

Sediment Disasters Caused by Typhoon No.14, 2005, in Miyazaki Prefecture

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Typhoon No.14 struck Japan in September, 2005, subjecting large areas to danger for many hours. The maximum hourly rainfall was not so great, but the total rainfall for 72 hours was > 500 mm in areas which suffered considerable damage. The typhoon caused 116 debris flows, 185 slope-collapses, and 30 landslides. Concerning human and building casualties, twenty-seven people were killed in Kagoshima, Miyazaki and Yamaguchi Prefecture, and two people went missing in Oita Prefecture. Additionally, 1,178 houses were completely destroyed and 3,692 houses were partly destroyed in Japan by the typhoon. These damages were due to comparatively heavy rainfall which continued for many hours. Large scale slope-collapses occurred in particular, around Miyazaki Prefecture due to heavy continuous rainfall (862 - 1,321mm).

Key Words: Sediment disaster, Typhoon No.14, Miyazaki Prefecture, Slope-collapse

1. OVERVIEW OF TYPHOON No.14

Typhoon No.14 was originated in the Mariana Islands on August 29th, 2005, and grew to full strength of 930 hPa (central pressure) with 50 m/s maximum wind speed by September 2nd (Fig. 1). Conspicuous characteristics of this typhoon included a very slow speed (10 - 15 km/h) and very wide storm area. The typhoon took 12 hours to pass from Makurazaki City in Kagoshima Prefecture to the Japan Sea in Yamaguchi Prefecture. Because of this path, a record rainfall occurred over the entire area on the east side of the Kyushu Mountain range. Particularly, 1,321 mm of rainfall from September 4th to 6th, 2005, in Nangou Village, Miyazaki Prefecture (Taniguchi et al., 2005).

It also rained heavily in some areas, including Ebino plateau in Ebino City (1,284 mm), Mitate in Hinokage Town (1,184 mm), and Mt.Wanitsuka in Tano Town (1,013mm). In addition, 1,451 mm of rainfall was recorded at Mt. Shimizu in Shiiba Village, Miyazaki Prefecture. The hyetographs at

Mikado and Mt. Wanitsuka are shown in Fig.2 and 3, respectively.

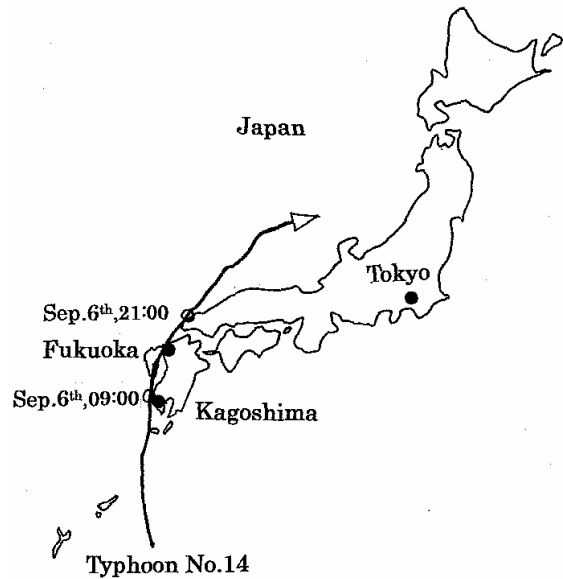


Fig. 1 The pathway of typhoon No.14 in 2005.

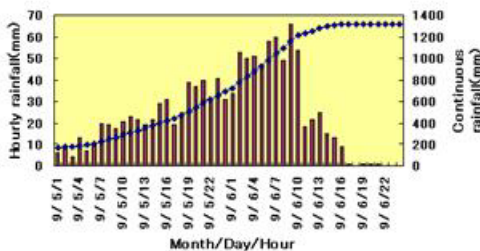


Fig. 2 A hyetograph at Mikado in Nangou Village.

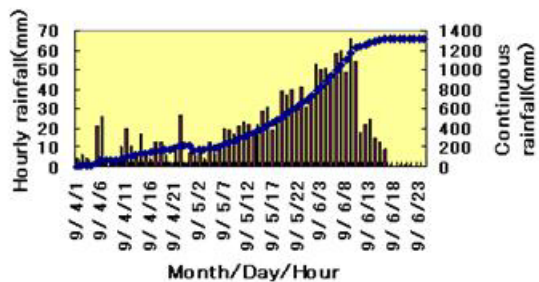


Fig. 3 A hyetograph at Mt. Wanitsuka in Tano Town.

Table 1 The total damage by typhoon No.14 in 2005 in Miyazaki Prefecture(million yen).

Matters	Civil engineering	Forestry	Agriculture	Fishery	Public facilities	Shopping stores
Money	64,718	31,448	16,213	1,713	6,990	5,750

Table 2 Damages caused by sediment disaster from typhoon No.14 in 2005.

	Number of incidents	Detail of damages				
		Number of dead people	Number of wounded people	Number of completely destroyed houses	Number of half destroyed houses	Number of partially destroyed houses
Debris flow	46	8	1	17	4	4
Landslide	17	2	0	1	0	1
Earth fall	61	1	0	16	4	16
Total	124	11	1	34	8	21

Table 3 Housing damage caused by flooding and sediment disasters.

	Complete destroy	Half destroy	Partial destroy	Flooded house above the floor	Flooded house under the floor
Number of houses	1,030	2,679	365	2,179	2,110

2. DAMAGE BY TYPHOON No.14

In momentary terms, the damages caused by typhoon No.14 totaled 130.3 billion yen according to an investigation by the Risk Management Bureau of Miyazaki Prefecture. This represents an extreme level of damage compared to disasters in Miyazaki Prefecture in recent years. The extent of damage in various sectors is shown in Table 1.

Damages to property and people based on the report by the Erosion Control Section of Miyazaki Prefecture are shown in Table 2. In addition to these sediment disasters, Miyazaki Prefecture also suffered from considerable flooding damages. Total housing damages are shown in Table 3.

3. RETURN PERIODS OF RAINFALLS DURING TYPHOON No.14

It is assumed that the slope-collapses in the areas around Miyazaki Prefecture's active volcano were influenced by the intensity of hourly rainfall. These slope-collapses may have been initiated by heavy short-term rainfall. There were very few collapses caused by typhoon No.14 in the areas around Kirishima Volcano in spite of high precipitation (total rainfall = 1,284 mm, daily rainfall = 639 mm). Conversely, the northern part of the prefecture was subjected to extremely great

daily or total rainfall.

Return periods of maximum hourly rainfalls, daily rainfalls and total rainfalls for the 3 day period in selected towns and villages are shown in Table 4.

4. DISTRIBUTION OF RAINFALL AND SLOPE-COLLAPSES BY TYPHOON No.14

The general consensus in Miyazaki Prefecture is that sediment disasters are largely associated with earthquakes, volcanic activity or the existence of faults and tectonic lines under equal precipitation (Taniguchi, 1997).

Large slope-collapses in Miyazaki Prefecture have been unevenly distributed until now, with many concentrated in the northern part of the prefecture. Therefore, northern villages and towns such as Shiiba, Nangou, Morotsuka, Saigo Village and Hinokage Town are very dangerous areas. All of these areas are located in or around a vast fault and tectonic line (the Butsuzo Tectonic Line and Nobeoka Thrust Fault). These areas had been formed in an older geological era and they are expected to be rather stable. However, they suffered from immense crust movement which occurred between the Palaeozoic and Tertiary periods and thus their respective bedrock was radically sheared.

The slope-collapses which occurred at Koba-Hazuware and Nonokubi in Shiiba Village, Nonoo and Shimado in Saigo Village and Mt.

Table 4 Return periods of hourly, daily and total rainfall in each heavily damaged area.

Area	Hourly rainfall Years(mm / hour)	Daily rainfall Years (mm / day)	Total rainfall Years(mm)
Nangou	82(628)	82(628)	120(1,321)
Morotsuka	43(468m)	43(468)	80(968)
Shiiba	36(459)	36(459)	150(862)
Saigo	66(511)	66(511)	120(942)
Takachiho	35(355)	35(355)	33(544)
Mt. Wanitsuka	26(388)	26(388)	350(1,013)

Wanitsuka in Tano Town during typhoon No.14 were all larger in scale compared to the ones which had occurred at Kashiba in Nangou Village in 1954, Tobinomoto in Nishimera Village in 1971, Nishiuchitate in Ebino City in 1972, and Yuzuriha in Saito City in 1982 (Miyazaki Prefecture, 2006). Except for Mt. Wanitsuka, all of these collapses occurred in or around the zone of the Butsozo Tectonic Line and Nobeoka Thrust Fault. This indicates that the collapses have a close connection with the large fault or tectonic line in addition to rainfall. The immense fault and tectonic line of Miyazaki Prefecture as well as sites of large slope-collapses caused by typhoon No.14 are shown in Fig. 4. Rainfall distribution and sites of slope-collapses during typhoon No.14 are shown in Fig. 5.

Four areas of heavy rainfall occurred in

Miyazaki Prefecture during the period from September 4th to 6th. Heavy rainfall was widespread in Nangou-Shiiba.

5. LARGE SLOPE-COLLAPSES IN THE FAULT AND TECTONIC LINE ZONES

Two large slope-collapses were caused by typhoon No.14 at Koba and Hazuware in Shiiba Village (Photo 1). Investigations by the Higashiusuki Agriculture and Forest Division of Miyazaki Prefecture found that the collapsed area of Koba was encompassed about 5 hectares and in Hazuware about 4.2 hectares. These areas are mainly underlain with sandstone and shale, which are extremely compressed and eroded. Talus accumulation is thick. Depths of these collapsed soil layers were estimated to reach 30 - 40 meters. Many fissures were found out on the earth surface around the scarp of the collapse in Koba. These fissures arose within a zone of 50 - 100 meters from the scarp. Therefore it is feared that this collapse may expand in the near future. The road which was used by school children before the collapse was completely demolished, thus making the safe transit of children to school a major problem for the community. According to one resident, this collapse might have occurred at about 07:30 on September 6th. The resident's neighbors did not notice that the land by their house had collapsed. The collapsed slope is composed of sandstone and shale.

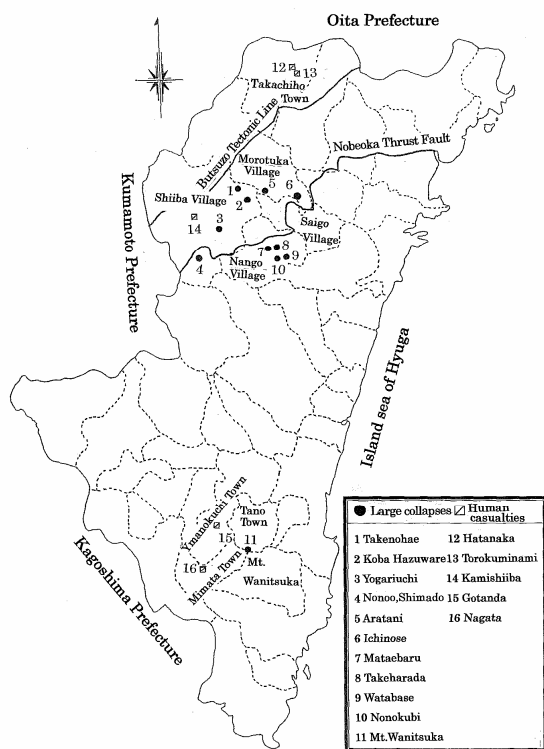


Fig. 4 Location of the immense fault and tectonic line and large slope collapses in Miyazaki Prefecture.

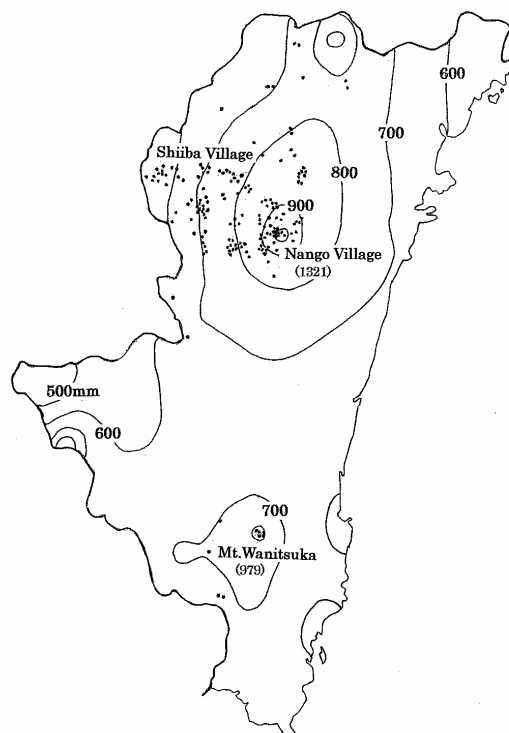


Fig. 5 Rainfall distribution and large slope collapses in Miyazaki Prefecture.



Photo 1 A large slope-collapse at Koba in Shiiba Village.



Photo 2 A scene of a large gully in the collapse at Koba.



Photo 3 The mark of a debris flow left in the Hazuware Torrent in Shiiba Village.



Photo 4 A large slope-collapse at Takenohae in Shiiba Village.

Excessively eroded mudstone layers were embedded in the soil layers and at some locations spring waters appeared. Some conspicuous gullies which were formed on the slope could be observed below springs. Excessively eroded mudstones are located in both sides of these gullies (Photo 2).

Springs still existed in some places on September 21st, 15 days after the typhoon. Flooding marks by the typhoon were seen in the gully (Photo 2). They were located at a height of about 2 meters above the stream bed. This indicates that a large amount of flooding occurred at the peak of the typhoon. Thus, an upsurge of spring water may have occurred then, as well. Some fissures were also noticed in this area 42 years ago, and a house which had been located there had already been moved to another place. The weathered sandstone, which the slope is comprised of, contains many vertical cracks. Additionally, a road with a hairpin curve located in the middle of the slope may have contributed to this collapse. Cracks in the sandstone layer would allow the deep infiltration of surface water run-off from the road into the soil layer near the hairpin curve during the storm. The collapsed soil mass was completely converted into a debris flow and ran up to a height

of 25 meters above the stream bed on the opposite side of the Hazuware Torrent. The debris flow partly destroyed two check dams in the Hazuware Torrent and moved into the Mimikawa River after that. Judging from marks of the debris flow shown in Photo 3, it was about 40 meters wide and 20 meters deep. However, most of the debris flow was caught, reducing its force and radically changing the course of its flow to the left by way of aforementioned check dams. Thus, a house which stood on the right bank of the torrent below the dams was saved from the disaster.

Another debris flow occurred at Takenohae in Shiiba Village. It completely destroyed and washed the 10- m long Nakahata Bridge, indicating that the debris flow had great intensity. The debris flow crashed against the slope on the opposite side of the river, causing a large slope-collapse there (Photo 4).

The high flood point shows that the debris flow might temporarily dam the Mimikawa River. The cross section of the debris flow was 20 meters wide and 7 meters deep. A debris flow also occurred at Yogariuchi in Shiiba Village, and the ground collapsed underneath where a factory stood. Its factory slipped 30 meters down to the bottom of the Yumiki Torrent and it was completely washed away.



Photo 5 A large slope-collapse at Nonoo in Saigo Village.



Photo 6 Mark of a landslide dam at Nonoo in Saigo Village.

The slope-collapses temporarily isolated Shiiba Village.

A large slope-collapse also occurred at Nonoo in Saigo Village (Photo 5). This collapse may be attributed to the following causes: pore water pressure accretion in the talus accumulation layer and erosion of the foot of the slope (composed of eroded sandstone about 40 meters thick) by the flood water. In fact, the water level in the Mimikawa River was 2 - 3 times as high as in the usual flooding during typhoon No.14. The time of the collapse occurrence was at 21:49 on September 6th. An observation by the National Research Institute for Earth Science and Disaster Prevention which makes seismological observations certified that their seismograph caught an earthquake caused by this collapse at 21:49. Connected to this event, there was the fact that a resident had seen three cracks on the slope at about 16:00 on September 6th.

The river was temporarily blocked by a collapsed soil mass which had formed a landslide dam. As evidenced by the dam, the flooding mark shown in Photo 6 was found at a height of 15 meters above the channel bed. This landslide dam was further evidenced by the fact that a water level gauging of Yamasubaru dam which is located about 6 kilometers downstream from there dropped abruptly after the event. Another large slope-collapse occurred at Shimado close to Nonoo. Some new fissures were found after the collapse, located within an area of several hundred meters from the scarp. The community surrounded by these fissures indicated the possibility of a future collapse.

The common characteristics of these large slope-collapses are summarized as followings: longitudinal slope profiles near the river side are steep while the upper parts are rather moderate, and the foot of the slope, which is just on the outside bend of the stream, is extremely eroded and



Photo 7 One of houses averted from a debris flow owing to a check dam.

undercut by flooding. Thus, the slope becomes unstable at its foot.

In spite of many slope-collapses during a record-breaking storm (1,321 mm in 3 days), there were not any casualties in Nangou Village except for damages related to civil engineering facilities. This is attributed to the fact that Nangou Village is on a more moderate grade than Shiiba Village in Miyazaki Prefecture. Nangou Village has a larger plain compared with Shiiba Village. This is why there were few human casualties in Nangou Village.

Additionally, many erosion check dams have been constructed to control sediment discharge. Thus, casualties related to sediment disasters have been often prevented owing to these check dams. In fact, the Mataebaru check dam protected residents during typhoon No.14 (Photo 7).

However, Noji Bridge, located on a path through the forest, which links Ume Town in Oita Prefecture with Suki Village in Miyazaki Prefecture, was destroyed by a debris flow which occurred at Kumaji in Nangou Village. The base of this bridge was displaced downstream about 1 meter by this debris flow. A large amount of collapsed soil mass still remains as unstable sediment in the stream. These sediments could easily move again during



Photo 8 A large slope-collapse in the basin of the Byutano River at Mt. Wanitsuka.

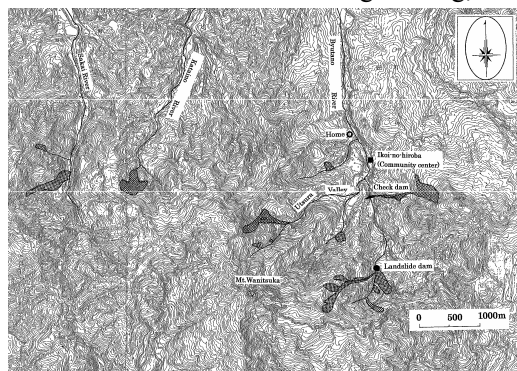


Fig. 6 Sites of large slope-collapses at Mt. Wanitsuka. Each mark(●) shows the sites of these collapses.

Table 5 Amount of collapsed soil mass and unstable sediment deposit in each stream.

River	Amount of collapsed soil mass (m ³)	Amount of residual sediment (m ³)	Unstable sediment deposit (m ³)
Byutano R.	3,826,380	2,174,740	1,640,290
Kataino R.	965,580	513,820	449,580
Sakai R.	1,468,650	508,420	505,170

heavy rains. Most of these collapsed soil masses caused by typhoon No.14 in Nangou Village were converted into debris flows, thus increasing the travel distances and flooding areas.

6. LARGE SLOPE-COLLAPSES AT Mt. WANITSUKA

6.1 Geological characteristics of Mt. Wanitsuka

Large slope-collapses shown in Fig. 6 occurred at Mt. Wanitsuka in Tano Town, Miyazaki Prefecture on September 6th, 2005. Mt. Wanitsuka consists of sandstone and shale. These strata originated on the bottom of the Sea of Hyuga in the Tertiary period and they gradually thrust upwards to form land (Miyazaki Prefecture, 1978).

Because of their tectonic background (geology), collapses which arose here in the past conceptually belong to another type compared to those in the northern part of the prefecture. According to a field survey, many stones with glassy surfaces were found, indicating that faulting or deep layer sliding has been occurring since time immemorial. This indicates that landslides have often occurred in the geological Hyuga group layers, and these geological factors may be associated with the collapses.

6.2 Outline of collapses on Mt. Wanitsuka

There are three rivers on the north flank of Mt. Wanitsuka: the Byutano River (drainage area = 15.2 km², mean bed slope = 1/10), the Kataino River (area = 7.8 km², slope = 1/11), and the Sakai River (area = 6.6 km², slope = 1/8). Large slope-collapses

were caused by typhoon No.14 on September 6th, 2005, and large debris flows followed. The sites of these large collapses are shown in Fig. 6. Another large collapse occurred along the south flank of Mt. Wanitsuka in the Hiroto River basin.

A resident living beside the Byutano River (Fig. 6) mentioned that stones were rolling down through the river around 07:00, but this sound stopped at about 08:30 and a stoppage of electric current happened at about 09:00. He saw trees swinging violently along the river at that time. It can be assumed that the river must have been blocked by the collapsed soil masses at about 09:00 and the debris flow followed. This scenario is consistent with the peak precipitation during the typhoon. One of large slope-collapses at Mt. Wanitsuka is shown in Photo 8.

Based on the report of Miyazaki Prefecture, the amount of collapsed soil mass, residual sediment on the slope and unstable sediment deposited in the stream are shown in Table 5 (Miyazaki Prefecture, 2006).

An equivalent friction coefficient of a debris flow is expressed as follows.

$$f = H / L \quad (1)$$

where f is the equivalent friction coefficient, H is the vertical length of a travel distance, and L is the horizontal length. An equivalent friction coefficient calculated from the debris flow of the Byutano River from the equation (1) was 0.14. This is close to the value of 0.13 which was the value of the Denjo River in Nagano Prefecture (volume = 3×10^7 m³). It has been verified that a friction coefficient of a debris flow is inversely proportional

Table 6 Velocity and discharge of debris flow in each river at Mt. Wanitsuka.

River	Velocity (m/s)	Discharge (m ³ /s)
Byutano R. (main stream)	6.4 - 8.3	600 - 700
Kataino R. (tributary)	5.7 - 9.0	320 - 550
Kataino R.	8.3 - 9.7	600 - 1,000
Sakai R.	5.8 - 7.1	700 - 800

to the enlargement of its scale due to the observed results (Okunishi, 1976).

An extremely large slope-collapse occurred in the basin of the Byutano River and a landslide dam was formed by this collapse (Fig. 6). Field surveys by the Miyazaki Forest Management Office indicate that the height of the landslide dam was 18 meters, the length of its slope from the crest to the foot was 60 meters, and its slope gradient was 17 degrees. Tests on the soil samples collected from the dam 5 days after the occurrence of the collapse indicated that soil hardness was 0.85 kgf/cm², void ratio of it was 63.5%, and the coefficient of its permeability was 6.9×10^{-3} cm/s. Sediment deposits in the dam were very watery. A potential crisis of flood levee failure of the dam was averted because a channel for drainage was excavated along the left side. Sediment in the stream bed of the Byutano River was also rather fluid 22 days after the debris flow occurrence. The percentage of water content was 17.5% on September 28th, indicating that the sediment deposit was still in a dangerous state for the occurrence of a debris flow. A grate amount of wood transported by the debris flow was deposited into the Byutano River just after the debris flow occurrence, but was soon removed.

6.3 Velocity and discharge of the debris flow

Manning's Law or regime theory can be applied to estimate the velocity and discharge of the debris flow (Ikeya, 2004).

$$V = (1/n) R^{2/3} I^{1/2} \quad (2)$$

$$B = \alpha Q^{1/2} \quad (3)$$

where V is the velocity, n is the roughness coefficient, R is the hydraulic radius, I is the stream bed gradient, B is the width of the cross section, Q is the discharge, α is the coefficient. Cross section widths of the debris flow, gradients of the stream bed, and high water marks by the debris flow were measured in the Byutano River. Using these observations, cross-sectional areas of the flow were calculated at every point. Cross sections were assumed to be triangular in shape, and the values of n and α were assumed to be 0.05, which was the roughness coefficient of the debris flow at Minamata on July 20th, 2003, and 3, respectively. Substituting these values into the equations (2) and (3), the velocity and volume of various debris flow

discharges at Mt. Wanitsuka were calculated (Table 6). These values were independently derived from the equations (2) and (3) and are within the same range except for those of the Kataino River. These calculated values show that the debris flows at Mt. Wanitsuka were on a very large scale, judging from the fact that the discharge of the debris flow at Minamata was 769 m³/s (Kumamoto Prefecture, 2004).

7 . CHARACTERISTICS OF HUMAN CASUALTIES BY TYPHOON No.14

Five casualties occurred during typhoon No.14 in 2005 in Miyazaki Prefecture. One death occurred in Yamanokuchi Town, two deaths in Mimata Town, three deaths in Shiiba Village, and five deaths in Takachiho Town. A total of 11 people were killed by these disasters. Sites of these casualties are shown in Fig. 4. Characteristics of these casualties are as follows: distances between the points of collapses and the stricken homes were very short, evacuation was not sufficient, most of victims were elderly (64.4 years old on average), scales of all slope-collapses were small, and calamities occurred at dawn or noon.

The slope-collapse happened at Nagata in Mimata Town at about 15:00 on September 6th, 2005, 15 hours after the peak of rainfall (Photo 9). This slope-collapse was 15 meters high and 30 meters wide in a shirasu layer (volcanic ash) with a slope gradient of 35 - 40 degrees. Rainfall intensity of 20 - 27 mm/h continued for 5 hours from 07:00 to 11:00. Likely this sequence of rainfall must have caused the slope failure, because a large amount of water seeped into the slope, causing the weight of the soil layer to increase substantially. A retaining wall for collapse prevention had already been constructed at the foot of the slope behind the damaged house. However, the collapsed soil mass ran over the retaining wall and destroyed the home. Two people were killed by this slope-collapse.

A slope-collapse occurred at Gotanda in Yamanokuchi Town on September 6th, and one person was killed. The hill slope is underlain by welted tuff and shirasu. A large V-shape gully emerged after the collapse. A large amount of water must have seeped into the shirasu layer during the

rainfall causing pore water pressure to rise and triggering slope-collapse. The collapsed soil mass was converted into a debris flow and ran over the national road (Route 269) into the Higashitake River. Based on this observation, it is assumed that the soil mass had already been incorporated a large amount of water before slope-collapse occurred. Thus, the slope-collapse became a debris flow within a travel distance of about 100 meters.

Two incidents of casualties took place in Takachiho Town. One person was killed by a slope-collapse at Hatanaka and 4 people were killed by a debris flow at Torokuminami. The former was a talus slope-collapse which had previously been used as farmland. Several rills etched on the earth surface were found along the right side of the relin-quished farmland, indicating a lot of water had seeped into the talus during the heavy rain. Another slope-collapse occurred at the head of the small stream at Torokuminami (Photo 10). This was the largest of collapses related to casualties by typhoon No.14 in Miyazaki Prefecture.

This slope was composed of volcanic ash and talus accumulation, and has a gradient of 30 - 35 degrees. The soil hardness was 3 - 4 kgf/cm² and 0.5 - 0.7 kgf/cm² for volcanic ash and talus, respectively.

A great amount of water must have percolated into the talus accumulation layer which was located above an aquiclude of the volcanic ash layer during heavy rainfall. This stream is perennial, and flood discharge during the heavy rainfall would be fed in great amount to the collapsed soil mass. Thus, the soil mass was converted into a debris flow while running through the channel and then struck a house located about 300 meters downstream from the head of the stream. Nevertheless, the entire soil mass did not liquefy, because a portion was still plasticized.

Three people were killed at Kamishiiba in Shiiba Village by a debris flow which rose up at the foot of a retaining wall along a prefectural road (Photo 11). The slope consists of talus and eroded sandstone. It is assumed that talus accumulation must flow along the boundary between the underlying sandstone layers. Some instability was apparent along this road. There was a crack along the left shoulder of the road, and the guardrail had already subsided about 30 centimeters prior to the collapse. It is believed that a lot of water must have seeped into the talus accumulation layer through this crack during heavy rainfall. This was evidenced by the appearance of spring water on the slope. However, residents of this area believed that it was absolutely safe, because no disasters had occurred in the past 800 years. However, a debris flow occurred in 2004 in a neighboring stream which

was very close to this collapse and an agricultural storehouse was damaged. This indicates that few places in Shiiba Village are completely safe.

8. CONCLUSION

Many extremely large slope-collapses were caused by typhoon No.14 in 2005 in Miyazaki Prefecture and total of 11 people were killed. The volume of individual collapses ranged 105 - 106m³. However, it was fortunate that there were not any



Photo 9 A slope-collapse at Nagata, Mimata Town.



Photo 10 A debris flow at Torokuminami, Takachiho Town.



Photo 11 A debris flow at Kamishiiba, Shiiba Village.

casualties resulting from these large collapses, since

they occurred in sparsely populated and mountainous areas. However, Shiiba Village was quite isolated for a while because of these disasters caused by typhoon No.14. Results of surveys after the sediment disasters indicated that northern part of Miyazaki Prefecture is likely susceptible to the occurrence of large slope-collapses compared with other areas. In addition, it was found that the same attention as the north (the Butsuzo Tectonic Line and Nobeoka Thrust Fault) should be paid to the latent dangerousness of the occurrence of a large slope-collapse in Hyuga strata of the south of the prefecture.

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