GEODISASTERS IN KYUSHU AREA CAUSED BY TYPHOON NO. 14 IN SEPTEMBER 2005

MITSUHIRO SEZAKIⁱ⁾, RYOSUKE KITAMURAⁱⁱ⁾, NORIYUKI YASUFUKUⁱⁱⁱ⁾, AKIHIRO HIROOKA^{iv)},
HIDETOSHI OCHIAIⁱⁱⁱ⁾, HIROSHI YOKOTAⁱ⁾, SHIGEKI SAWAYAMA^{v)},
HIROMI IMANISHI^{vi)} and KAZUHARU MATSUMOTO^{vii)}

ABSTRACT

Typhoon No. 14 moved along the west coast of Kyushu from 4th to 7th September 2005 and caused severe damages at many locations mainly in Miyazaki-prefecture, Kagoshima prefecture and Oita prefecture. This typhoon moved at a very slow speed of travel varying from 25 km/h to 30 km/h in Kyushu area and this caused successive formation of strong clouds for a long time in the east side of the Kyushu Mountain Region which exists on the right side to the direction of this typhoon. According to AMeDAS data, the rainfall at Osumi in Kagoshima prefecture exceeded 900 mm and at Mikado in Miyazaki prefecture exceeded 1300 mm since the beginning of the rainfall. This typhoon is characterized by heavy rains and many places in the south and east of Kyushu have exceeded the maximum record of rainfall. Flood disaster hit many places along the Oyodo River and Gokase River including their tributaries and more than 6000 houses suffered from inundation above floor. Geodisasters also occurred at many places due to this typhoon and 22 lives were lost and some villages had been isolated for a long time. In this paper, the mechanisms of slope failure observed in the geodisasters in Kyushu area caused by Typhoon No. 14 in September 2005 are mainly outlined in relation to the rainfall characteristics and geological and soil mechanical aspects.

Key words: debris flow, heavy rainfall, slope failure, typhoon, volcanic ash soils (IGC: B5/D4/E6)

INTRODUCTION

As shown in Fig. 1, Typhoon No. 14 moved along the west coast of Kyushu from 4th to 7th, September 2005 and caused severe damage at many locations mainly in Miyazaki-prefecture, Kagoshima prefecture and Oita prefecture. This typhoon is characterized by heavy rains because of the typhoon's slow speed of travel varying from 25 km/h to 30 km/h. This slow movement of typhoon in Kyushu area caused successive formation of strong clouds for a long time in the east side of the Kyushu Mountain Region which exists on the right side to the direction of this typhoon. According to AMeDAS data the rainfall at Osumi in Kagoshima prefecture exceeded 900 mm and at Mikado in Miyazaki prefecture exceeded 1300 mm since the beginning of rainfall. Damages caused by this typhoon are summarized in Table 1 comprising of loss of human lives, damage to houses and other properties in whole of Japan, Kyushu area and Miyazaki prefecture. These statistics indicate

Fig. 1. Track of Typhoon No. 14, 2005

that 70–90 percent of damages due to this typhoon occurred in Kyushu area and that the affected areas were concentrated in Miyazaki prefecture where the rainfall

i) Miyazaki University, Japan.

ii) Kagoshima University, Japan.

iii) Kyushu University, Japan (yasufuku@civil.kyushu-u.ac.jp).

iv) Kyushu Institute of Technology, Japan.

v) Geological Investigation Association in Miyazaki Prefecture, Japan.

vi) Civil Construction Department in Miyazaki Prefecture, Japan.

vii) Kiso-Giban Consultants Co., Japan.

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at many locations had exceeded the maximum record.

While Typhoon causes not only geodisaster but also flood disaster and traffic closure, including power failure and suspension of the water supply, Typhoon No. 14 can be mainly characterized by the severity of geodisaster.

Table 1. Summary of damage caused by Typhoon No. 14, 2005

Damage		JAPAN	Kyushu area	Miyazaki prefecture
Human damage	Dead or missing	29	22	13
	Severe injury	45	21	5
	Minor injury	134	67	21
Housing damage	Completely destroyed	1,178	1,164	1,104
	Halfly destroyed	3,504	3,351	3,284
	Partially destroyed	2,770	2,522	331
	Inundation above floor	7,626	2,083	1,462
	Inundation below floor	13,534	5,647	2,919
Non-housing damage	Public structures	150	90	71
	Others	2,354	871	446

The reason is that 22 lives were lost in geodisasters from among 29 victims who were dead or missing in this typhoon in the whole of Japan. Damages by the geodisaster due to Typhoon No. 14 are summarized in Table 2 for each prefecture, in Kyushu area and in Japan on the basis of reference. We can conclude that most human losses and 90 percent of the number of housing damage due to the geodisasters caused by Typhoon No. 14 occurred in Kyushu area, in comparison with other areas the damage rate in Kyushu area is higher in the severe damage category such as “completely destroyed”. It is no doubt that extremely heavy and long rain was the primary exogenous factor of geodisaster since most damages occurred in Miyazaki, Kagoshima and Oita prefectures where heavy and long rainfall was observed.

Figure 2 shows some geodisaster sites due to Typhoon No. 14 with a focus on the sites where heavy human losses occurred or a massive landslide was observed. In Tarumizu city of Kagoshima prefecture, debris flow occurred and the lives of 3 elders were lost at Shinjo-Otani district and the earth flow claimed one life and the debris flow killed an elder at Shinmido district. It is a

Table 2. Summary of damage caused by geological hazard

Region	Type	Number of cases	Human damage			Housing damage		
			Dead	Missing	Injury	Completely destroyed	Halfly destroyed	Partially destroyed
Fukuoka	Earth flow	1	0	0	0	0	0	1
Nagasaki	Debris flow	1	0	0	0	0	0	0
	Earth flow	1	0	0	0	0	0	0
Kumamoto	Debris flow	26	0	0	0	1	1	3
	Earth flow	5	0	0	0	0	1	0
Oita	Debris flow	4	0	3	0	1	1	1
	Earth flow	20	0	0	0	0	1	11
	Landslide	5	0	0	0	1	2	1
Miyazaki	Debris flow	48	7	0	1	16	4	5
	Earth flow	73	2	0	1	20	5	21
	Landslide	17	2	0	0	1	0	2
Kagoshima	Debris flow	19	4	0	0	26	3	2
	Earth flow	40	1	0	0	8	7	11
	Landslide	1	0	0	0	0	0	0
Kyushu	Debris flow	98	11	3	1	44	9	11
	Earth flow	140	3	0	1	28	14	44
	Landslide	23	2	0	0	2	2	3
	Total	261	16	3	2	74	25	58
JAPAN	Debris flow	122	11	3	1	45	10	15
	Earth flow	200	3	0	1	33	15	63
	Landslide	30	5	0	1	4	3	3
	Total	352	19	3	3	82	28	81

Fig. 2. Typical geological disaster sites by Typhoon No. 14

pity that these three human losses were caused even in the designated geological hazard areas that had an evacuation advisory. In Miyazaki prefecture, the landslide carried away 2 elderly persons at Kitamorokata-gun Mimata-cho Kiriyoze district and the earth flow took one life at Kitamorokata-gun Yamanokuchi-cho Gotanda district. 3 elderly lives were lost by the debris flow at Higashiusuki-gun Shiiba-son Kamishiiba district and in Nishiusuki-gun Takachiho-cho the debris flow claimed the lives of 4 elderly persons at Torokuminami district and the earth flow killed one at Toroku district. These human losses also occurred in the designated geological hazard area even though the residents were told or ordered to evacuate their homes except in Mimata-cho. In Miyazaki prefecture many massive landslides were observed, for example, near the upstream of Hiroto Dam in Minaminaka-gun Kitago-cho, Mount Waniduka in Miyazaki-gun Tano-cho, the downstream of Tsukabaru Dam in Higashiusuki-gun Saigo-son and the upstream of Iwayato Dam in Higashiusuki-gun Shiiba-son. In some places massive landslide movements have formed natural dams. And we are concerned that this would cause secondary disasters and quite a few districts were isolated due to traffic closure for a while after Typhoon No. 14 passed. In Oita prefecture two elder persons at Ogi-machi Minamikawauchi district in Taketa city and an elder person at Yufuin-cho Shimoyunohira were missing as a result of the debris flows. The residents were told to evacuate their home in neither of two districts.

We can not stop these damages mentioned above because they were triggered by natural phenomenon but we can mitigate damage, especially human losses by investigating past geodisasters in detail and from various directions. In this paper, the generation status and features of the geodisasters in Miyazaki prefecture and Kagoshima prefecture were mainly outlined in relation to

Table 3. Severe geological disaster sites in Kyushu area

Prefecture	Number	Site
Kagoshima	①	Tarumizu-shi Shinmido Uenomiya Dai 2 Ogawa
	②	Tarumizu-shi O-aza Sinjo Otani Dai 1 Ogawa
	③	Tarumizu-shi Shinmido Uenomiya 6 chiku
Miyazaki	④	Kitamorokata-gun Mimata-cho Kiriyoze
	⑤	Nishi-usuki-gun Takachiho-cho Toroku-chiku
	⑥	Nishi-usuki-gun Takachiho-cho Torokuminami-chiku
	⑦	Kitamorokata-gun Yamanokuchi-cho Gotanda-chiku
	⑧	Higashi-usuki-gun Shi-iba-son Kamishi-iba
Oita	⑨	Taketa-shi Ogi-machi O-aza Minamikawachi
	⑩	Yufuin-cho Shimoyunohira
Miyazaki	⑪	Higashi-usuki-gun Shi-iba-son Iwayato Dam
	⑫	Higashi-usuki-gun Saigo-son Tsukahara Dam
	⑬	Miyazaki-gun Tano-cho Mount Wanitsuka
	⑭	Minaminaka-gun Kitasato-cho Hiroto Dam

the rainfall characteristics and geological and soil mechanical aspects.

OUTLINE OF RAINFALL CONDITIONS IN TYPHOON NO. 14

Table 3 shows the record of rainfall in several points of Kyushu area with moving along the west coast of Kyushu of Typhoon No. 14 2005. Some of the locations in Miyazaki have exceeded the 1000 mm of rainfall since the beginning of the rain, and many locations in the south and east of Kyushu have broken their historical record of rainfall. This typhoon slowed down in south of Kyushu and this caused successive formation of clouds that hit same places. Figure 3 shows contours of accumulated rainfall from 4th to 6th September over Kyushu area.

Figures 4 and 5 show two typical rainfall conditions at Mikado and Takaoka-cho respectively such as the trend in the intensity of rainfall and the total accumulated rainfall during the three days against the elapsed time. According to AMeDAS data the accumulated rainfall at Mikado in Miyazaki prefecture reached 1322 mm and the accumulated rainfall at Takaoka-cho in Miyazaki prefecture was 722 mm according to the data from the Ministry of Land, Infrastructure and Transport.

From 4th to 5th noon when Typhoon No. 14 was near The South-west Islands of Japan and moved to Kyushu area slowly, at Mikado the intensity of rainfall was less than 20 mm. As Typhoon No. 14 approached the west of Kagoshima prefecture, the intensity of rainfall was increasing in the north area to the eye of typhoon with south wind and reached 70 mm and was kept for more than 10 hours.

At Takaoka-cho from 4th to 5th noon the intensity of

Fig. 4. Rainfall situations during 3 days from 4th to 6th September, 2005 recorded in Mikado (Data from AMeDAS (JMA))

Fig. 5. Rainfall situations during 3 days from 4th to 6th September, 2005 recorded in Takaoka town (Data from Ministry of Land, Infrastructure and Transport (MLIT))

rainfall became 40 mm at a maximum and after that the intensity of rainfall did not increase much although Typhoon No. 14 approaches.

OVERVIEW OF TYPICAL GEODISASTERS

As the features of geotechnical disasters caused by Typhoon No. 14, it is pointed out that no shallow failure of the Shirasu slope was observed which were popular in 2003 geotechnical disaster. It is assumed that this feature was related to the rainfall characteristics. In Miyazaki prefecture about 10 massive flank collapses of which the volume reached 100 million m^3 occurred in the slopes mainly facing north such as the slope of the upstream of Iwayato Dam in Photo 1 and the slope near the upstream of Hiroto Dam as we will describe next.

It is only conjecture until the investigation is fully finished that the reasons why deep slip failure occurred is that the infiltration of rain water progressed to the deep layer due to extremely heavy rain. This reason is suggested by that almost these slope are facing north and that the accumulated rainfall near the slope exceeded 1000 mm and that at the beginning of rainfall by the typhoon's approaching not only the surface layer but also the deep

layer were in unsaturated condition where the suction could be existing because of intermittent rain showers as we mentioned before.

From this point of view, we discussed on the slope failure being considered two categories; the deep slope failure and the shallow slope failure. Referring to the example of disasters in Kagoshima prefecture we also discussed on the relation to existence of pumice fall and the mechanism of the slope failure.

Debris Disasters in Shi-iba Village, Miyazaki Prefecture

Shi-iba village was severely damaged by the isolation of colony due to the main trunk road closure and the riverside slope failure. In particular at Kamishi-iba district where the village office is located, in the early morning of 6th September 2005. The slope behind colony failed at a height of 80 m. The deposits from the collapse became mud flow and moved down the slope. It caused severe damages which resulted in complete or partial destruction of 9 houses and 3 losses of lives.

Shi-iba village which is located roughly in the center of Kyushu Mountain Region and steep cliff along riverfront was formed in Mimi-river basin. For this reason the residential areas are scattered over the mild slope on the mountainside (past landslide area) and the tableland or the terrace which consists of Aso-pyroclastic deposit. It is concluded that this place was easily subjected to geodisaster and flood hazard (Photo 2).

Geological Features (Saito et al., 1996)

Typical geological features in Kamishi-iba district include the basement rocks consisting of sandstone and shell which belong to Shimanto formation group and these are covered with the Aso-pyroclastic flow and terrace deposits. As shown in Fig. 6, the basement rocks and welded tuff are supposed to be placed below a failure surface which are indicated by a narrow red line, and also the talus deposits and volcanic ash soils are distributed above the failure surface. The welded tuff includes a large number of cracks and partially non-welded sandy type masses. In the ridge slope which is located in the lower reaches of Mimi-river, the basement rocks are easily found in the shallow depth whose stratification plane has an opposite slope. Further, the Aso-pyroclastic flow deposits (above sea level) which are located in the lower reaches, are found to distribute in the lower height greater than 30 m comparing with the slope failure that occurred.

Rainfall Characteristics

Figure 7 shows a typical rainfall situation in a duration of 3 days from 4th to 6th September 2005. The accumulated rainfall up to the early morning of 6th September 2005 reaches around 600–700 mm. The intensity of rainfall was less than 10 mm until 7 AM, 5th September and after the intensity gradually increased with the elapsed time. After 7 PM on that day, the intensity reached 25 mm. Further, after 6 AM, on 6th September the intensity of the rainfall reached around 50 mm, which

Fig. 3. Contours of the accumulated rainfall from 4th to 6th in Kyushu area

Fig. 6. Schematic cross section of a typical geological profile in Shi-iba village, Nishi-Usuki County, Miyazaki prefecture

Fig. 10. Schematic cross section of a typical geological profile and an image of debris flow disaster in Mikagekami region, Hinokage town, Miyazaki prefecture

Photo 1. Massive flank collapse of the slope at the upstream of Iwayato dam

Photo 2. Debris flow in Shi-iba village, Miyazaki prefecture

Photo 3. Overview of a typical site in Mikagekami region before rainfall disaster

Photo 4. Overview of a site in Mikagekami region after rainfall disaster

Photo 5. Typical section of a slope failure in Kamiya, Nogiri town, Miyazaki prefecture

Photo 6. Typical section of a deep slope failure in Nakahama district, Tarumizu city, Kagoshima prefecture

Photo 7. Overview of a shallow slope failure in Shinjo-Kotani district, Tarumizu city, Kagoshima prefecture

Photo 8. Typical section of a debris flow failure in Shin-Mido district, Tarumizu city, Kagoshima prefecture

Fig. 12. Schematic cross section of a typical geological profile in Kamiya, Nojiri town, Miyazaki prefecture and the trends of infiltration water flow

lasted for four hours. It is assumed that the slope failure occurred when the accumulated rainfall kept on increasing and the intensity of rainfall further increased.

Ground Geotechnical Feature

The Shimanto formation group, which distributed in the failure slope shown in Fig. 6, consists of a fresh sandstone and shell layers without any weathering.

Fig. 7. Rainfall situations during 3 days from 4th to 6th September, 2005 recorded in Shi-iba village (Data from Miyazaki prefecture)

Fig. 8. Image view of the slope collapse (No. 1) mechanism in Shi-iba village, Miyazaki prefecture

Although there exists some cracks in the shallow depth, the layers gradually formed fresh and hard ones with increasing depth. The core of Aso-pyroclastic flow deposits formed a stable rock mass and however the upper and lower parts indicted a fragile rock mass and also a sandy and gravelly mass with the N -values of 5–30. The volcanic ash soils, covered the Aso-pyroclastic flow deposits, showed the low N -values from 1 to 5, which were like a clayey soil. In addition this layer was covered with a thin talus deposit with gravelly soils. In this region the upper part of the basement rock with a large number of cracks indicted a relatively high permeability, when compared with that of the core basement rock. Based on the field investigation, the permeability in the layer that consists of the welded tuff with some cracks was supposed to be higher than that in the basement rock and also the volcanic ash layer was considered to work as a seal layer.

Failure Mechanism Considered

Figure 8 is a schematic drawing of a supposed failure mechanism of a part of the slope encircled by a red mark of collapse image 1 in Fig. 6, based on the field investigations. The following is a supposed slope failure process in this site in relation to the analysis of the failure factors, the correspondence of the rainfall intensity with the level of the ground water table and so on.

The failure clearly took place in the layers of the volcanic ash soil and the talus deposit layers. Thus one of

Fig. 9. Image view of the slope collapse (No. 2) mechanism in Shi-iba village, Miyazaki prefecture

the important causative factors for the slope failure was considered to be the unstable sediment of the volcanic ash soil and the talus deposits. On the other hand, it was simply that an important cause was a continuous increase of the level of the ground water table due to rainfall.

It was noted that the potential of the infiltration of the volcanic ash soils distributed in the surface was very low and thus even with a rainfall of a high intensity, the water could rarely seepage in the ground and only flowed through the surface. In addition, it was considered that, within a relatively small amount of rainfall, the level of the ground water table could not exceed the upper part of the basement rock and also that in the case of a general heavy rainfall, which is however not still so heavy comparing with the rainfall caused by Typhoon No. 14, the water table could not reach the upper layers with which covered the Aso-pyroclastic flow deposits. Now, based on the careful site observations, the situation of the ground in this site during rainfall due to Typhoon No. 14 was supposed as follows: 1) As shown in Fig. 7, there existed a large amount of heavy rainfall in this site. So, such rainfall was considered to infiltrate from a hinter slope without little volcanic ash soil layers and flowed into the Aso-pyroclastic flow deposits. 2) In addition, the ground water level may exceed the upper part of the Aso-pyroclastic flow deposits layer. However, the permeability of the volcanic ash soil layer was very low, and thus an excess pore water pressure was considered to generate in the boundary between each layer. 3) The corresponding effective stress in the layer closed to the boundary was automatically assumed to decrease with the increasing excess pore water pressure. Then, gradually the degree of the instability of the slope must be increased and finally the slope achieved to fail. 4) A large amount of earth and sands with mud flow after the failure flowed down to the lower reaches and many roads, houses and several important lifelines were swept away by the flood. Moreover, an image of the failure mechanism related to the failure in the side of the prefectural road was shown in Fig. 9, which was a closed view of the red circled area named as collapse image 2 in Fig. 6. The brief explanations of the failure are also shown in this figure.

Fig. 11. Rainfall situations during 3 days from 4th to 6th September, 2005 recorded in Hinokage town (Data from Ministry of Land, Infrastructure and Transport (MLIT))

Debris Disasters in Hinokage Town, Miyazaki Prefecture

Eleven houses at Mikagekami district in Hinokage town were completely or partially destroyed by a debris flow which occurred at 9:50 AM, 6th September 2005, where the trigger of the flow was considered to be in the height of about 200 m in the mountain as shown in Photo 4. Photos 3 and 4 show the site before and after the debris disasters, respectively. It should be mentioned that, as all the local residents who lived in this area were evacuated from the expected dangerous area in advance to the primary school shown in both Photos, fortunately, there were no human losses this time.

Geological Features (Imai et al., 1982)

Figure 10 schematically shows the typical geological features in Mikagekami region, which is located to the right of Gokase River. The geological features include the basement rock consisting of the shale and sandstone in Shimanto formation group, which are covered with the terrace sand and gravel, Aso-pyroclastic flow deposit such as welded tuff, talus deposit, volcanic cohesive soil, and so on. The welded tuff is deposited along the ancient position of Gokase River, which forms a steep slope with 80–100m height from the current river bed. Then a thick talus, consisting of volcanic cohesive soil with rock mass of weathered welded tuff, is widely deposited just below the steep slope. Such ground with Aso-pyroclastic flow deposit forms a plateau with a gentle slope and also the surface is covered with a soft volcanic cohesive soil layer with the thickness of 5–7 m.

Rainfall Characteristics

Figure 11 shows the trend in the intensity of the rainfall and the total accumulated rainfall during the three days against the elapsed time. As shown in this figure, the total accumulated rainfall exceeded 600 mm during the three days. The accumulated rainfall was, however, less than 100 mm till 24 hours before the slope failure occurred. Then, both intensity of rainfall and accumulated rainfall started rapidly increasing from around 3 PM of 5th September. After the midnight of 5th September, the

intensity of rainfall exceeded 30 mm was measured 5 times, and just before failure the intensity became more than 50 mm. Thus it should be noted that the slope failure occurred when the rainfall gradually increased and then the intensity of rainfall even more increased.

Ground Engineering Characteristics

“Shimanto” formation group as a basement rock, which consists of the shale and sandstone, crops out only in the riverbed and riverside of Gokase River as shown in Fig. 10. The sandstone layer consists of a hard and massive rock without any clear bedding plane, and also the shale layer is categorized as a middle hardness rock. Although the cleavage and the bedding plane in the fresh part of the shale layer adheres closely, the weathering part indicates a clear looseness zone along such plane that is characterized as a plate shaped rock.

The terrace sand and gravel layer includes boulders and round shaped gravels from the sandstone and chart, which are distinguished to be a dense soil layer with N -values greater than 50. Main part of the talus deposit consists of the volcanic cohesive soils with a rock mass from welded tuff, which indicates a weak or loose sediment state with N -values from 1 to 10, except for a certain depth that a gravel layer is deposited. The maximum depth of Aso-pyroclastic flow deposit with welded tuff is supposed to be higher than 80 m in this site, which is characterized that the upper and bottom parts in this layer are relatively weak due to low welding, comparing with the middle part of this layer. Typical volcanic cohesive soils generally have high water contents and viscosities. It should be pointed out that any traces of failure were not found during rainfall in neighboring slopes consisting of similar types of soils.

Failure Mechanism

Based on the results of the field investigations, the slope failure was found to start from a layer just above the Aso-pyroclastic flow deposit. Thus, it was judged that the failure of volcanic cohesive soil layer became an important trigger of the debris flow in this slope and then the lower part of this slope gave rise to an erosion disaster of surface soil layer due to the debris flow. When checking out from the top to the middle of the failure slope, the welded tuff from Aso-pyroclastic flow deposit was intermittently exposed and also the failure surface was covered with the volcanic cohesive soils alone in the middle and bottom parts, in which the basement rock and welded tuff could not clearly be seen. Therefore, it was considered that the failure from the middle to lower part in the slope was caused by an increase of excess pore water in the boundary between the welded tuff and volcanic cohesive soil layers, and also that the failure in the upper part of the slope was caused by an increment of unit weight of the volcanic cohesive soil layer due to the rainfall seepage (see Fig. 10). A large amount of collapsed geomaterials suddenly flowed out right up to the downward of the slope due to the continuing rainfall and seepage water on the collapsed surface, and it was

supposed that such matter gave a huge damage to the facilities of the barrier against debris-slide and houses.

Typical Debris Disasters in Nojiri Town, Miyazaki Prefecture

A deep slope failure occurred along Root 268 in Kamiya, Nojiri town due to heavy rainfall. As a result, the national road was buried in the length of about 200 m by a large amount of collapsed geomaterials. The scale of the slope failure was that the width, height, depth and maximum slope gradient were about 40 m, 15 m, 15 m and 80 degrees, respectively and the time and day that the failure occurred was recorded as 10:30 AM, 6th September.

Geological Features (Kino and Ota, 1976)

The disaster area forms a hill land of about 250 m in height from the sea level, and also shows a ridge geographical feature spreading in the direction from the east-northeast to the west-southwest. Figure 12 schematically shows the typical cross section of this site. The basement rock consists of the laminated layers with shale and sandstone in Shimanto formation group, in which the main part is shale layer. Although the shale layer is basically very hard, a remarkable growth in joint set is found everywhere, and also in the upper parts of this, a clayey layer is partially produced due to the weathering effect. The deposit, which covers the basement rock, consists of the eruptions originated the Aira volcano, Kagoshima prefecture and Kirishima volcano, Miyazaki prefecture, where the eruptions includes Scoria layer with the thickness of 20–30 cm, volcanic ash sandy soils called Shirasu, volcanic ash soils with fine sand particles and several types of volcanic clayey soils having black and red color with the thickness of 30–50 cm. Such volcanic ash soil layer becomes thicker in the collapsed slopes and also the thickness of the layers in the ridge part and in the slopes faced on the east direction becomes very thin, which was supposed that the collapsed part formed a typical valley as geographical features.

Rainfall Characteristics

Figure 13 shows the trend in the intensity of the rainfall and the total accumulated rainfall during the three days against the elapsed time. As shown in this figure, the total accumulated rainfall exceeded 800 mm during the three days. The accumulated rainfall was around 10 mm till 8 PM, 4th September. After that, the rainfall intensity of about 25 mm continued for around 2 hours and the accumulated rainfall reached 100 mm. There was no rainfall as a measurement for five hours after that. Then the rainfall intensity with 15 to 30 mm kept constant from 2 AM, 5th to 6 PM, 6th September, in turn, which was more than 40 hours. The deep slope failure occurred when the rainfall intensity started decreasing and the accumulated rainfall became stable around 750 mm whose time was around 10:30 AM, 6th September.

Table 4. Rainfall amount at various points in Kyushu

Points	Accumulated rainfall (mm)	The maximum daily rainfall		The maximum hourly rainfall	
		Rainfall (mm)	Date	Rainfall (mm)	Time
Fukuoka	95	64.5	9/6	11.5	9/6 15:12
Saga	131.5	114.5	9/6	35.5	9/6 15:19
Oita	375	232	9/6	26.5	9/5 23:39
Nagasaki	69.5	58	9/6	14	9/6 11:54
Kumamoto	93.5	76	9/6	32.5	9/6 14:51
Kagoshima	234	136	9/6	28.5	9/6 8:39
Miyazaki	608	310	9/5	34.5	9/5 10:19
Mitate	1184	558	9/5	39	9/5 22:40
Morotsuka	1000	468	9/5	51	9/5 19:50
Mikado	1322	628	9/6	71	9/6 9:30
Ebino	1284	639	9/6	62	9/6 11:50
Mt. Wanitsuka	1013	388	9/5	46	9/6 8:00

Table 5. Strength and physical parameters of soil layer in Kamiya, Nogiri town, Miyazaki prefecture

	Internal friction angle (degree)	Cohesion (kN/m ²)	Density (g/cm ³)
Scoria	$\phi_d = 37$	$c_d = 18$	$\gamma = 1.0$
Shirasu and AT tephra	$\phi_d = 29 \sim 36$	$c_d = 2 \sim 20$	$\gamma = 1.25 \sim 1.38$
Volcanic ash clayey soil	$\phi_u = 0 \sim 7$	$c_u = 40 \sim 51$	$\gamma = 1.43 \sim 1.47$

Ground Engineering Characteristics

A typical scoria layer above the basement rock shown in Fig. 12 consists of the round or sub-round gravelly particles of 2 mm to 15 mm. This layer indicates a high permeability with a coefficient of permeability of 1.1×10^{-3} cm/s. However, in general, the individual scoria particles are stable against a flow of groundwater. Shirasu and volcanic ash soils (AT tephra) layers included a piece of pumice with its grain diameter of about 2 mm and show a considerably loose structure. Thus, its erosion resistance against water was considered to be very low while the coefficient of permeability is 4.1×10^{-3} cm/s. On the other hand, the volcanic ash clayey layer (tephra layer in Fig. 12) has a relatively high erosion resistance against water flow, whose coefficient of permeability was considered to be in the ranges of 10^{-7} to 10^{-5} cm/s. The strength and physical parameters of each layer are shown in Table 5.

Failure Characteristics and Mechanism

Watching the situation in this site just after the slope failure, it was characterized that the collapsed sediments showed the state of mud flow and many vegetation roots rest in the top part of the slope were cut off due to the

Fig. 13. Rainfall situations during 3 days from 4th to 6th September, 2005 recorded in Nogiri town (Data from Ministry of Land, Infrastructure and Transport (MLIT))

sliding. The former evidence indicated that the collapsed sediments became an over-saturation condition, where the mud flow was a typical phenomena for the amorphous volcanic ash sandy soils, which corresponds to Shirasu and AT tephra (see Fig. 12). From the second evidence, it was considered that there existed the volcanic cohesive soil layer with many vegetation roots entwined. Based on the collapsed futures, the failure mechanism was considered such that:

- 1) The rainfall intensities with 10 to 25 mm were measured from 8 PM to 10 PM, 4th September (see Fig. 12). Through this rainfall, infiltration water permeated only the upper part in the Tephra layer.
- 2) It had rained continuously for 40 hours from 2 AM, on 5th September. During the rainfall, the infiltration water permeated from the top to the lower layers and the degrees of saturation gradually increased. However, the rate of seepage was quite low due to the low permeability, and thus the water without seepage flowed through the surface. On the other hand, in the slope faced to the east direction, the volcanic ash layers which covered the basement rock were quite thin, and thus the rainfall reaches to the basement rock layer in relatively short time.
- 3) The seepage water reached to the basement rock layer infiltrated into the slope faced to the west direction, which flow rate might be extremely fast.
- 4) As shown in Fig. 12, scoria layer with high permeability is placed above the basement rock. Thus it is easy to raise the degree of saturation in short time and the table of the ground water tends to rapidly increase with time.
- 5) As Shirasu and AT volcanic ash soils deposited above scoria layers had a high permeability, it was considered that the degree of saturation increases quickly with the increasing ground water table. This was supposed to be a primary factor to lead to a deep slide failure in this site.
- 6) In the sliding parts, the water not only infiltrated from the upper part, but also came up from the lower layer, which leaded to the high water contents. The lower part of Tephra layer (I) might keep an unsaturated condition for a long time because the rate of permeability from the upper part was low.
- 7) The upward ground water started

Fig. 14. Rainfall situations during 3 days from 4th to 6th September, 2005 recorded in Tatumizu city including three districts mentioned, Kagoshima prefecture (Data from Ministry of Land, Infrastructure and Transport (MLIT))

flowing out from the AT Tephra (II) and thus the rise of the ground water table was kept below a constant level. 8) It was finally supposed that the deep combined slide failure was induced by a decrease of shear resistance of AT volcanic ash soils (II), Shirasu (III) and Scoria (IV) layers with the changes of boundary conditions due to rainfall and also by an increment of surcharge load related to the infiltration water from the lower layers.

It is again important to note that such failure mechanism was considered on the basis of the situation of collapsed sediments and the shape of the remained vegetation roots just after the failure, the strike dip of basement rock and the deposit environment of volcanic ash soils, and further the old geographical and rainfall features. In this disaster site, although the effect of a strong wind due to typhoon on the disaster should also be considered, it is difficult to evaluate its extent at a moment.

Typical Debris Disasters in Kagoshima Prefecture (The Japanese Geotechnical Society, 2003)

Several debris flows and slope failures occurred one after another mainly in the Osumi region, Kagoshima prefecture. Typical debris flows occurred at Nakahama, Shinjo-Kotani and Shin-Mido districts in Tatumizu city located at a tributary of Kan-non River. The days and times of the occurrence of each debris flow are shown in Fig. 14. It was considered that because the Pumice fall and Scoria deposits were widely distributed in each disaster area and thus these deposits were closely related to the characteristics of slope failure.

Outline of Geological Features

Typical geological features of each disaster area mentioned above were briefly outlined below:

- a) Nakahama district: It is located at the outer rim of an Aira-caldera, which is characterized that, taking a broad view of the situation, the site indicates a geological feature which has a continuously steep slope, and also the living area forms an alluvial fan, in which a large quantity of pyroclastic materials are deeply deposited.
- b) Shinjo-Kotani district: The basement rock consists

Fig. 15. Distance between sampling sites and Mt. Sakurajima (South Peak), Kagoshima prefecture

of sandstone and granite originated by the Shimanto formation, which are remarkably clayey due to weathering, especially, most of granite changes to various decomposed granite soils with fine particles. These are covered with a large quantity of pyroclastic materials. Stratigraphy becomes volcanic cohesive soil and pumice fall deposits in order from the surface.

c) Shin-Mido district: The basement rock is similar to that in Shinjo-Kotani district, which is covered by the weathered talus deposits and pyroclastic materials. The pyroclastic materials are mainly volcanic cohesive soil and pumice fall deposits.

Rainfall Characteristics

Although, as shown in Fig. 14, the accumulated rainfall during the three days from 4th to 6th September reached around 650 mm, it was found that the rainfall strengthened from 5th September onwards. The accumulated rainfall in 4th September was only about 20 mm/day. After that, from the early morning, of 5th September to noon of 6th September, the rainfall intensity was more than 15 mm/hour and as a result, accumulated rainfall reached 650 mm in total. The day and time of the occurrence of each collapse was also shown in Fig. 14. It was clear that the slope failures at each district occurred when the rainfall intensity was just increasing, or decreasing and also the accumulated rainfall became constant. Thus, the time zone of each occurrence of the slope failures was not the same, and may depend on the sediment formation, and the physical and mechanical characteristics of the consisting soils.

Ground Engineering Characteristics (Suzuki et al., 2006)

The main deposit in each failure site consists of the volcanic materials, and it was especially characterized that the various pumice fall deposits were distributed in thick-layered. Most of pumice fall deposits distributed in Kagoshima prefecture were originally spurted from

Fig. 16. Typical distribution curves of soils sampled in each debris disaster site

Kirishima volcano group, Aira-caldera, Ata-caldera and Kikai-caldera. These pumice fall materials were generally translated elsewhere by the prevailing westerlies, and then they became finer when the distance from the volcano became longer. However, even if they were geologically the same materials, the distribution curves were different from each other because of the changes in the degree of weathering due to the differences of the eruption ages, the sediment environments and so on. Figures 15 and 16 showed the distance from the source of eruptions and the corresponding particle distribution curves of pumice fall deposits. It was clear that when the distance became longer, the contents of the gravel particles tended to be smaller. However, in the case of the pumice fall deposits spurted in relatively old period, such mutual relationships were not always clearly found. In addition, it was noted

Table 6. Physical test results of soils sampled in failure site (Kagoshima)

Soil sampled	Natural water content (%)	Soil particle density (g/cm ³)
Oike Bora	84.7	2.51
Osumi pumice fall deposits	71.4	2.53
Paleosol I	124.3	2.56
Paleosol II	33.6	2.64

Table 7. Permeability test results of soils sampled in failure site (Kagoshima)

Soil sampled	Coefficient of permeability (cm/s)
Oike Bora	5.18×10^{-1}
Osumi pumice fall deposits	1.39×10^{-1}
Paleosol I	1.41×10^{-6}

that, except for a peculiar sample, the fine contents in all cases of the pumice fall deposits shown in Fig. 16 were less than 10%. The reason being the greater the particle size the more porous the particles became and also the finer the particle size, the particles increased more heavy minerals. Some physical properties and coefficients of permeability of several pumice fall deposits derived in this study are summarized in Tables 6 and 7. Finally, it was important to mention that soil characteristics in situ were difficult to discuss uniformly, that is, such irregularity related to them had an important influence on the failure mechanism and formation.

Failure Characteristics and Mechanism

Based on the rainfall characteristics and geotechnical considerations, the failure processes in each site were discussed as follows:

a) Nakahama district: In this site, a relatively deep slope failure occurred, in which the process was summarized as follows: 1) Due to the rainfall for a long time, the infiltration water reached to the volcanic cohesive soil layer just above the basement rock. 2) Its layer momentarily worked as an impermeable layer because of the low permeability. The ground water, which could not infiltrate, saturated the pumice fall deposit above the volcanic cohesive soil layer and then the piping phenomenon happened in this layer. 3) After a time passed, the lower volcanic cohesive soil layers gradually saturated and then the infiltration water reached to the weathering basement rock layers. 4) Finally, a deep slope failure was induced due to a decrease in shear resistance in this layer according to the progress of the saturation.

b) Shinjo-Kotani district: In this site, a shallow slope failure and a debris flow occurred. The process of the failure was considered as follows: 1) It started raining from the early morning of 5th September. In the beginning, the intensity of the rainfall was less than 10 mm/hour. Thus, it was supposed that the water kindly permeated into the volcanic cohesive soil layer deposited

in the surface and the layer was saturated. 2) Because of its high permeability, the seepage water easily infiltrated the pumice fall deposit and then started infiltrating the lower volcanic cohesive soil and decomposed granite soil layers. At this point, the pumice fall deposit was under the way of reaching the fully saturated conditions. 3) As the permeability of lower volcanic cohesive soil layer was very low, the degrees of saturation in the pumice fall deposit was considered to gradually increase with time. 4) Then, after the volcanic cohesive soil layer in the surface and the pumice fall deposit layers were fully saturated, the slope failure occurred. This was a typical shallow slope failure, which took place on the side of the mountain at midnight of 5th September, when the rainfall intensity became relatively high. At this stage, the accumulated rainfall was about 300 mm. 5) The collapsed deposits generated in the middle reaches of the mountain torrent momentarily remained in the same place. However, due to the consecutive rainfall, the mass of the collapsed deposits was carried away as a debris flow at 9:36 AM, 6th September, which was just before the peak state of the accumulated rainfall.

c) Shin-Mido district: In this site, a circle slope failure occurred, together with a debris flow. 1) Due to a long-term rainfall from the early morning of 5th September, the infiltrate water passing through the surface volcanic cohesive soil layer reached to the weathered talus deposit by way of the pumice fall deposits. 2) As a soil mass of the weathered and talus deposits had a gravelly loose structure, the infiltrate water gave an increment in ground water. 3) Then, it was considered that the slope failure occurred due to the decreasing of shear resistance in the weathered talus deposits resulting from a rising of the ground water level and the degree of saturation. 4) Such collapsed deposits run downward as a debris flow. Occurrence of this failure was when the accumulated rainfall indicated a peak state and the rainfall intensity was less than 10 mm/hour, which was at 1:14 PM, 6th September.

CONCLUSIONS

In this report, based on the field investigations and analysis until now, the debris disaster by Typhoon No. 14 hit in Miyazaki and Kagoshima prefectures which were located at the south part of Kyushu Island in the beginning of September 2005 were mainly outlined in relation to the features and mechanism of slope failure according to the rainfall characteristics, and geological and soil mechanical aspects. Main results are summarized as follows.

Most of slope failures in debris disaster were mainly relevant to the rainfall characteristics, which were remarkably influenced by the geological features and ground conditions. Especially, the rainfall characteristics were strongly dependent on the mutual position with typhoon rather than the mutual distance. Therefore, it was pointed out that when considering the protections against disaster, the evacuation system and attitude were

necessary to examine not only the location of typhoon, the rainfall intensity and the accumulated rainfall but also a comprehensive system including the geotechnical aspects. In addition, the seepage pattern and speed due to rainfall linked with geotechnical characteristics and profiles needs more consideration, together with the relevance to the laminated ground and the old geographical features.

Based on these results still in progress, more detailed field and laboratory investigations are continuously being carried out in order to make a persuasive suggestion for the proper restorations works in each disaster area in the near future.

REFERENCES

- 1) Imai, I., Teraoka, Y., Okumura, K., Kambe, N. and Ono, K. (1982): Geology of the Morotsukayama District, *Geological Survey of Japan*, 6–59 (in Japanese).
- 2) Kino, Y. and Ota, R. (1976): Geology of the Nojiri District, *Geological Survey of Japan*, 1–29 (in Japanese).
- 3) Saito, M., Kimura, K., Naito, K. and Sakai, A. (1996): Geology of the Siibason District, *Geological Survey of Japan*, 6–59 (in Japanese).
- 4) Suzuki, T., Matsumoto, S. and Kitamura, R. (2006): Geo-disasters in South Kyushu caused by Typhoon No. 14 in September 2005, *Proc. 3rd Symp. Geodisasters*, 193–198 (in Japanese).
- 5) The Japanese Geotechnical Society (2003): The debris flow, *Geotechnote*, 12, 1–20 (in Japanese).