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The September 2000 Torrential Rain Disaster in the Tokai Region: Investigation of a mountain disaster caused by heavy rain in three prefectures; Aichi, Gifu and Nagano

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ABSTRACT

Torrential rain on September 11, 2000 in the Tokai region caused floods and many landslides. In this disaster, most of the soil and rock slope failures that caused closure of roadways occurred concentrically in Gifu Prefecture. In addition, flooding caused bridges to collapse, and many residential areas were inundated. Slope failures and damage to trees in the southern mountainous district of Gifu Prefecture were investigated taking into consideration the geomorphological and geological characteristics of this area. The relationships between slope failures and torrential rain characteristics as well as possible causes are discussed. Old eroded stubble was found to be the caused frequent slope failures in a young plantation.

1. INTRODUCTION

A stationary autumn rain front produced by stagnation from September 11 to 12 2000 of Typhoon 14 caused flooding in the Tokai region of Japan. In this disaster, about 65,000 houses were flooded, and about 58,000 persons in this region required refuge advice.

Sediment disasters such as slope failures with debris flow were frequent in the broad mountainous region which spans the three Tokai prefectures of Gifu, Aichi and Nagano. Many roads in the region became impassable and many settlements were isolated. In particular, Kamiyahagi Town, Ena District, Gifu Prefecture received intense rainfall which exceeded 80mm (per hour) at the time amount and the total rainfall in this region was 590mm. Severe damage, which included the collapse and washing away of civil engineering structures and houses, occurred.

Results of a disaster investigation made in the Yahagi River basin are reported, and the causes of damage to mountain slopes and civil engineering structures are discussed.

2. RAINFALL CHARACTERISTICS

The observed total rainfall in Yahagi River basin from 8 p.m., September 10th to 11 a.m., September 12th and the position of the observatory of the Ministry of Land, Infrastructure and Transport near Kamiyahagi Town are shown in Fig.1. Fig.2 gives the observed times and total rainfall per hour at Kamiyahagi and the Yarigairi observatories from 0 a.m., September 10th to 6 p.m. September 12 (Ministry of Construction, Chubu District Construction Bureau, Toyohashi Construction Work Office, 2000).

As seen from Fig.1, an area with 500mm total rainfall is centered mainly on Kamiyahagi Town, Gifu Prefecture. This area of severe rainfall covers a narrow region from the north of Aichi Prefecture to the south of Nagano Prefecture. This heavy rain produced a record-breaking amount of rainfall at both observatories. In particular, the maximum hourly rainfall at the Yarigairi observatory was 80mm, and the total rainfall 595mm between 11 p.m., September 11th and 0 a.m., September 12th. The maximum hourly and total rainfalls at the Kamiyahagi observatory respectively were 65mm and 437mm. The Ministry of Land, Infrastructure and Transport reported that these amounts set records in the past 500 years.

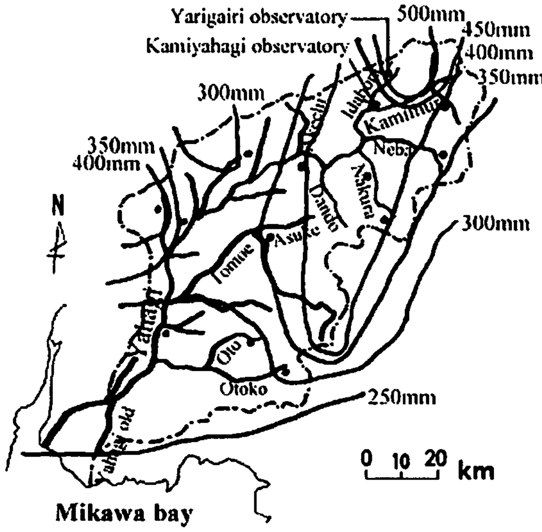

Fig. 1 Total rainfall for the Yahagi River system.

KEY WORDS: torrential rain, landslide, investigation report, granite zone plantation

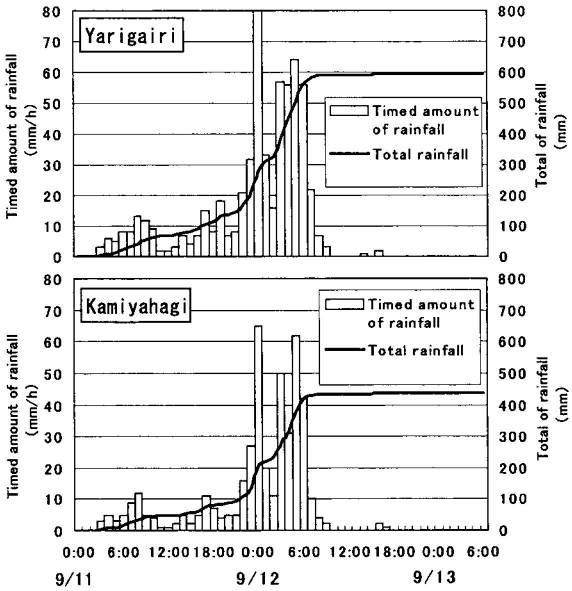

Fig. 2 Observed times and total rainfalls at Yarigairi and Kamiyahagi observatories. (Ministry of Construction, Chubu District Construction Bureau Toyohashi Construction Work office.［2000］)

Table 1. Civil engineering structures in the Mt. Ena region damaged by the Tokai 2000 torrential rain.

Structure	Number of cases
Road	178
River	273
Checkdam	45
Bridge	19

It is based on the examination of the Ena construction office.

3. THE DISASTER

In the area where the total rainfall exceeded 400mm during this torrential rain, many civil engineering structures were damaged by mountain slope disasters and debris flows. A summary by the Gifu Prefecture Ena construction office of the damage to civil engineering structures is given in Table 1. Damage was most frequently caused by driftwood striking bridges and driftwood deposited in housing area. Results of resistance to the flow of streams due to the piling up of driftwood at the sides of bridges was observed at most bridge piers in the basin. Examples of bridge piers and bridge girders washed away are shown in Photo.1.

Photo.2 shows a failed revetment and the asphalt paving on a national highway. The main causes of the washing away of the revetment seem to have been the bulging in the river channel at the disaster position and local scour of the foundation ground by the flow in the stream.

A large quantity of driftwood was produced by this torrential rain disaster. The dam control office reported that about 40,000 m^3 of driftwood flowed in to Yahagi Dam Reservoir. This was 70 times the average (about 600 m^3) for the previous two years. Photo.3 shows the pile up of driftwood after the heavy rain.

Simultaneously, much gravel flowed down and accumulated in the dam's reservoir. The amount of sedimented silt was about 1,100,000m^3, estimated as more than 12 times the average annual rate (80,000 m^3). The estimated quantity of banking sand that flowed into Yahagi Dam is shown in Fig.3.

Photo. 1 Collapsed bridge washed away by the accumulated driftwood.

Photo. 2 Collapsed road and revetment washed due to scour of the retaining wall base.

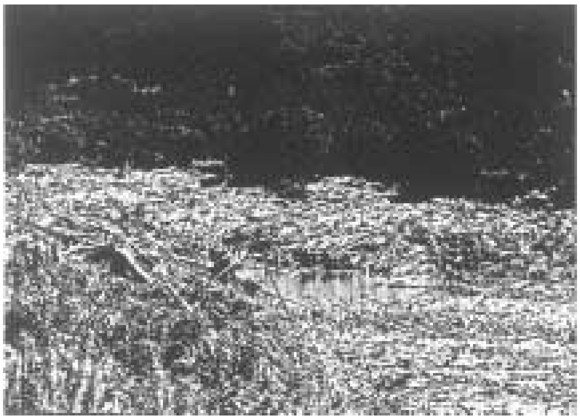

Photo. 3 Yahagi Dam Reservoir with piled up driftwood.

4. FIELD SURVEY

The shapes and cross sections of collapsed rock slopes were measured as well as the gradient and inclination direction of the slip surface. A non-prism laser range finder, a clinometer, a map with the scale 1 to 25000, and aerial photographs were used. Results of the survey are given in Table 2 (Tujimoto, etc. 2001, Shimizu, etc. 2001). This Table shows that the gradients of the collapsed slopes were steep, the collapsed slope length long, and the catchment areas were wide.

Granitic bedrock underlies the mountains in this area, and rock converted to a surface layer, called Masado is widely distributed. In the neighborhood of the Kamiyahagi Town, 90% of the area is forested, and the most of the tree plantings are cedar and cypress.

The surface soil was exposed in most of the plantations investigated in which the undergrowth is 20 to 30 years old. The surface soil is composed of Masado or decomposed granite and humus soils, the thickness varying about 50cm to 3m. Slope collapse mainly occurred at the boundary with the unweathered division. As the thickness of soil layer in the slip area is thin, grove failure was frequent. A typical example of the characteristic slope failure found in this survey follows.

The case of a steep landform, No.A11 is shown in Table 2. The rock mass was exposed on the failed slope of this stricken area, and a joint Nagareban of about 80 degrees developed on the surface of the slope. The valley became V-shaped, and there was some cross fall in this V characteristic at the maximum gradient of 45 degrees.

In the lower section of Photo.4, there is a landform in which width and height are continuous in steps of several meters, but in the upper part of the failed slope, it continues as a gradient along the joint plane and there is a banquette of several centimeters. This phenomenon seems to represent the stripping off of the joint plane to a depth of several meters caused by collapse over a long period and by the force of the debris flow generated in this disaster.

In Table 2, No.D1, destruction of a forest road is induced. In this case, the surface layer in the stricken area was mixed with the Masado layer of weathered granite rock and humus soil. There was gully erosion in middle of the slope at almost overall length. Photo.5 shows that this failed cross section was that of slope of the U type and afforested full face before it failed.

The topographic map for this collapsed ground is shown in Fig.4. Photographs were used simultaneously to determine the detail of the collapsed shapes. In the plan seen in this figure, cross sections are shown in which the gradient of differs at points. The longitudinal map shows the height of each interval, the lowermost

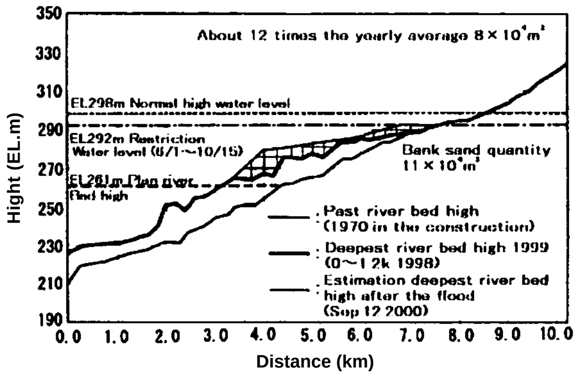

Fig. 3 Bank sand quantity curve, the Yahagi Dam inflow division.（Ministry of Land, Infrastructure and Transprt Chubu District improvement station material［2000］）.

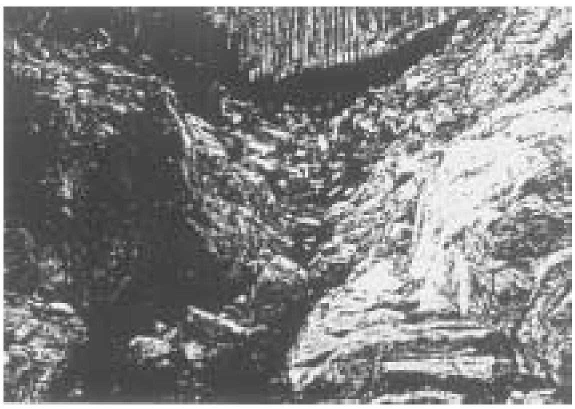

Photo. 4 Steep slope failure in Tappara, Kamiyahagi Town（lower part of the slope）.

Table 2. Disaster field inventory findings for the Tokai 2000 torrential rain.

No.		Area	Spot	Rock	Drainage basin area × 10^4 (m^2)	Slope (°)	Dimension (m) Length	Width	Thickness	Configuration	Water
A	1	Kamiyahagi Town	Nakashima	Granite	2.5	31～47	130	7～17	1.0～2.5	Slope	None
	2	Kamiyahagi Town	Yokomiti	Granite	14.3	41	28	3～6	0.5～1.0	Infiltration	Existent
	3	Kamiyahagi Town	Tappara	Metamorphic rock	77.5	38	30	4～20	0.5～2.0	Infiltration	Existent
	4	Kamiyahagi Town	Tappara	Metamorphic rock	0.5	47	27	6～18	0.5～1.5	Infiltration	None
	5	Kamiyahagi Town	Tappara	Granite	13.1	35	52	4～20	0.5～0.7	Infiltration	None
	6	Kamiyahagi Town	Tappara	Granite	0.7	28～38	172	16～20	0.5～1.5	Slope	None
	7	Kamiyahagi Town	Tappara	Granite	1.2	47	28	3～6	0.3～0.5	Infiltration	Existent
	8	Kamiyahagi Town	Tappara	Granite	3.0	33～44	101	6～7	1.0～1.5	Infiltration	Existent
	9	Kamiyahagi Town	Tappara	Granite	3.7	17～47	154	5～13	1.0～3.0	Infiltration	Existent
	10	Kamiyahagi Town	Tappara	Granite	6.2	18～39	522	8～40	0.5～3.5	Infiltration	Existent
	11	Kamiyahagi Town	Tappara	Granite	9.6	23～36	592	4.5～17	0.5～3.0	Infiltration	Existent
C	1	Kamiyahagi Town	Adera	Decomposed granite soil	2.5	16～38	337	19～23	0.5～3.0	Slope	None
D	1	Kamiyahagi Town	Kamasawa	Decomposed granite soil	11.0	1～37	479	11～60	0.3～1.0	Slope	Existent
E	1	Inabu Town	Odako	Humic soil	1.0	11～35	123	12～14	0.3～0.5	Infiltration	None
K	2	Kamiyahagi Town	Yamakoshi	Granite	6.4	19～33	334	15～22	0.3～1.0	Infiltration	None
N	2	Neba Village	Odona	Granite	1.5	22～37	147	10～20	1.0～2.5	Infiltration	Existent
	3	Neba Village	Odona	Granite	1.3	23～40	89	8.5～24	0.5～2.0	Infiltration	Existent
	4	Neba Village	Odona	Granite	1.3	35	31	3～13	0.1～0.3	Infiltration	None
	5	Neba Village	Odona	Decomposed granite soil	1.2	28～31	48	3～18	0.5～1.0	Infiltration	None

height of the forest road being the standard. It shows a 153m difference in elevation, 296m in horizontal distance, 337m in slope distance, a maximum width of 23m, largest tilt angle of 38° and largest collapsed depth of 3m. Valley erosion occurred for about 200m in this landslide area at the forest road in its lowermost part, and flooding deposited a layer of gravel in the farming area that was several meters high. Fallen trees with diameters of more than 80cm and length of 20m are present.

The existence of the 6.0m wide forest road which is in contact with the upper most end of the landslide scar is considered to have been the inducement for this slope failure. This forest road became a sluice as rain water fall from it in to the watershed within about 200m of the highland. Water corrected at this site where there is a bend. The catchment area, as increased by the forest road was about $8.6\times10^3 cm^3$ produced an increase of 34% in the catchment area of the same landslide scar. This also was an inducement to erosion because none occurred in the adjacent area that was without water inflow from forest road.

Photo. 5 Slope failure at Adera. Kamiyahadi Town, in which a forest road was an inducement (middle part of the slope).

Another case in which the erosion of stumps was an inducement is shown in Table 2, Nos.2 to 5. A partial investigation of this landslide scar has been made because of the occurrence of too many slope failures. These landslide scars were present in the south of Nagano Prefecture. An aerial photograph of one landslide scar is shown in Fig.5. Much decay has occurred in the plantation over 10 to 15 years, whereas there has not been much generated in the natural forest and plantation area over a 20-year. In this landslide area, the catchment area is $9.9\times10^5 m^2$, average gradient of the failure slope about 42 degrees, and density of failure high at $17/km^2$. Also, the maximum rainfall in this area was 69mm/h, and total rainfall 403mm.

Slope failures have been in close in this region, and many failures have occurred on concave or otherwise flat landforms. A distinguishing characteristic, seen in Photo.6 is the eroded stumps produced by tree trimming at the crown of the slope.

Clear cutting cypress trees 50 years old took place 15 years ago, and this region has been reforested in respect to new cypresses. As shown in Photo.6, erosion of the stumps has progressed, part of the underground root system has become hollow, and the resistance of the soil mass been reduced. The match rain water

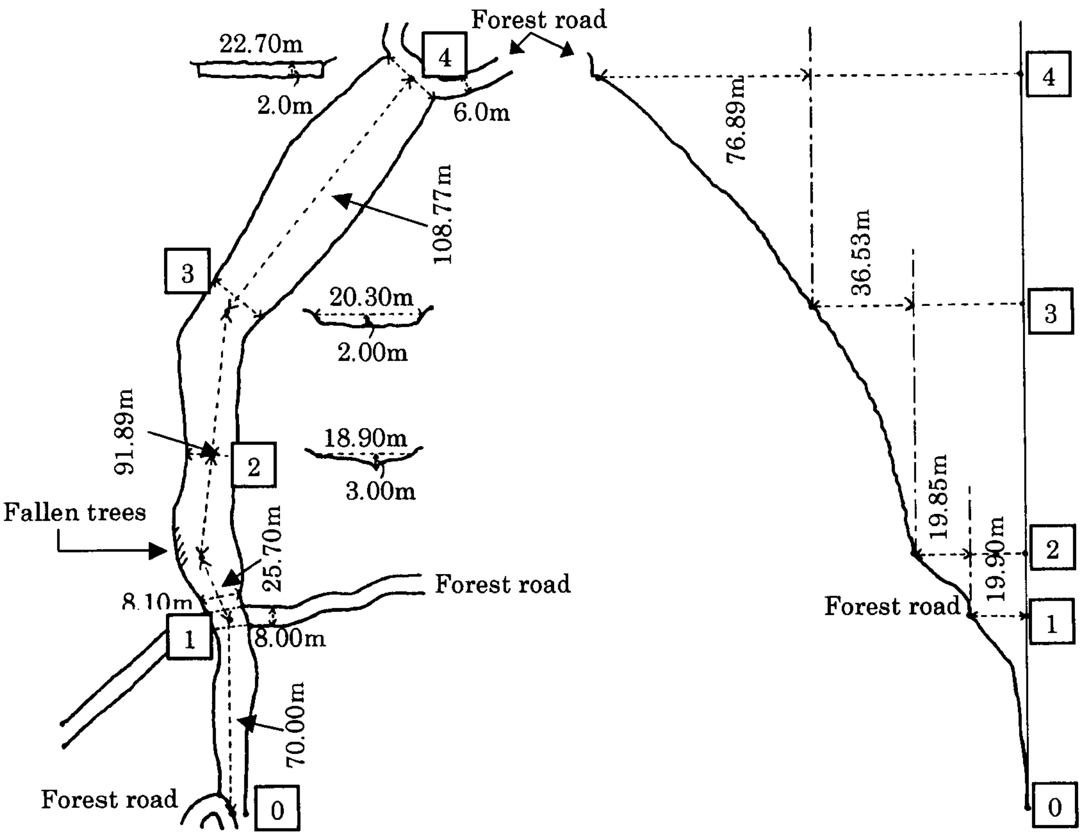

Fig. 4 Plan and longitudinal section of the failed slope in Kamiyahagi Town.

was flooded underground because the eroded stumps acted like a pipe. These phenomena seem to have been the cause of the slope failures concentrated in this region. Such failure comparatively easy to generate under geotechnical conditions where there is a thin sand layers e.g. weathered residual soil, and rain water easily permeates the layer.

Fig.5 shows that slope failure mainly occurred on the southwest as compared to the northeast side of the slope. This phenomenon is explained as follows: 1) Though the erosion progressed on stumps which remained after the clear-cutting, its progress on southwest side was more rapid than on the northeast one due to sunshine and the temperature gradient at ground level. 2) After the 15 years that have passed since the tree clearing, the slope direction has affected progress of erosion, and the number of slope failures generated differ according to the direction of the slope. More over, it is said that “the surface in the area with the erosion stumps is soft like the thick carpet”.

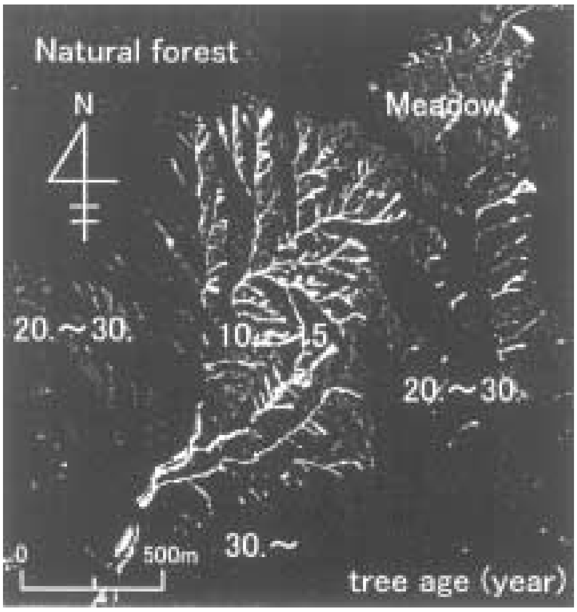

Fig. 5 Trees planted near lna County, Neba Villge, Nagano Prefecture.

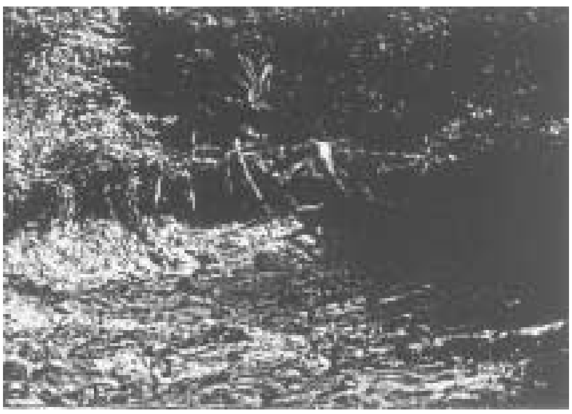

Photo. 6 Top of the failed sloppe in the eroded stump area.

5. FAILURE OF WEATHERED RESIDUAL SOIL IN ODONA, NEBA VILLAGE.

Bamboo grass has grown widely over the top of a failed slope in this region. The depth of the failed soil is about 0.5m -1m, and the surface soil at the failed slope is mostly homogeneous, decomposed granite where there is partially weathered rock. The surface of the failed slope is a sandy layer composed of weathered residual soil, as classified by Nishida (1986, 1991) and Deere and Patton (1971) (Fig.7). This is regarded to be the underlayer of the sandy

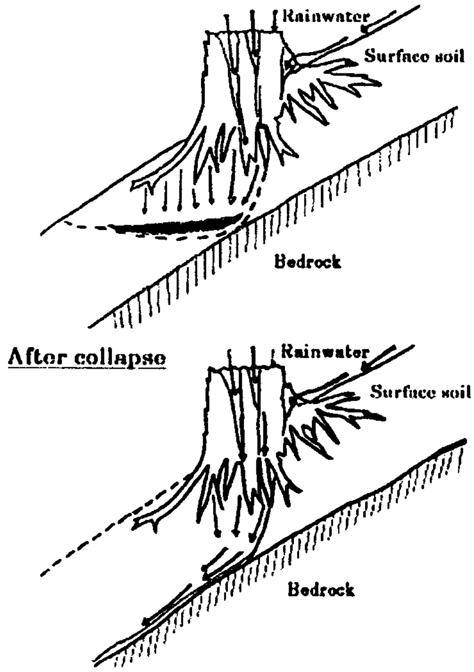

Fig. 6 Decay mechanism of slope failure due to erosion.

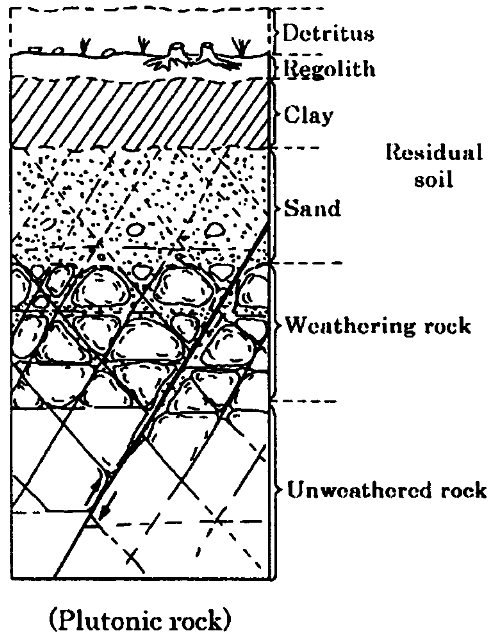

Fig. 7 Schematic representation of a weathering layer section. (Deere and Patton 1971)

layer as there is partially weathered rock. Because the field survey was done by visual inspection and the hammer test, further examination is necessary to determine whether the failed surface classifies as a granite soil (zone IV, Masado B) or (zone V, Masado A) in the weathered soil classification of Kimiya (1975).

Geomorphological observation of the failed slope showed that it is convex, with a center top where the slope has a concave cross section. If slope failure is assumed to be limitless in weathered residual soil, the mechanism of failure caused by rainfall is explained by three stages (Enoki, 1999), as shown in Fig.8:

1) "Vertical infiltration of rainfall": Rainfall permeates the slope is surface soil, forming WF drops over time.
2) "Bedrock parallel infiltration process": The ground water table is in the surface soil layer after WF reaches the bedrock, and seepage flow parallel to the bedrock is generated.
3) "Collapse process" : Because this groundwater level is as high as downstream, it exceeds the limitation for the ground water level of some sites downstream, and this part collapses.

The slope in Neba Village seems to have failed by the abov process.

6. SOIL SURVEY OF GROUND OF THE FAILED SLOPE

A soil test was done to examine the characteristics of the surface soil which seems to be an important factor in slope failure. Physical constants for the collected surface soil are shown in Table 3. Particle size distribution in the soil sample shows there is only several percent or less in terms of grain size and a content mostly of sand and gravel.

The constituent minerals of the surface soil as estimated by X-ray analysis are shown in Table 4. The particles consist of large amount of quartz and feldspar as the primary minerals, and may also contain gibbsite talc and a few clay minerals. Compaction of the surface soil therefore is assumed to be loose. An enlargement of the Masado layer is shown in Photo.7.

A direct shear test was made on the same sample. Test results for Odona in Neba Village are given in Fig.9, which it shows a relationship between the shearing stress τ, shearing displacement D and normal displacement Δ_H. In this test, the normal stresses applied were σ_N = 24.5, 49.0, 73.5 and 98.0 KPa. In this sample, displacement reached D = 7mm, and the shear stress τ, increased linearly. The volume change characteristic during shear shows that the specimen increases in volume under the normal stress σ_N =24.5kPa, but decreases little at the other normal stresses.

Lines of rupture, including those of other landslide areas, are shown in Fig.10. Landslide areas where shearing tests were made, are beside Odora Neba Village, Adera and Hongo, Kamiyahagi Town, as well as Nakato and Inabashi, and Inabu Town. Strength coefficients, C_d and ϕ_d , as well as K_{15}, results of a constant-head

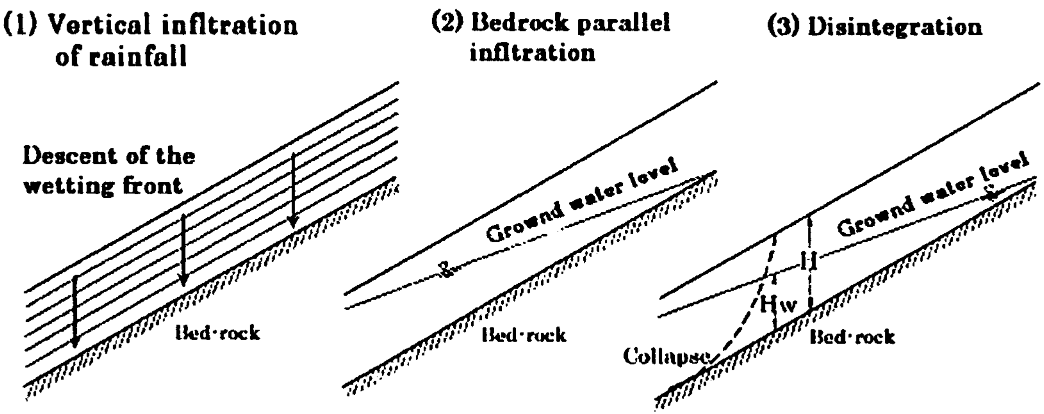

Fig. 8 The three slope failure mechanism stages. (Enoki 1999)

Table 3. Geological characteristics of surface soils on the failed slopes.

Area	Spot	Density ρ_s(g/cm^3)	D_{max} (mm)	$P_{2.0}$ (%)	$P_{0.075}$ (%)	D_{50} (mm)	D_{10} (mm)	U_c	U_c	ω (%)	Soil class
Kamiyahagi Town	Tappara	2.503	22.3	75.0	5.6	0.88	0.12	10.8	1.19	20.4	SG
Kamiyahagi Town	Adera 1	2.517	12.5	54.9	1.5	1.4	0.15	15.3	0.64	11.2	SG
Kamiyahagi Town	Adera 2	2.406	20.2	73.5	1.1	0.46	0.1	8.5	0.52	31.5	SG
Kamiyahagi Town	Honngou1	2.536	16.7	42.6	0.7	2.5	0.28	12.1	0.89	8.1	GS
Kamiyahagi Town	Honngou2	2.538	19.5	42.9	0.4	2.6	0.22	17.3	0.60	10.4	GS
Kamiyahagi Town	Shiraisawa	2.551	32.8	55.0	3.9	1.7	0.24	10.0	0.98	10.2	GS
Inabu Town	Nakaatari	2.487	31.8	67.7	5.0	0.33	0.085	8.2	0.43	31.7	SG
Inabu Town	Inabashi	2.365	14.3	95.8	2.1	0.46	0.11	5.0	1.12	42.0	S
Neba Village	Odona	2.472	23.1	68.8	2.1	1.1	0.16	9.4	1.13	13.2	SG
Obara Village	Mitukuri	2.538	35.2	41.4	4.1	2.9	0.17	26.5	2.04	8.7	GS

The number in the spot show the picking place.(1: Slope upper part, 2: Slope lower)

Table 4. Constituent minerals of the surface layer soil on the failed slopes.

Area	Spot	Typical clay minerals	Rock minerals
Kamiyahagi Town	Tappara	None	Quartz, Gibbsite
Kamiyahagi Town	Adera 1	None	Felspar
Kamiyahagi Town	Adera 2	Montmorillonite, Vermiculite	Quartz, Felspar, Gibbsite
Kamiyahagi Town	Honngou 1	Montmorillonite, Vermiculite, Chlorite	Quartz, Felspar
Kamiyahagi Town	Honngou 2	Montmorillonite	Quartz, Felspar, Gibbsite
Kamiyahagi Town	Shiraisawa	None	Quartz, Felspar
Inabu Town	Nakaatari	Vermiculite	Felspar, Talc, Gibbsite
Inabu Town	Inabashi	Vermiculite, Chlorite	Quartz, Felspar, Talc
Neba Village	Odona	Kaolinite	Felspar, Talc
Obara Village	Mitukuri	None	Quartz, Felspar

Table 5. Box shear and permeability test results.

Area	Spot	C_d (kPa)	ϕ_d (°)	k_{15} ($\times 10^{-3}$ cm/s)
Kamiyahagi Town	Adera	20.9	34.9	0.8
Kamiyahagi Town	Hongou	6.0	47.9	10.1
Inabu Town	Nakatou	25.4	27.5	0.6
Inabu Town	Inabashi	17.6	38.3	3.0
Neba Village	Odona	13.0	38.1	2.1

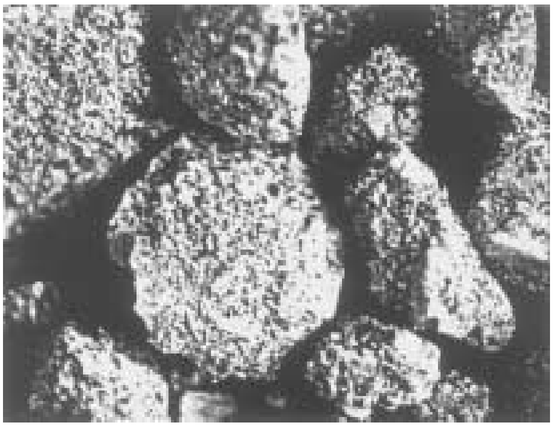

Photo. 7 Enlargement of strong wind granite（granite soil）.

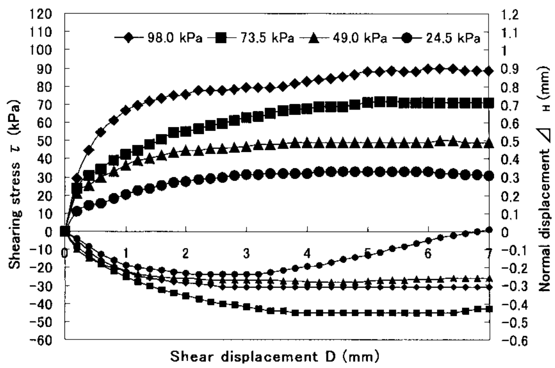

Fig. 9 Direct shear test（CD）results, Odona Neba Village

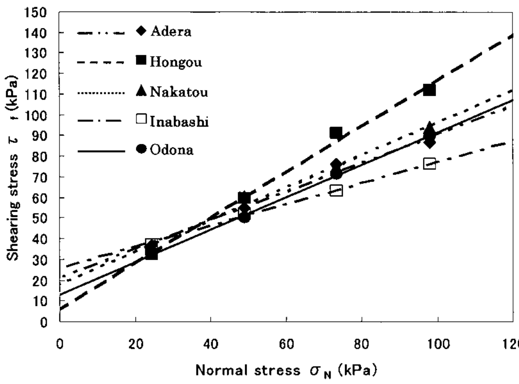

Fig. 10 Relationship between normal and shearing stress various sites.

permeability test, (Fig.10) are given in Table 5. In this table, the adhesive strength becomes C_d = 6.0-25.4kPa, and internal friction angle ϕ_d =27.5°-47.9°. These findings give values closer to those of the soil whereas the strength constant of the general Masado gives someone higher/lower values in the report of Yamamoto, et al. (2001). These findings also seem to be affected by the mixing of humus soil and the difference in the degree of weathering of the Masado. The permeability test gave a permeability coefficient of K_{15} = 2.1-10.1$\times 10^{-3}$cm/s.

The geologic map near Kamiyahagi Town in the region investigated is shown in Fig.5. Inagawa granite, Tenryukyo granite, Mitohashi granite, Busetu granite and Ryoke metamorphic rock are distributed in this area (Nakai, 1970). The area (Table 2, No.A3-A11) with rainfall more than 400mm in particular abounds in Tenryukyo granite. It has a steep landform in which the rock mass has been exposed, weathering erosion is slower than for the other granites, and the Masado of the surface layer is thinly extensible.

7. RELATIONSHIP BETWEEN SLOPE FAILURE AND THE AMOUNT OF RAINFALL

Fig.12 shows the relationship between the slope gradient and catchment area of the catchment landform of the area near Kamiyahagi Town for the occurance of landslides. The unfailed slope shown was chosen, because of the watersheds of both shores along several kilometers of the upper and lower stream between ridge and river, base on the mapping of 1/25000 and an aerial photograph. Although unfailed slopes are frequent even for steep slopes, there could be many failed slopes when the slope gradient is small and the catchment area large. We showed that the scale of the catchment area has a greater effects on slope failure than the size of the slope gradient. The failed slope area in Odona, Neba Village is shown in Fig.13. No wide catchment area can be seen in this area in Fig.12, the area being about $32 \times 10^3 m^2$ at maximum. The slope gradient is 20°-55°, and the failed area also is within a similar landform condition.

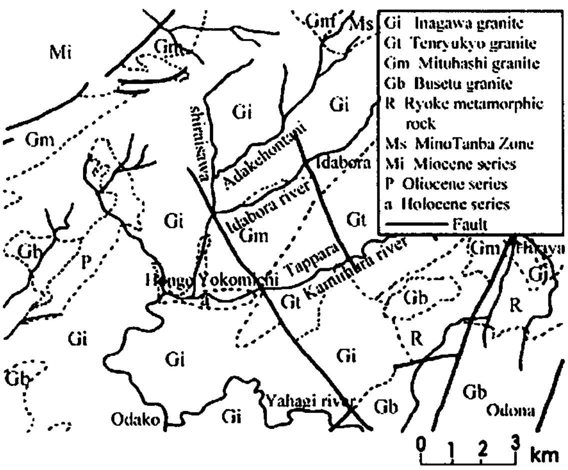

Fig. 11 Geological map of the Kamiyahagi Town area.

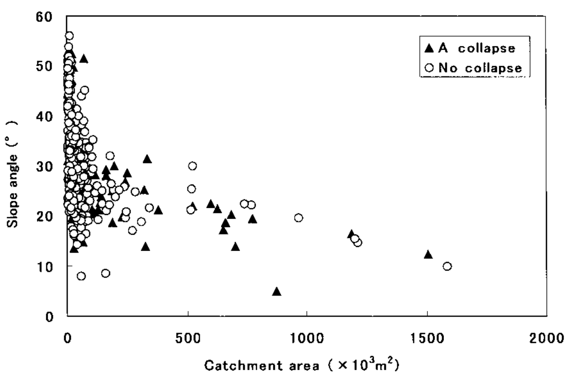

Fig. 12 Relationship between the catchment area and slope gradient of the failed slope.

8. SUMMARY

Te torrential rain disaster of September 2000 in the Yahagi River basin was investigated. Because the heavy rain region covered a highland 500 - 1,000m above sea level, and the steep slope and catchment area constituted a large catchment landform, the slope failure caused by the torrential rain seriously damaged the national highway and the downstream part of the river. The survey results are summarized as follows:

1) Slope failure occurred mainly in the highland and wide catchment area in a catchment landform that had steep slopes.
2) Failed slopes showed for easy failure, the surface soil consisting of a weathering residual soil and a colluvial deposit.
3) Slope failure mainly occurred in a plantation area where the surface soil layer was thin, and plantings were the short root type.
4) Driftwood produced when trees in a planted grove fell, the liver bank erosed, and debris and soil of $40{,}000 m^3$, flowed into Yahagi Dam Reservoir, nearly 70 times the average annual amount.
5) Looseness of the mountain slopes due to the erosion after tree clearing, leaving stumps, became an inducement for slope failure.

Investigations of the disaster in the mountainous area caused by the Tokai heavy rain are extensive, and further investigations are being done at present. Research findings on the relationship between stumps and slope failure, however have been few and that topic is considered a future area of research.

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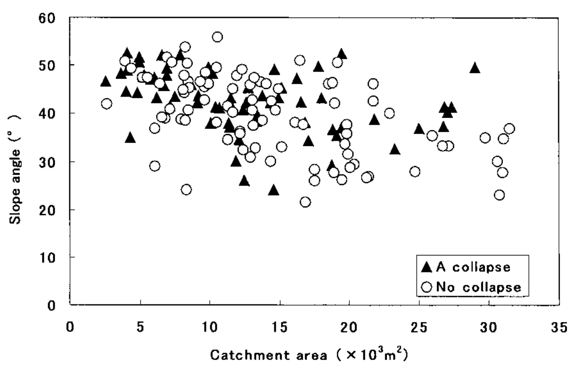

Fig. 13 Relationship between the slope gradient and catchmet area (Odona Neba Village)

Construction Office, Nagano Prefecture; and the Nagano Prefecture Ina Local Office (forest section). Thanks also are owed to graduate students Miyuki Mizuno and Shingo Miyata who are activity involved in this field study.

REFERENCES

Deer, D.U., Patton, F.D., 1971: Slope stability in residual soils, Proc. 4th Pan-American Conf. S.M.F.E., Vol.1, p.92 .

Enoki, M., 1999: Slope surface failure caused by precipitation, Soils and Foundation, Vol.47, No.5, pp.17-20.

Kimiya, K., 1975: Tensile strength as a physical scale of weathering in granitic rocks, Jour. Geol. Soc. Japan, Vol.81, No.6, pp.349-364.

Ministry of Land, Infrastructure and Transport, Chubu District Improvement Station, 2000: The material of Ministry of Land, Infrastructure and Transport, Chubu District Improvement Station, (in Japanese).

Nakai, Y., 1970: On the granites in the Mikawa district, Aichi Prefecture, Central Japan Earth Science (Chikyu Kagaku), Vol.24, No.4, pp.139-147, (in Japanese).

Nishida, K., 1986: The engineering properties of weathering residual soil, Kajima Institute Publishing, pp.16-20, (in Japanese).

Nishida, K., 1991: Engineering properties and problems of residual soil, Soils and Foundation, Vol.39, No.6, pp.1-8.

Shimizu, Y., H. Okada, 2001: An investigation of slope failures induced by the Tokai torrential rain, Advances in River Engineering, Vol.17, Proc. Japan Natural Disaster Institute Scientific Lecture Association, pp.81-82, (in Japanese).

Shimizu, Y., H. Okada and T. Kamai, 2001: An investigation of the slope failures induced by torrential rain, Soil and Foundations, Vol.49, No.11, pp.13-15.

Shimizu, Y., N. Tokashiki and H. Okada, 2002: On the investigation of slope failure of a granite zone by torrential rain, 11th Japan National Symposium on Rock Mechanics, No.102, CD, 6p, (in Japanese).

Tsujimoto, T. (Head investigator), 2001: Study on disaster caused by heavy rainfall in Tokai region, Japan, September 2000, Reports of research results of “Grant-in Aid for Special Purpose 1, 2000”, (in Japanese).

Yamamoto, T., Suzuki, M., Harada, H. and Terayama, T., 2001: Recent rainfall characteristics and granite slope failure in Hiroshima Prefecture, Case history of the 1999 heavy rainfall disaster in Hiroshima, Soils and Foundation, Vol.49, No.1, pp.13-16, (in Japanese).