Features of Slope-Movements due to Heavy Rainfalls in the SHIRASU Region of Southern Kyushu

Motohisa HARUYAMA

(Laboratory of Erosion Control)

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ABSTRACT

Baiu-fronts and typhoons passing through southern Kyushu and its adjacent area often bring about extraordinarily heavy rainfall, and, consequently, result dangerous floods and collapses of hill-slopes with Shirasu. Shirasu, which is widely distributed over souhern Kyushu, is very susceptible to water erosion and ready to collapse. This paper deals with the failure of hill-slope that occurs in the period of heavy rainfall. In this paper, the author classifies the failure of hill-slope into ten basic types according to the features of slope-movements and describes their causes for failures briefly.

The hill-slopes with Shirasu are likely to be led to the most frequent collapses in the event of the rainfall exceeding about 300 *mm* during a spell of rain and in less than several hours after the time when the maximum hourly rainfall has occurred. *Key words: erosion, landslide, Shirasu, site investigation, special soil, volcanic soil. IGC: B3*

INTRODUCTION

Shirasu, the great volcanic product from Aira and Ata volcanoes, is widely distributed over southern Kyushu, Japan. Shirasu is classified geologically into twenty several kinds. However, the author has classified Shirasu into five groups, namely, decomposed Shirasu, proper Shirasu, hard Shirasu, Shirasu-like deposit, and pumice-fall deposit, from the standpoint of soil engineering, according to its physical and mechanical characteristics (HARUYAMA, 1973).

The schematic section of hill-slope with Shirasu is shown in Fig. 1. Shirasu deposits are covered directly with a loam bed. The loam bed is the decomposed product derived from younger volcanic ash-beds, and is of a black or brown color. Layers of secondary and decomposed Shirasu are occasionally present between loam bed and proper Shirasu. Secondry Shirasu is a thin bed of pumiceous sand and gravel derived from the proper Shirasu. Decomposed Shirasu is a weathered product derived from the beds of secondary and proper Shirasu and is very loosely accumulated, having large porosity. Proper Shirasu is a loose pumiceous tuff-breccia, having some welded part in its lower part.

Humus is a top portion in the undisturbed forest soils, composed of the dark or black carboniferous residue in the soil resulting from the partial decomposition of plants and animals originally growing therein. The term topsoil is used to denote a humus and loam.

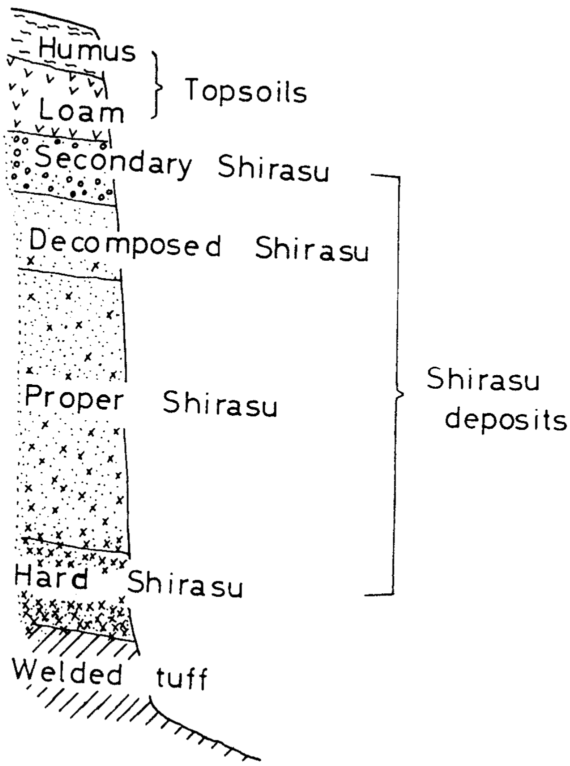

Fig. 1. Schematic section of hill-slope of Shirasu.

The beds of secondary and decomposd Shirasu are very easy to collapse, hard Shirasu suffers little from collapsing, and proper Shirasu has intermediate characteristics between the above two. Topsoil has a tendency to slide down over the Shirasu deposits.

Shirasu has a structural arrangement that bestows on it considerable strength in the undisturbed condition, and at its natural moisture content, it is possible for it to form a steep slope and cliff as shown in Photo 1. The strength in natural state seems to be caued by intergranular friction and interlocking of grains, accompanied with some cementing binder or with welding at the grain contacts (YAMANOUCHI and HARUYAMA, 1969 ; YAMANOUCHI and MURATA, 1973). But when subjected to a flow of water, Shirasu is extremely weak in the action of flowing water. In the analyses of many engineering problems in Shirasu, the largest trouble is caused by an erosive property. Accordingly, any addition of water would cause the grains to be separated to some extent, producing a loss of the strength due to interlocking and bonding. In many cases the utmost supply of water is due to heavy rainfall.

It may be assumed that the rate at which the bonding effect diminishes in its effectiveness would depend on the properties of the contaminations in rainwater and the natural rate of the solution of materials involved. The cause for the loss of strength, however, is largely dependent on the mechanical action of the flowing water, seepage water, and ground water flow. The process of it involves the detachment, pickup, and transportation of soil grains, by which is caused the collapsing of hill-slopes of Shirasu deposits.

This paper deals with the dependence of slope-movements on the amount of rainfall and the classification of various types of failure which have occurred in hill-slopes of Shirasu deposits and their mechanism of failure.

DEPENDENCE OF SLOPE-MOVEMENTS ON PRECIPITATION

In the period of extraordinarily heavy rainfall Shirasu slopes suffer extremely from erosion through sheet runoff, stream flow, and ground water flow, and if a ground becomes saturated, in that condition the action of seepage and ground water often causes the failures of hill-slopes.

Heavy rainfalls in Japan are due to two main causes, one is typhoons which are the

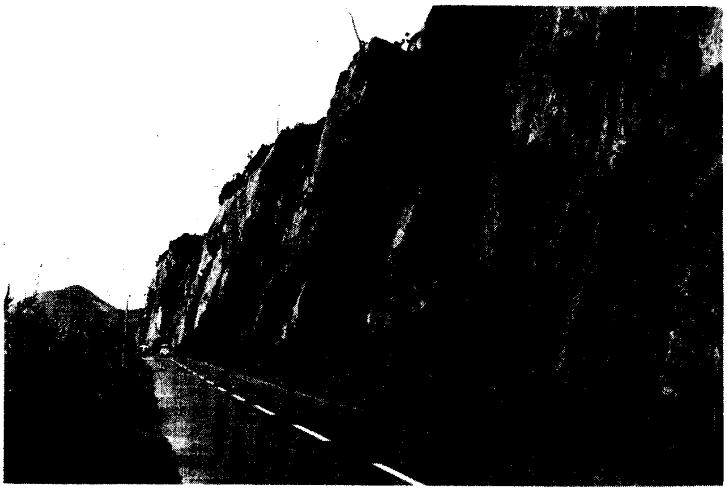

Photo 1. Cliff of Shirasu deposits.

rainstorms in autum and the other is *Baiu* which is the rainy season of long duration in early summer (FUKUI, 1970). Southern Kyushu is often struck by typhoons and characterized by a rainy location.

The average amount of precipitation for thirty years at the Meteorological observatories and the typical weather stations situated in southern Kyushu is shown in Table 1. *Baiu*-fronts and typhoons frequently bring about extraordinarily heavy rainfalls, and consequently this district suffers largely from flood disasters and failures of hill-slopes. Table 2 gives the examples of main observations of extraordinarily heavy rainfalls which recently occurred and were resulted in subversive disasters.

Table 1. Monthly and anual precipitations at the typical spots in southern Kyushu (the average of rainfalls for thirty years)

Observatory	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Anual	Period
Kagoshima	91	108	144	235	273	493	347	246	205	107	101	83	2433	1941-1970
Kanoya	78	126	165	239	289	501	392	290	237	147	106	82	2652	1931-1960
Tarumizu	67	108	137	193	228	407	312	247	212	99	92	75	2177	1931-1960
Shibushi	60	113	148	202	213	350	304	276	239	139	93	63	2200	1931-1960
Miyazaki	56	97	143	216	289	440	343	302	296	207	139	67	2594	1941-1970

In individual collapsing areas of Shirasu slopes, the author has studied the influence of the amount of precipitation on the activation of the failures of hill-slopes with geological and topographical aspects taken into consideration. The typical failures of hill-slopes brought about by the extraordinarily heavy rainfalls in 1971 and 1972 are summarized in Table 3.

In rainy and typhoon seasons the hill-slopes of Shirasu are likely to be led to the failure due to topsoil slide in the event of heavy rainfall exceeding 200 to 250 *mm* during a spell of rain as well as due to piping in the event of rainfall exceeding about 400 *mm* during a spell of rain. The area where the most frequent collapses of slopes in Shirasu region happens nearly coincides with the area where a spell of rainfall exceeds

Table 2. Example of main observations of extraordinarily heavy rainfalls in southern Kyushu in recent years

Year	Month and Day	Cause	Observatory	Rainfall: Period (hours)	Rainfall: Total amount (mm)	Maximum values: 1 hour (mm)	24 hours (mm)	48 hours (mm)	72 hours (mm)
1969	Jun. 28 Jul. 1	Baiu-front	Kagoshima	96	386	62.5	259	326	369
			Akune		429	54.0	236	288	359
			Shibizan		650		403	514	606
			Yokogawa		640		374	478	580
			Makizono		636		416	516	604
	Jul. 3 11	Baiu-front	Miyanozyo	216	573	45.0	151	265	378
			Makizono		823		202	384	484
			Kihoku		627		141	238	312
			Kurino		570		135	267	379
			Kagoshima		410	20.0	88	151	223
1971	Jul. 21 24	Baiu-front	Akune	76	622	106.0	566	591	618
			Miyanozyo		350	72.5	299	336	348
	Aug. 3 5	Ty-phoon	Yokogawa	72	593	53.0	490	580	593
			Gamou		437	60.5	352	404	437
	Aug. 27 29	Ty-phoon	Osumi	72	445	30.5	306	444	445
			Tashiro		410	—	368	409	410
1972	Jun. 17 18	Baiu-front	Miyanozyo	25	356	84.0	341	—	—
	Jun. 29 Jul. 6	Baiu-front	Okuchi	192	908	63.0	422	617	702

300 *mm*. The collapses of hill-slopes also seem to have occurred in less than several hours after the time when the maximum hourly rainfall happened. As seen in Table 3, the bases of No. 13 and 14 are not Shirasu deposits but welded tuff ; the weathered materials on the surface of tuff have slided down. The amount of the maximum hourly rainfall preceding the time of activation of collapses is larger in tuff than in Shirasu.

BASIC TYPES OF SLOPE MOVEMENTS

The basic types of slope-movements observable on the hill-slopes in Shirasu region during the period of heavy rainfall are illustrated diagrammatically in Fig. 2.

Overland water erosion

Generally speaking, Shirasu is very susceptible to erosion occasioned by the action of flowing water on slope. Hard Shirasu, however, is resistant to erosion. Areas where Shirasu ground is left unprotected or is left stripped of its topsoil by the sliding of surface-layer, as explained next, are most susceptible to sheet erosion. Sheet erosion is led inevitably to rill erosion and advanced stage, gully erosion. Erosions have damaged sloping land throughout the Shirasu deposits. Of all the erosions, gully erosion is most active and dangerous. During the gully development, the gully head has progressed toward the upper end of watershed. Since Shirasu is easily eroded, gully cross-section is to be turned into a deep glen of U-shape. Under such condition gully tends to develop a vertical wall resulting from cavings and collapses of slopes. Rill and

Table 3. Typical failures of hill-slopes due to extraordinarily heavy rainfalls occurred in Shirasu region in 1971 and 1972

No.	Spot	Type of failure	Base	Occurred time of failure ; month, day, and time	Weather station	Cause	Maximum hourly rainfall: Occurred day and time	Maximum hourly rainfall: Amount (mm)	Preceding rainfall until time of failure (mm): Hours 1	Hours 2	Hours 3	Hours 5	Hours 10	Hours 24	Days 2	Days 3	Days 5	Days 7
In 1971																		
1	Nagatoshi-cho, Sendai-shi	Piping	Shirasu	Aug. 5, 21 : 30	Sendai	Ty-phoon	5, 6 : 50	55	52	62	66	78	134	340	395	395	395	395
2	Kamitakakuma, Kanoya-shi	Topsoil slides	ditto	Aug. 5, 7 : 00	Takakuma dam	ditto	5, 6 : 00	30	30	50	62	75	119	193	284	287	287	287
3	Shimohirabo, Kihoku-cho	ditto	ditto	Aug. 5, 14 : 00	Mobiki	ditto	5, 8 : 00	28	14	28	38	62	170	286	386	386	386	386
4	Sange, Aira-cho	ditto	ditto	Aug. 6, 1 : 00	Aira	ditto	5, 21 : 00	65	1	30	58	138	273	427	—	507	507	507
5	Fukitani, Osumi-cho	ditto	ditto	Sep. 22, 6 : 00	Iwagawa	Front	22, 1 : 00	44	20	40	55	111	144	203	211	211	211	211
In 1972																		
6	Nishinokuchi, Izumi-shi	Topsoil slides	Shirasu	Jun. 12, 2 : 00	Izumi	Baiu	12, 0 : 00	65	20	85	102	157	163	163	163	163	235	235
7	Nakamura-cho, Sendai-shi	ditto	ditto	Jun. 18, 2 : 30	Sendai	ditto	18, 1 : 00	75	75	90	107	119	171	212	212	212	212	372
8	Kochigasako, Tsuruda-cho	Topsoil falls	ditto	Jul. 6, 13 : 00	Miyano-zyo	ditti	6, 12 : 00	46	46	68	81	85	116	196	272	359	405	451
9	Shimo-osako, Tsuruda-cho	Topsoil slides	ditto	Jul. 6, 12 : 00	ditto	ditto	6, 6 : 00	23	22	35	39	39	70	150	226	316	362	408
10	Maemo, Hishikari-cho	Topsoil slides and piping	ditto	Jul.5, 16 : 00	Okuchi	ditto	5, 13 : 00	63	13	21	84	125	172	268	314	440	502	572
11	Shimode, Hishikari-cho ard Harada, Okuchi-shi	ditto	ditto	Jul. 6, 12 : 00	ditto	ditto	5, 13 : 00 6, 10 : 00	63 50	19	69	101	105	242	422	617	702	778	851
12	Tashiro, Okuchi-shi	ditto	ditto	Jul. 6, 13 : 30	ditto	ditto	ditto	ditto	20	39	89	122	248	411	632	713	798	870
13	Okawa, Akune-shi	Topsoil slides	Welded tuff	Jun. 12, 11 : 30	Akune	ditto	11, 21 : 27	87	3	6	17	35	75	203	203	203	247	247
14	Haginosako, Tsuruda-cho	ditto	ditto	Jun. 18, 2 : 00	Miyano-zyo	ditto	18, 1 : 00	84	84	159	173	199	240	306	308	308	308	479

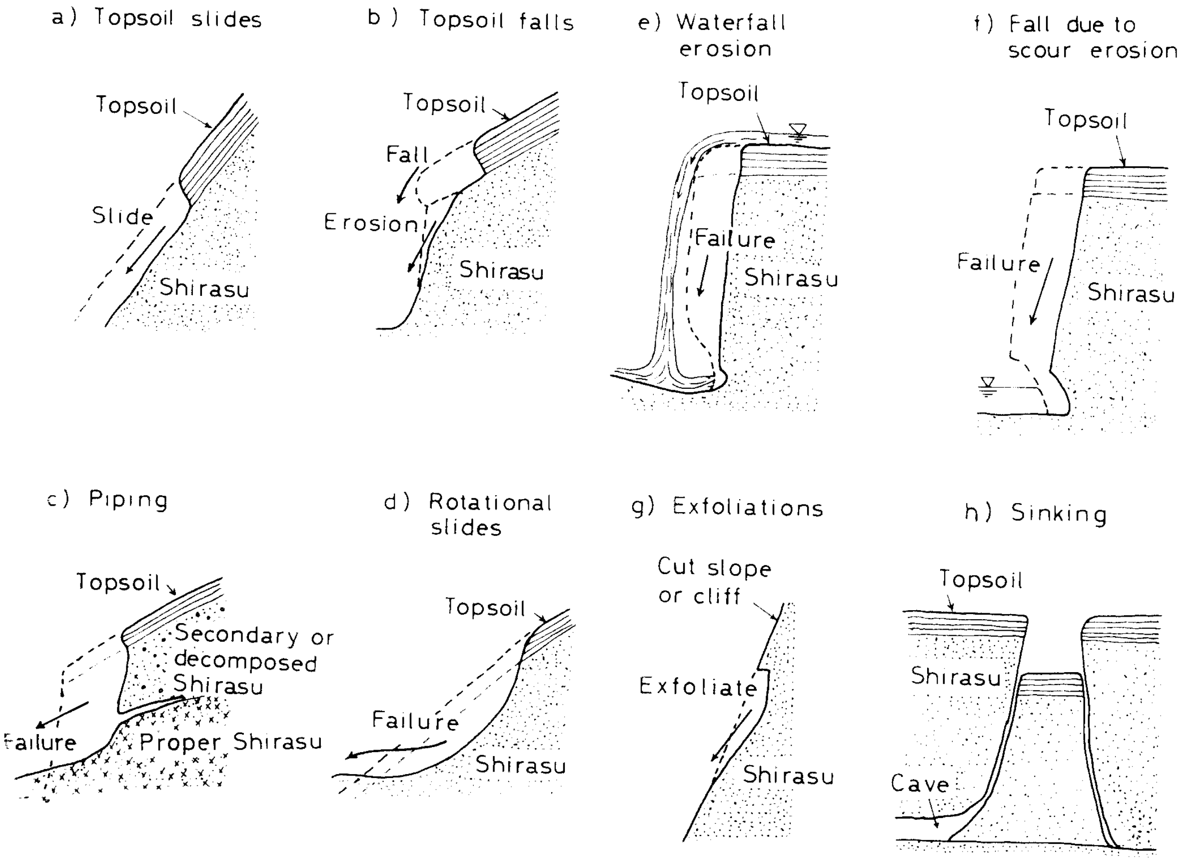

Fig. 2. Some basic types of mass-movemnts in Shirasu slopes

gully erosions are shown in Photo 2 and 3 respectively.

Topsoil slides.

Topsoil slides are the mass-movements of such shallow topsoils as humus, loam, or

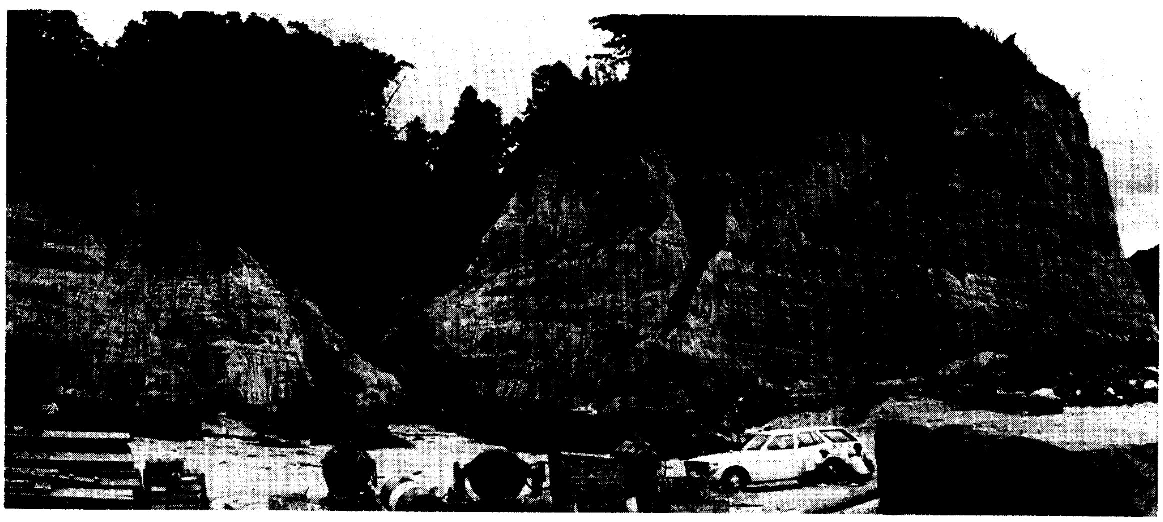

Photo 2. Rill erosion.

Photo 3. Gully erosion.

weathering materials of bedrock. This type occurs on the hill-slopes dipping 30 to 60 degrees and is especially frequent on the hill-slopes of 50 to 60 degrees. The topsoils may slide down in a thickness from several tens centimeters to some one meter. As a consequence of removal of topsoil, exposed Shirasu suffers from water erosions as described above, and the successive erosions often enlarge the scale of slope-failures. Topsoil slides on Shirasu deposits are the most frequent mass-movements in the basic types of slope-movements in the Shirasu region. The typical failure of hill-slopes due to this type is shown in Photo 4. These sliding failures of superficial deposits seem to take place as the results of the following phenomena : the increase in the weigt of soil itself caused by the infiltrated water in a rainfall, the lowering of shearing resistance caused by soil saturation, the development of excessive pore water pressure, the occurrence of intermediate flow in the topsoil layer, and others.

Photo 4. Topsoil slides.

Topsoil falls

Topsoils on the upper part of cliffs and cutting-slopes of Shirasu fall down, and consequently the bared Shirasu beneath topsoils suffers from erosions by waterflow on slope. Essentially topsoil falls probably take place out of the same causes as topsoil slides. But topsoil falls apparently differ from topsoil slides in getting no support from side. The hill-slopes where there are tall trees on the ledge of cliffs occasionally cause these fallings because trees are swayed by the windstorm. The failure of slope due to this type is shown in Photo 5.

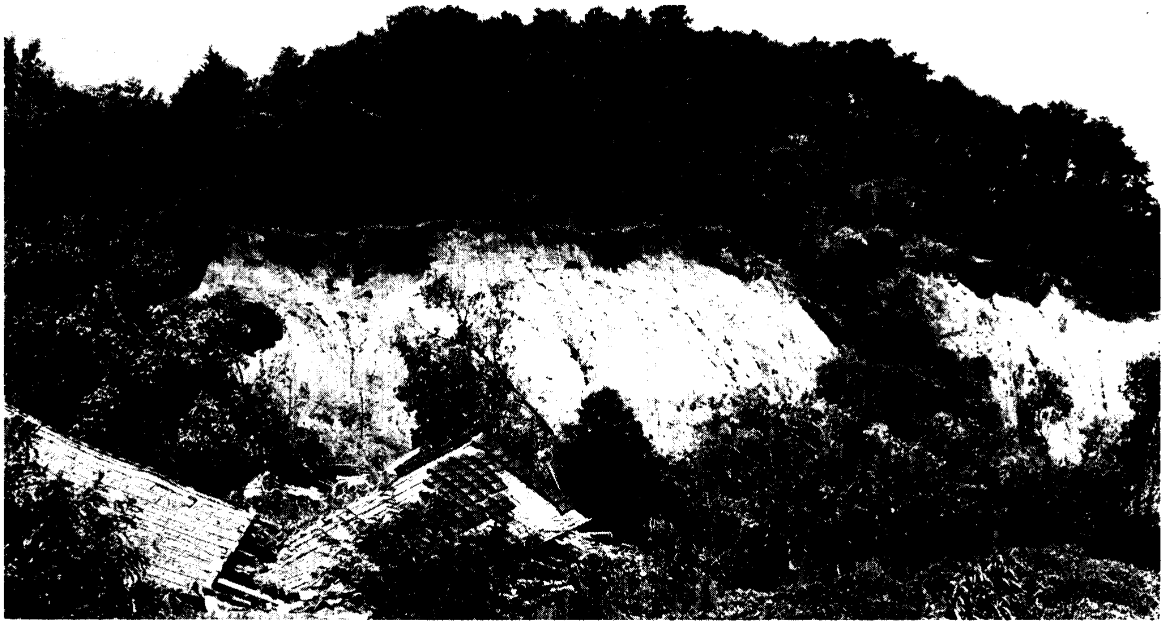

Photo 5. Topsoil falls.

Collapses caused by piping

This frequently occurs at a place where the foot of hill-slopes has been cut off and a fountain gushes out. Piping is caused by permeating-water or fissure-water squeezed along the boundary plane of beds which are different in Shirasu strength or in permeability. If the seepage-water-pressure becomes effective, ground-water concentrates in some weak points produced by the heterogeneity of the Shirasu deposits, often issuing from the foot of cliffs, the surface of slopes, the boundary plane of deposits, or from the fissures and joints in Shirasu deposits. If such phenomena occur, fine grains of Shirasu are washed out by the subsurface-erosion due to action of water, leaving some pipe-like water channel in Shirasu deposits, and this finally is led to collapse of slopes. The occurrence of failures of hill-slopes due to piping is especially frequent in layers of decomposed and secondary Shirasu. The examples of piping are shown in Photo 6.

Rotational slides

This type of slope-movements usually occurs in the hill-slopes of deeply weathered and homogeneous deposit standing at an inclination of 20 to 30 degrees, and occasionally in the steep slopes of nearly 60 degrees. This, however, is a rare occurrence in Shirasu deposits. Rotational slides are caused by the following phenomena: the weight-increase of soil due to the permeated rainwater, the rise of groundwater level, the developing of pore water pressure, the lowering of shearing resistance, or the decrease in bearing capacity of the ground under the hill-slopes. Sometimes, several days after the end of heavy rainfall rotational slides suddenly cause a major slope-movement, and

Photo 6. Slope failure due to piping in the slope of decomposed Shirasu.

the reason is probably due to the time-lag in the rise of groundwater level, based on the permeability of Shirasu. Photo 7 shows the rotational slide that initially occurred in hill-slope of proper Shirasu at a clear weather after a period of extraordinarily heavy rainfall. Therefore, there is no mark of the water erosion peculiar to Shirasu on the exposed slope of Shirasu hill.

Photo 7. Rotational slides in hill-slope of proper Shirasu.

Waterfall erosion

At the marginal part of Shirasu plateau waterfalls are often formed in a period of heavy rainfall by the concentrated falling of overland water and by that of the overflowed water from gutters. Thus waterfall developes a plunge pool at its bases which

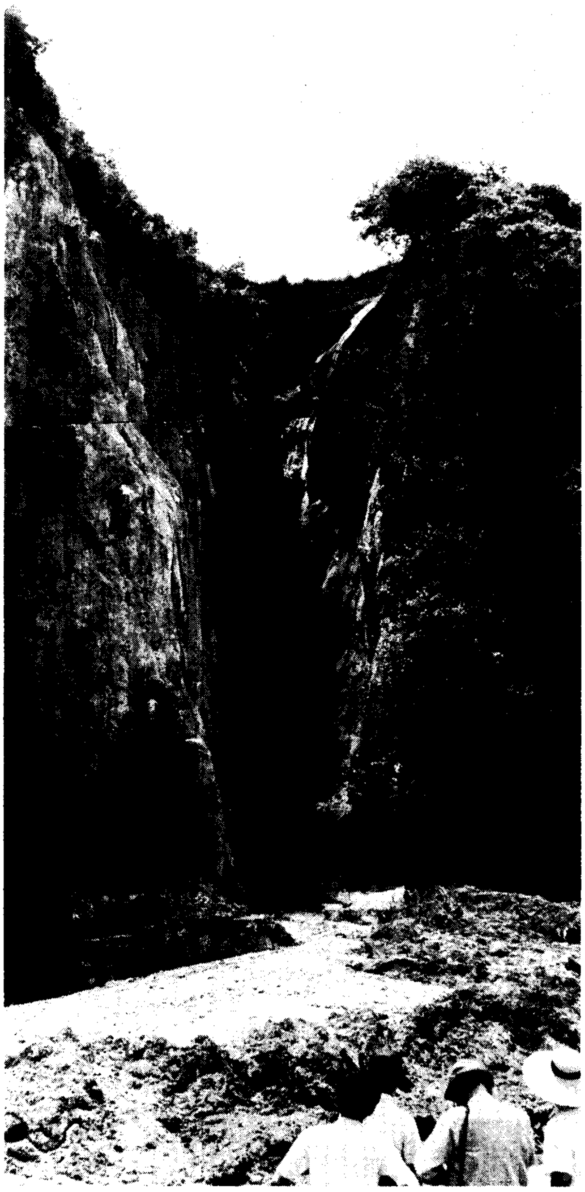

Photo 8. Waterfall erosion.

are cut back under the fall, and it brings forth scouring below the water surface and caving of the wall above. Then collapses in the overhung cliffs may be caused by the loss of supporting capacity of Shirasu itself and by the development of tension cracks behind the cliff-crest. Waterfall erosion at the gully head causes the upstream movement of the head, and develops a deeply erosion ravines. Photo 8 shows the collapse of tihs type in Shieasu hill.

Falls by scour erosion

If the supporting part of slope is removed by the washing out of the foot of criff, owing to cliff-side streams or groundwater effusion, caving is brought forth at the cliff-foot of Shirasu depostis. The development of caving results in tension cracks behind cliffcrest in the same way as above. The cracks initially develop along the pre-existing joints or fissuses in Shirasu deposits. The joints and the fissures are usually filled by clay, sand, lor gravel derived from foreign rocks. They look like a sheet of membrane or a muddy or gravelly pipe (Photo 9) and trees have occasionally spread deep roots quite fan-likely shaped into them (Photo 10). The progressive growth of caving and cracks bring about the increase in the unsupported weight of separating cliff-mass, and eventually is led to falls along nearly vertical plane. YAMANOUCHI et al. (1973) explained this collapse as the example of typical brittle failure in slopes. This type of slope-collapses is sometimes called the toe failure due to caving, to cliff-foot erosion, or to stream bank erosion. The typical failure due to this type is shown in Photo 11.

Exfoliations

Exfoliations are rather neglected and small-scale failures inside the steep slopes of, for instance, the artificial cuts or cliffs, and particularly in nearly vertical slopes. Exfoliations usually occur along the pre-existing joints or fissures, or along the fan-like spread of roots fastened deep into joints or fissures. The detection of the initiator of exfoliating may probably be performed by the following interpretation that inside the surface zone of slopes the changes in water content due to weather conditions or rain-

Photo 9. Joint filled with clayey soil.

Photo 10. Fan-like spreading of roots into joint and exfoliation along that.

falls are the principal triggering events. Photo 12 is the example of this failure in hill-slope of Shirasu deposits.

Debris flows

The term debris flows designates a swift flow of pumiceous sand and mud heaped up on ravine bed or that of degraded slope debris oversaturated by rainwater. This also occurs in some weathering mantles of tuff or andesite ; and when this occurs in Shirasu deposits a peculiar appearance as if the whole ground were liquated may be seen. A typical failure due to debris flows is shown in Photo 13. The place in Photo 13 was proper Shirasu hill and paddy field before the damage due to debris flows, but in only a single night, a complex of Shirasu and rocks of about half a million cubic meters in volume was washed-out away by debris flows accompanied with downward erosion and lateral corrosion, and consequently a short-cut was fromed. The heavy rainfall brought about this damage resulted from the typhopn on Aug. 3, 4, and 5, 1971 (Table 2).

Sinkings

This is a rare type of collapse, observable in a form of ground sinkings accompanied by the piping action previously mentioned. Some air-raid shelters opened in Shirasu grounds in the war time may possibly cause such sinkings.

Photo 11. Slope failure due to scour erosion.

Photo 12. Exfoliation in a steep cut slope.

CONCLUSIONS

The following were ascertained after the investigations on the failures of hill-slopes that occurred in Shirasu region during the period of extraordinarily heavy rainfall.

1) The hill-slopes of Shirasu deposits are likely to be led to the most frequent collapses in the event of rainfall exceeding about 300 *mm* during a spell of rainfall. The amount of precipitation seems to have a direct effect upon the failure type of hill-slopes.

Photo 13. Debris flows accompanied with erosion and corrosion.

2) The slope-movemeots in Shirasu hills frequently occur in the area where the maximum hourly rainfall exceeds 50 to 60 *mm* and in less than several hours after the time when the maximum hourly rainfall occurred.

3) The failures of Shirsu hill-slopes due to heavy raifall are to be classified into ten basic types, namely, overland water erosion, topsoil slides, topsoil falls, piping, rotational slides, waterfall erosion, falls by scour erosion, exfoliations, debris flows, and shinkings.

4) The types of the most frequnt slope-movements are slides and falls of topsoils bringing about sheet and rill erosions. Piping secondarily occurs, and waterfall erosion and falls by scour erosion also considerably occur, rotational slides occur rarely, exfoliations are sheet failure of slope-surface, and debris flows and shinkings are peculiar types.

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