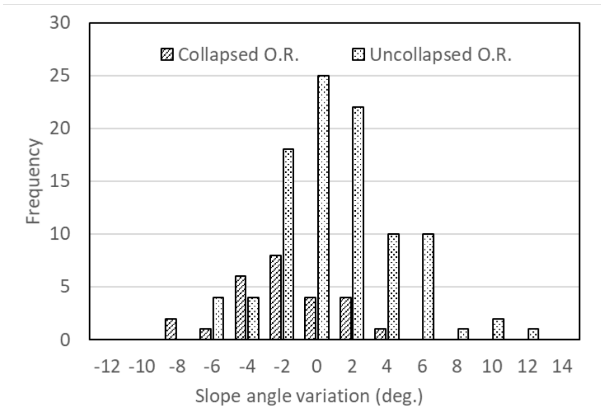

Fig.5. Distribution of slope angle variation for O.R.

3 COLLAPSED BEHAVIOUR OF MODEL SLOPE BY RAINFALL

Collapsed model slope tests by rainfall were carried out to understand the effects of slope angle variation.

3.1 Model slope and test condition

The sample used is decomposed granite soil with similar physical characteristic with a collapsed mountain stream in Hiroshima. The initial water content of model slope was adjusted the water content of the soil sampled at in-site. The model slope consists of upper slope with length of 70 cm and width of 30.5 cm, and lower slope with 60 cm of length, and 30.5 cm in width. Each slope angle can be changed arbitrarily. The changeable range is 20 – 40 degrees, respectively.

In the experiment, in order to measure the tilting angle of slope surface and the variation of pore pressure, the accelerometers and the pore pressure transducers were installed. The pore pressure transducers were setup on the slope bottom as P-1 to P-4, as shown in Fig. 6. The slope model was prepared by compaction method for sample with the water content so that the in-situ density was reached. The glass bead was set on the side of a block line during slope preparation as becoming markers of image analysis. Five accelerometers were installed on the upper slope surface as A-1~A-5, and one accelerometer for the lower slope surface was as A-6.

Pseudo-rain was given by spray nozzles with the water pressure supplied from a pomp. The uniform rain to the whole region of the model slope was adjusted by the nozzle type, the nozzles number and installation interval. The rain tested is the maximum hourly rainfall of 120 mm/hr of the day when the disaster occurred. Table 1 shows the slope conditions, collapse situation and collapse time of seven cases.

Table 1. Model tests condition and result

Case	Upper slope angle (deg.)	Lower slope angle (deg.)	Slope angle variation (deg.)	Collapse	Collapse time (s)
1 (30-20)	30	20	-10	None	-
2 (30-30)	30	30	0	None	-
3 (30-40)	30	40	10	Yes	1466.3
4 (35-20)	35	20	-15	Yes	1730.9
5 (35-30)	35	30	-5	Yes	1528.5
6 (35-40)	35	40	5	Yes	1082.6
7 (20-35)	20	35	15	None	-

3.2 Result for Case 4

The Case-4 result with the slope of the 35 degrees upper slope and a 20 degrees lower slope (steep and gentle slope) is shown in Figs. 7-10. Photos 1 and 2 indicate the slope model at the times of 60 s and 1730.9 s (collapse) after the pseudo-rain starts. The experiment did not appear to any cracks on the slope surface prior to collapse. The outflow of underground water was observed from the downstream end after 720 s passed. Fig. 7 shows the time history of pore water pressure at slope bottom. In time of 1730.9 s, collapse occurred near the No.2 and 3 blocks. The pore pressure of P-1 rises suddenly in 500 s and has reached 2.9 kPa just before collapse. The pressure of P-2, P-3, and P-4 began the rise in 930 s, 585 s and 790 s and rose to 0.60 kPa, 1.13 kPa and 0.75 kPa just before collapse respectively. The tilting angle measured by the accelerometers began to change from 60 s of rain start. Fig. 8 shows the time history of tilting angle at slope surface. Here, the tilting angle take a positive value when the slope surface tilts to the lower. The tilting angle of A-6 appeared to the direction of the upper. The tilting angle of A-1, A-4, and A-5 appeared to the direction of the lower. At 500 s of the time when the pore water pressure of P-1 increased rapidly, the surface tilt is clearly observed at A-1 to A-6.

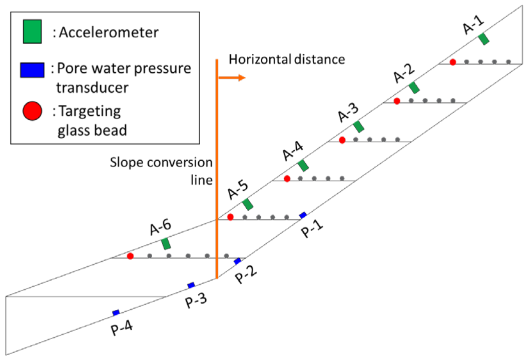

Fig. 6. Layout of accelerometers, pore water pressure transducers and target.

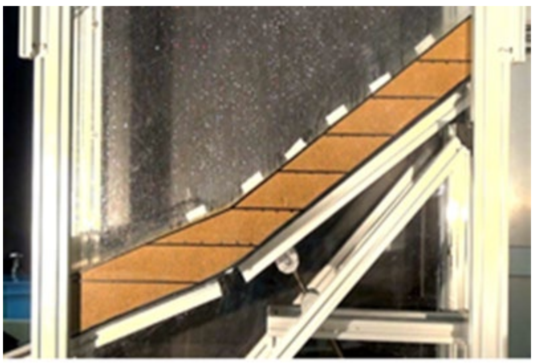

Photo 1. Overview of model slope at 60s of elapsed time.

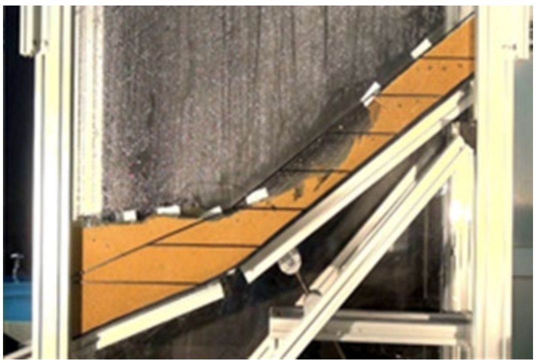

Photo 2. Overview of model slope at collapsed time.for case 4

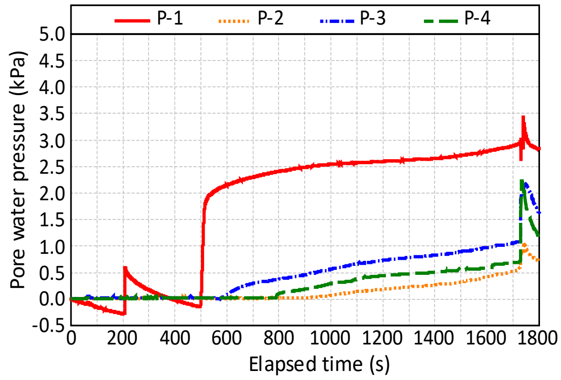

Fig. 7. Time history of pore water pressure transducers.

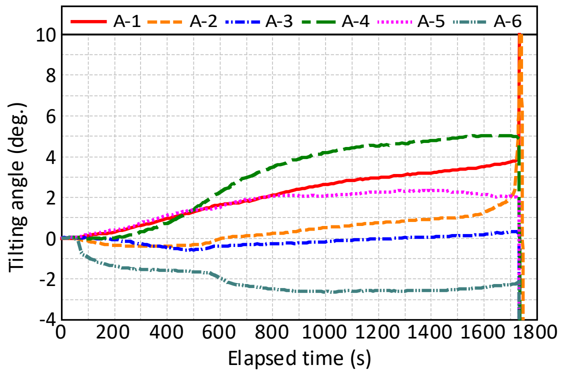

Fig. 8. Time history of tilting angle computed by accelerometers.

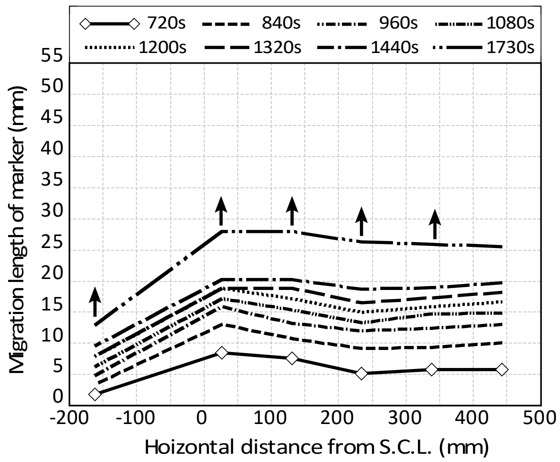

Fig. 9. Migration length for Case 4.

3.3 Effects of cross-sectional slope pattern

The migration length on the surface was drawn by image analysis in movement of the glass bead installed as markers. The installation position of the analyzed glass bead is given in Fig. 6. The horizontal distance from the conversion line of slope angle is used after this. As shown in Fig. 9, the migration length of marker is observed from 720s. The marker near the conversion line shows a greater movement. The lowest marker indicates smaller. In Case4, all marks other than the upper marker flowed out at the time of collapse.

Fig. 10 shows the migration length for all Cases at the elapsed time of about 1440s. The data of Case6 shows the result about time of collapse in 1080s of elapsed time. Collapsed cases were shown by the solid line and uncollapsed cases were drawn by the broken line. It is confirmed that four Cases with the slope of 35 degrees or more collapsed. Moreover, it is concluded that Cases with steap gentle slope tends to show more movement. This is understood by comparing Case4 (35-20) with Case7 (20-35) clearly.

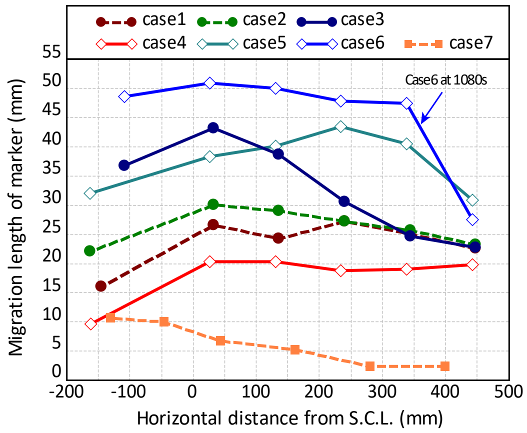

Fig. 10. Effects of cross-sectional slope pattern on migration length.

4 CONCLUSIONS

The paper described a series of examinations for understanding the topographical characteristics of the occurrence region (O.R.) of the debris flow generated at Hiroshima city in August 2014. The main factors of the collapsed O.R. were the slope angle and the catchment area for rainfall. Most of collapsed O.R. had the slope angle more than 33 degrees and the catchment area more than 2000 m^2. In the case of Hiroshima disaster, 84 % of the collapsed O.R. was satisfied by the two factors. Furthermore, the slope model tests showed that the third factor was the cross-sectional slope pattern which was characterised as the combination of steep upper and gentle lower slopes. This is that the O.R. with gentle lower slope (concave slope) tended to collapse than the reversed pattern.

ACKNOWLEDGEMENTS

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