Characteristics of Small-scale Slope Failure Occurrence Depending on Rainfall Pattern

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In 2011, the Kii Peninsula was hit by widespread large scale sediment-related disasters due to typhoon No. 12 (Talas) which is referred to herein as T1112. The typhoon resulted in rain for a long period with a record 1,808.5 mm in Kamikitayama-mura.

We created a distribution map of slope failures that occurred in Odai-cho and Mitsue-mura due to T1112, the spatial distribution was revealed by analysis of aerial photos. And we created isohyetal map using that data from the Mie Prefecture rainfall observatory to determine the difference in the rainfall distribution of the typhoon No.21 in 2004 which is referred to herein as T0421 and T1112 in Odai-cho. Small-scale slope failures due to local heavy rainfall usually occur around the rainfall peak, but if the rainfall is continuous, small-scale slope failures can occur after the peak rainfall. Small-scale slope failures due to long-term continuous rainfall are likely to encompass a larger collapse area than those due to local heavy rainfall.

Key words: 2011 typhoon No.12, aerial photo analysis, hearing, scale of landslide, occurrence timing

1. INTRODUCTION

In 2011, the Kii Peninsula was hit by a large and widespread sediment-related disaster due to the season's typhoon No. 12 (Talas), which is referred to herein as T1112. Figures-1 shows the rainfall situation in Odai-cho (Miyagawa Dam Observatory) and in Mitsue-mura (Tsuchiyahara Observatory).

T1112 initially developed at sea west of the Mariana Islands on 25 August, 2011. After slowly moving northward and strengthening, it made landfall in Shikoku at 10:00 on 3 September, and became extratropical cyclone in the Central Japan Sea at 15:00 5 September. The total precipitation from 17:00 August 30 was more than 1000 mm. A wide range of the Kii Peninsula was inundated; heavy rain continued for more than three days, and the total amount of rain associated with T1112 was two-thirds of the annual precipitation in Nara Mitsue-mura and Mie Odai-cho. T1112 resulted in 92 people missing or dead and 202 sediment-related disasters. The three prefectures of Mie, Nara, and Wakayama, had 56 people missing or dead and 101 sediment-related disasters (sediment disasters resulted in human suffering in all three prefectures).

In 2004, the No. 21 typhoon, which is hereafter referred to as T0421, resulted in many

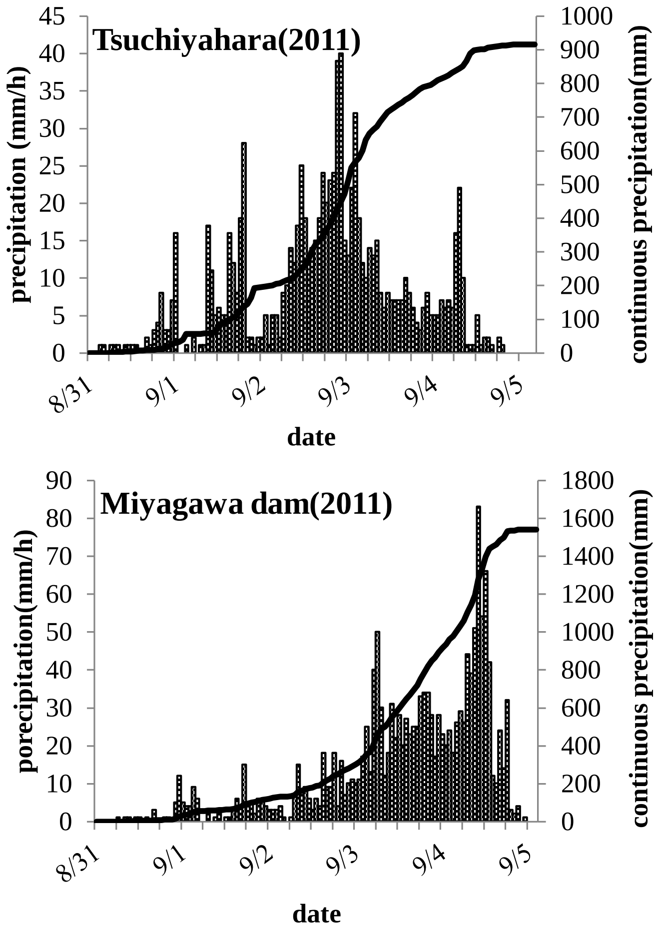

Fig-1. Actual situation of typhoon No.12 during August 30 to September 4, 2011(upper: Tsuchiyahara observation under: Miyagawa dam observation) sediment-related disasters and killed 6 in Odai-cho due to the associated heavy rain. T0421 formed at sea west-southwest of Guam at 3:00 21 September, and made landfall in Kyushu about 8:30 on 29 September. After passing Tohoku and Hokuriku, it became an extratropical cyclone off Sanriku at 12:00 on 30 September. Between 28 and 30 September 2004, the daily precipitation exceeded 100 mm/day in some locations in the Mie Prefecture, and on 29 September many areas had a daily rainfall total in excess of 500 mm. In particular, the typhoon concentrated heavy rain in Odai-cho where more than 800 mm of rain fell in 30 hours.

Most previous researches on shallow landslides focused on those due to by heavy rainfall (ex. *Shuin, et.al*, 2012, *Komata*, 2005 etc.). In addition a new method for predicting shallow landslides resulting from the rapid increase of the Normalized Soil Water Index with the long-term continuous rainfall, and from the gentle rise of the Normalized Soil Water Index by the heavy rainfall was proposed (*Saito et. al*, 2010). However, the relationship between rainfall type and scale of slope failure are little known. Few have examined the impact of long-term continuous rainfall. The characteristics of slope failure due to long-term continuous rainfall are examined by comparing small-scale slope failures due to T0421 to those due to T1112.

2. METHOD

Two places were set as study areas. One is immediately downstream of the Miyagawa Dam in the central region of Mie (Figure 2). The other is Mitsue-mura in the northeastern region of Nara pregecture.

2.1 Study area

The Miyagawa River is designated as a first class river by the Japanese government. It flows from Mt. Hinodegatake, which is the part of the Odaigahara range located in the southeastern part of the Kii Peninsula, into Ise Bay through the plains in the central part of the Mie Prefecture. Odai-cho is located in the most upper reaches of the Miyagawa River. The study area, which is 18.25 km from north to south, and 13.52 km from east to west, covers 132.8km^2 area. The study area includes from Miyagawa Dam to the junction of Miyagawa River and Kuritani River.

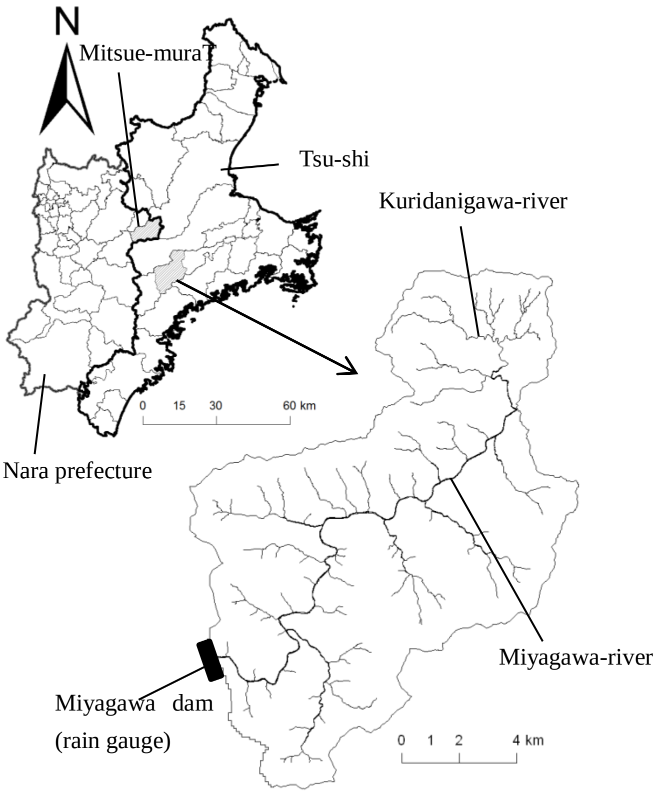

Fig-2 Study area

The northeastern part of the area is Sanbagawa Metamorphic Rocks. The Chichibu terrain constitutes the upper portion of the study area, and is sedimentary rock comprised mainly of sandstone, shale, etc. The Sanbagawa Metamorphic Rocks, which make up the lower portion, metamorphic rocks consist mainly of black schist. It is estimated that the Chichibu terrain was generated in the Jurassic-Cretaceous period, while the Sanbagawa Metamorphic Rocks, were generated in the Cretaceous period.

The highest elevation of the study area is the summit of Mt. Mayoidake (1,309 m), while the lowest elevation is the Miyagawa main stream (90 m). The average altitude is 496 m. In addition, the annual precipitation (Japan Meteorological Agency AMeDAS Miyagawa Observatory, 2001 - 2010) is 3,098 mm.

Mitsue-mura is located on the east end of the Nara Prefecture, which is in the central part of the Kii Peninsula, adjacent to Tsu-shi, Mie Prefecture (Figure-2). About 90% of the 79.63 km^2 is covered with forest (13.8 km from north to south). The Shorenji River, a class 1 river, flows from the Tsuchiyahara southern district in the northwest direction, but then turns north at Soni-mura.

Mitsue-mura contains Ryoke Metamorphic

Rocks, which are found in all districts except the Sugano District. The Sugano District contains Older Ryoke Granite. In addition, sedimentary rocks, which are estimated to have been deposited in the previous fiscal year to Middle Miocene, are distributed along the river channel.

The highest elevation of the study area is 1,235 m Mt. Mimuneyama, while the lowest elevation is 370 m east end of Mitsue-mura. In addition, the annual precipitation (Japan Meteorological Agency AMeDAS Tsuchiyahara Observatory, 2001 - 2010) is 1,700 mm, which is the average for all of Japan.

2.2 Method

To create a distribution map of slope failures that occurred in Odai-cho due to T1112, the spatial distribution was revealed by analysis of aerial photos taken by the Geographical Survey Institute. Slope failures with a collapsed area greater than 10,000 m^2 were defined as large-scale slope failure, whereas failures with collapsed areas less than 10,000 m^2 were defined as small-scale slope failure. Slope failure include both of small-scale slope failure and large-scale slope failure. Analysis of aerial photographs taken after T0421 by Nakanihon Air Service CO., LTD confirmed which the slope failure was pre-existing before T1112 or enlarged due to T1112.

Slope failures in Mitsue-mura were identified by analyzing aerial photographs provided by the Nara Prefectural Government. In the aerial photo analysis, there were some places that look like a landslide along the forest road and river channel were excluded, because they may be due to road collapse or river brank erosion.

The distribution map of the slope failure due to T1112 that was identified by aerial photo analysis was created using the ArcGIS9.3 software. Polygon data was created by tracing the shape of the slope failure on ArcGIS9.3 after importing the aerial photographs onto a computer. The distribution map of slope failures due to T0421 was created using the shape file data of *Kondo etc.al*. (2006).

To determine the difference in the rainfall distribution of T0421 and T1112 in Odai-cho, isohyetal maps were created using that data from the Mie Prefecture rainfall observatory (hourly precipitation of 24 points in the southern part of Mie). The isohyetal maps with the amount of hourly precipitation at the time slope failures occurred and cumulative rainfall were created by the Kuriking method by the Surfer7.0 software (Golden Software, Inc.).

Rainfall associated with the T0421 and T1112 was evaluated by the soil water index (SWI), which was obtained by indexing the accumulated amount of water in the ground using a three-stage tank model. The SWI is usually utilized as one of important index for the warning and evacuation from sediment-related disaster in Japan.

To estimate the time that a small-scale slope failure occurred in Odai-cho by T1112, interviews with local residents were carried out by visiting houses near where the aerial photographs indicated a slope failure. The occurrence time of small-scale slope failures was estimated in Mitsue-mura using the results of interviews by the Nara Prefectural Government in addition to those by the authors.

The time of slope failure in Odai-cho due to T0421 was determined using the results of *Kondo et al*. (2004), *Hayashi et al*. (2004), and *Kondo et al.* (2006).

On the basis of the aerial photographs and slope failure distribution maps, we visited actual sites and measured the small-scale slope failure. Specifically, we measured the collapse depth, length, and width using 2-m poles and a laser range finder at one location in Mitsue-mura and four in Odai-cho.

3. RESULTS

3.1 Characteristics of slope failure distribution

Figure -3, -4, -5 show the distribution of slope failures and isohyetal map in Odai-cho. Of the 51 locations identified in the aerial photographs due to T1112, 27 were new slope failures and 24 were enlarged slope failures. Three of 27 new collapses were large-scale slope failures. According to the *Kondo et.al* (2006), slope failures caused by T0421 were 1062 locations and large-scale slope failures were two of those.

The total area of slope failures due to T1112 was 192,825 m^2. The sum of the small-scale slope failure areas was 50,250 m^2 and the average collapse area of each small-scale slope failure was 1,047 m^2. The sum of the total slope failure area due to T0421 was 474,675 m^2, the total small-scale slope failures was 37,800 m^2, and the average collapse area of each small-scale slope failure was 357 m^2.

Small-scale slope failures occurred at three

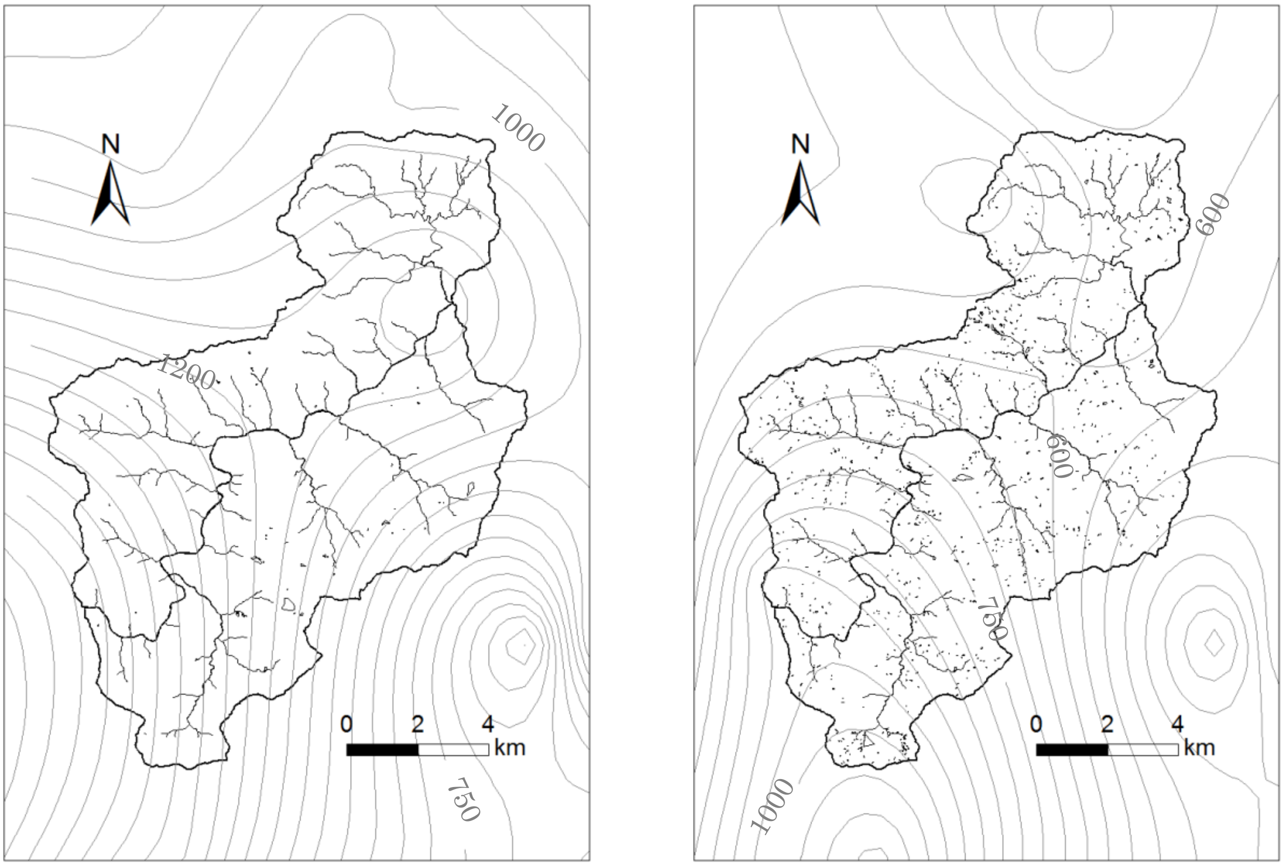

Fig-3. Distribution of slope failure caused by typhoon No.12 in 2011 (left) and typhoon No.21 in 2004 (right) shown on the isohyetal map (cumulative rainfall)

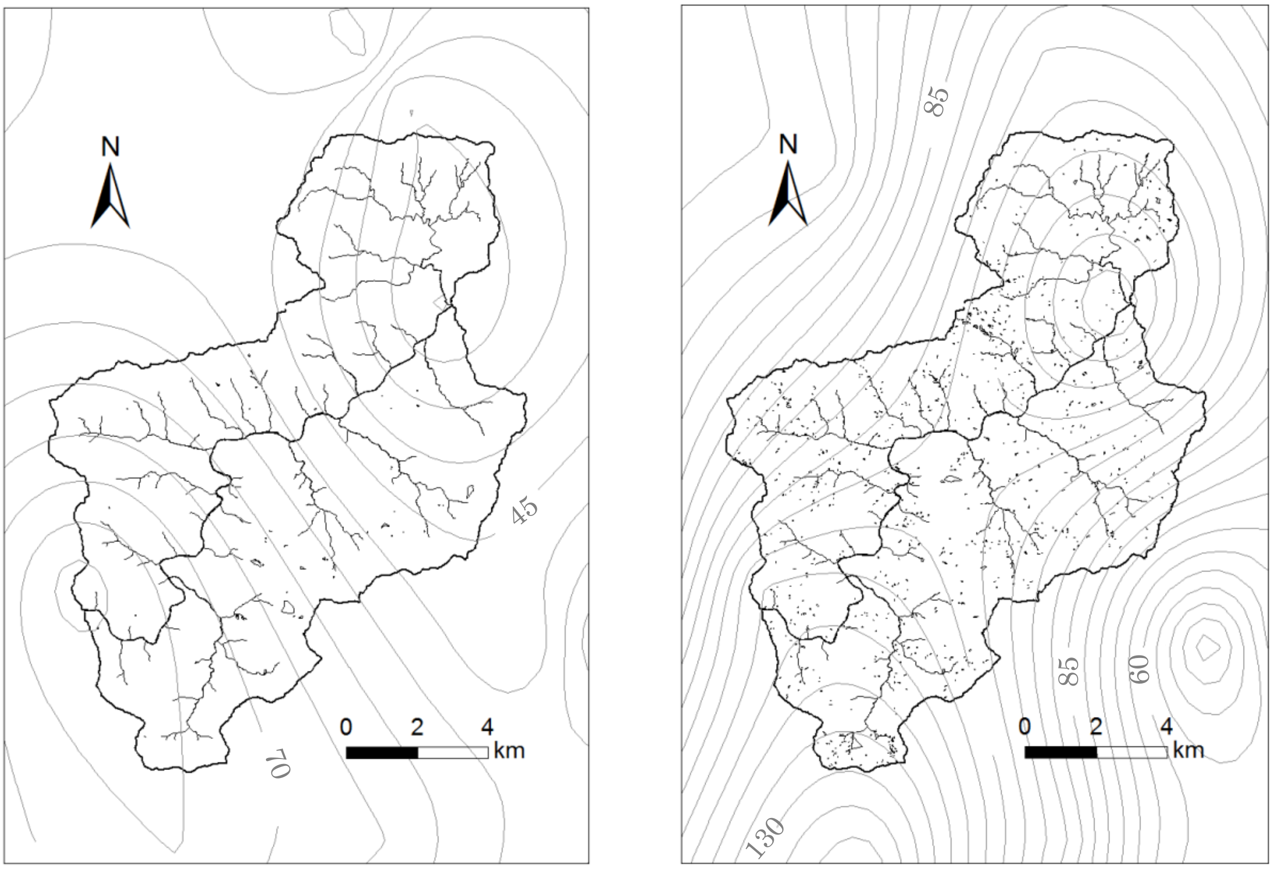

Fig-4. Distribution of slope failure caused by typhoon No.12 in 2011 (left) and typhoon No.21 in 2004 (right) shown on the isohyetal map (maximum hourly precipitation)

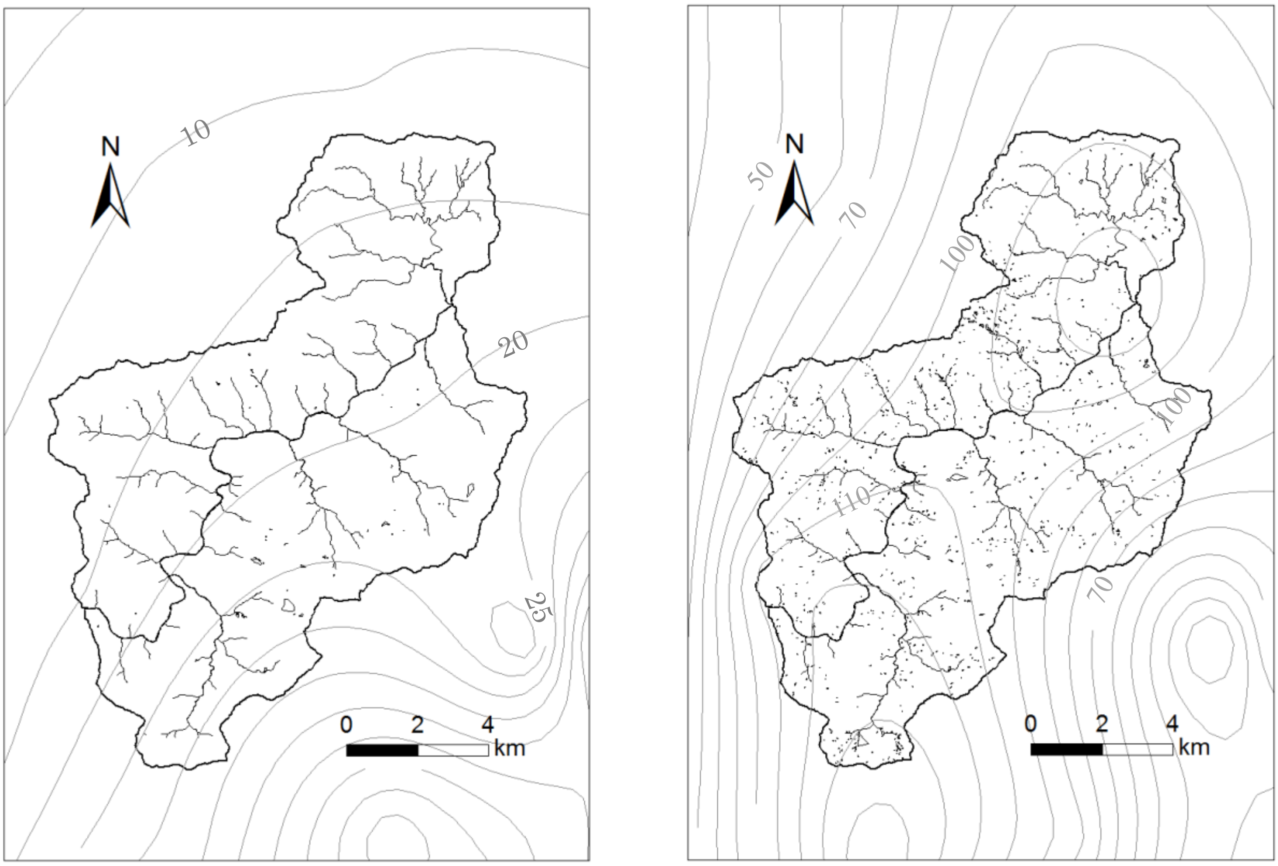

Fig-5. Distribution of slope failure caused by typhoon No.12 in 2011 (left) and typhoon No.21 in 2004 (right) shown on the isohyetal map (hourly precipitation at the time of small-scale slope failure occurrence)

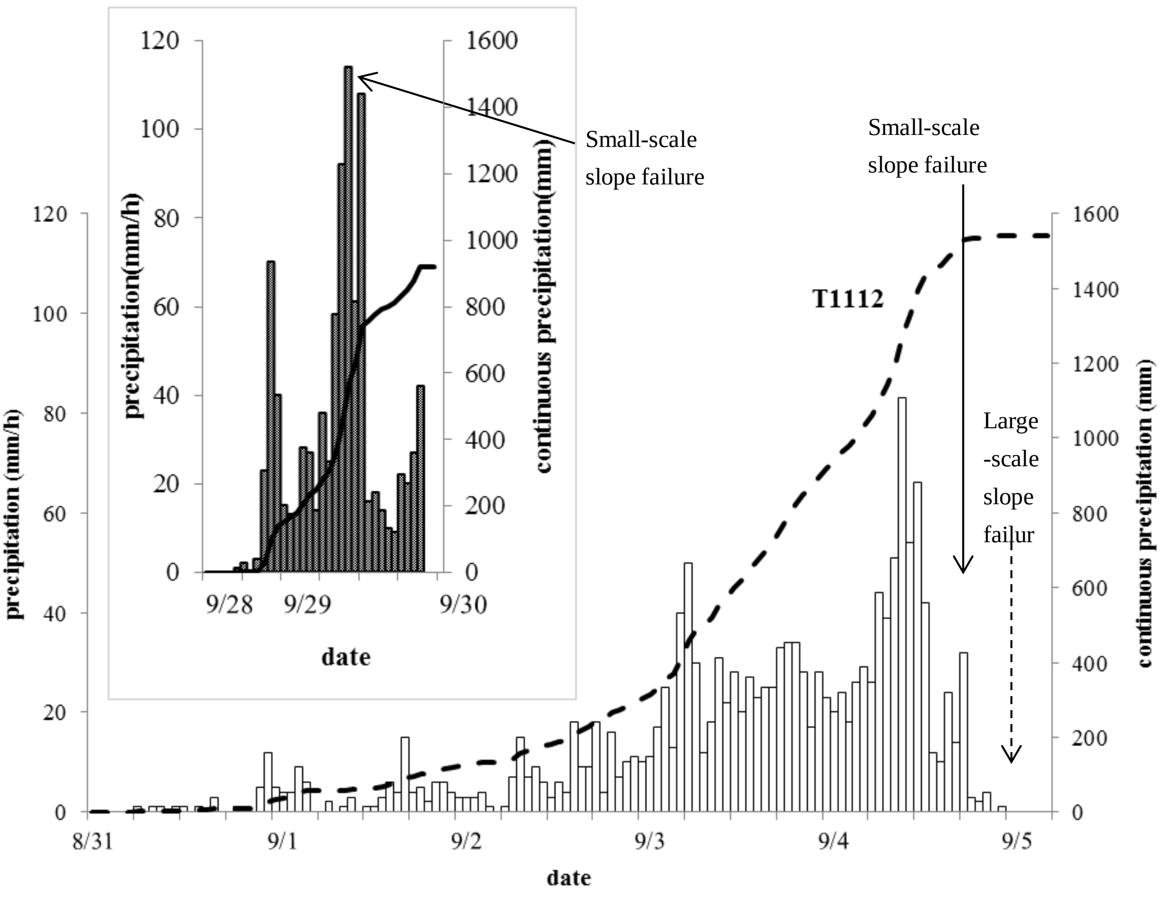

Fig- 6 rainfall situation of typhoon No.12 in 2011 and typhoon No.21 in 2004

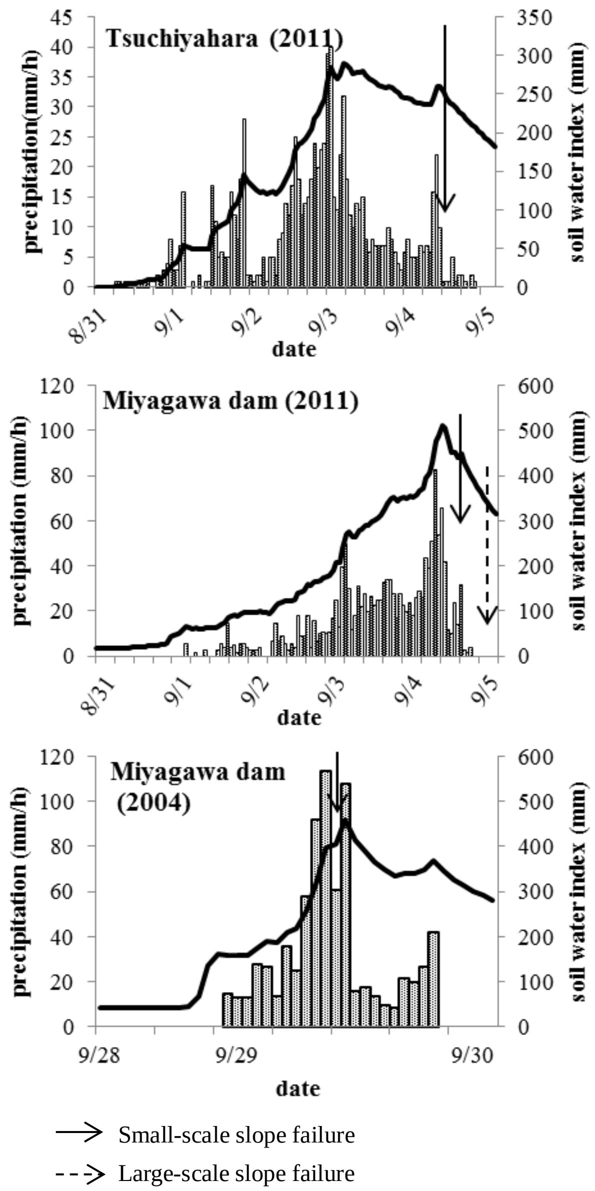

Fig-7. Value of Soil Water Index at the time of slope failures occurrence (upper: Tsuchiyahara in 2011, middle: Miyagawa dam in2011, under: Miyagawa dam in 2004)

locations in the Mitsune-mura, an average collapse area of those is 1,050 m^2.

3.2 Characteristic of rainfall

Figure -6 shows the rainfall situations in T0421 and T1112, where the arrows show the small-scale slope failure occurrence time based on the interviews with local residents. The data of the Mie prefectural government observatory (Miyagawa Dam) were used to create a diagram. A series of rainfall was defined as rainfall that was sandwiched between non-rainfall periods of 6 hours in this study.

The average hourly precipitation for heavy rain

Fig-8. Example of collapse depth of small-scale slope failure occurred in talus deposits in Miyagawa basin (taken on April, 28, 2013)

was more than 30 mm/h for more than 29 hours in Odai-cho as T0421 approached. Rainfall peaked at 114 mm/h at 10:00 on 29 September 2004, and the cumulative precipitation was 921 mm. Slope failure due to T0421 mostly occurred between 09:00 and 11:00 around 29 September. The rainfall intensity at this time was 61–114 mm, and the cumulative rainfall by 11:00 was 635 mm.

The rainfall associated with the T1112 was slightly heavier with an average of 13.5 mm/h rainfall for over 114 hours. The rainfall peaked at 83 mm/h at 07:00 on 4 September, which was about 30% that of T0421, but the cumulative precipitation was about 2.5 times greater than the rainfall associated with the T0421 (1541 mm). Small-scale slope failures by T1112 occurred between 12:00 and 14:00 on 4 September 2011. It was 5 hours after the rainfall peak. The rainfall intensity was 24 mm/h and the cumulative rainfall was 1,449 mm at 14:00.

Mitsue had a cumulative rainfall of 916 mm during 113 hours, and an average hourly precipitation was 7 mm. The highest hourly precipitation was 40 mm/h on September 2. Of the two places with a known time of occurrence, one occurred around the peak, while the other occurred during a small peak immediately after the peak when the hourly precipitation was 1 mm/h. In addition, according to the survey of the Nara Prefectural Government, some slope failures occurred five hours after the rainfall peak, and some occurred during rainfall of 10 mm/h in the southern to the central Nara Prefecture where variable slope failures occur frequently.

The SWI's at the time of small-scale slope failures due to T1112 were 450 mm in Odai-cho and 245mm in Mitsue-mura, and that by T0421 in Odai-cho was 398.6 mm (Figure-7).

The field survey indicated that the slope failure in Odai-cho had an average depth of 2 m and an average width of 13 m. In Mitsue-mura, the collapse depth was 1 m and the width was 23 m. A talus deposit was also observed. The measurement in Mitsue-mura was the reference value because the measurement was carried out in one place.

4. DISCUSSION

T1112 resulted in fewer small-scale slope failures compared to T0421. This may be due to the fact that there were fewer possible locations for slope failure because T0421 caused many slope failures eight years earlier. About 60% of the small-scale slope failures due to T0421 had a total collapse area less than 200 m^2. Although T1112 had fewer small-scale collapses, over 60% had a total collapse area less than 500 m^2 collapse, suggesting that slope failures were larger due to T1112. The geology in Mitsue-mura differed from that in Odai-cho, but the small-scale slope failures had larger collapse areas than Odai-cho in 2004. A field study revealed that collapse location is overlay by talus cone deposits, and the average collapse depth of the several small-scale slope failures may be deeper than usual surface failure of 2 m in Odai-cho (Figure-8). The timing of small-scale slope failure occurrences in T1112 was about 5 hours late from precipitation peak against these in T0421 was around precipitation peak.

The primary difference between T0421 and T1112 is the rainfall pattern (local heavy rainfall or long-term continuous rainfall). Although more data is necessary, it is speculated that the collapse scale due to T1112 is larger than that due to T0421 because T1112 resulted in long-term continuous rainfall and the rainwater was able to infiltrate deep into the ground, resulting in a relatively deep slope failure. In addition, it is guessed a part of the reason for that rainwater may infiltrates deeper in the ground is in talus cone deposits area. These may be also the reason of that SWI in T1112 is larger than it in T0421.

5. CONCLUSION

Small-scale slope failures due to local heavy rainfall usually occur around the rainfall peak, but if the rainfall is continuous, small-scale slope failures can occur after the peak rainfall. Small-scale slope failures due to long-term continuous rainfall are likely to cause a larger collapse than those due to local heavy rainfall.

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