3.4 Geological Survey

3.4.1 Geology of the landslide area

In this section, the results of the field observation for geological stratigraphy are described.

The area is characterized by the central Ethiopian highlands. Geologically, the gorge is made by thick stratified Mesozoic sedimentary rocks and overlain by a series of basaltic lava flows. Adigrat Formation is covered conformably by Abay Formation and Antalo Formation, which were deposited Middle to Late Jurassic. Ashangi Formation which was deposited during Tertiary covers them partially.

Rock appearance height and its thickness are shown in Table 3.4.1. Figure 3.4.1 is a geological map of this area as a result of the surveys, and Figure 3.4.2 is a schematic geological section of the Abay Gorge.

Table 3.4.1 Rock appearance height and its thickness

Era	Formation	Rock type	Dejen side		Height difference (m)	Goha Tsiyon side	
			Elevation (m)	Thickness (m)		Thickness (m)	Elevation (m)
			2440		80		2520
Tertiary	Ashangi F.	Basalt and Pyroclastic		380		380	
			2060		80		2140
Jurassic	Antalo F.	Upper limestone		550		500	
			1510		130		1640
		Gypsum		160		130	
			1350		160		1510
	Abay F.	Lower limestone		70		70	
			1280		160		1440
		Siltstone and Shale		40		120	
			1240		80		1320
	Adigrat F.	Sandstone		210		290	
			1030		0		1030

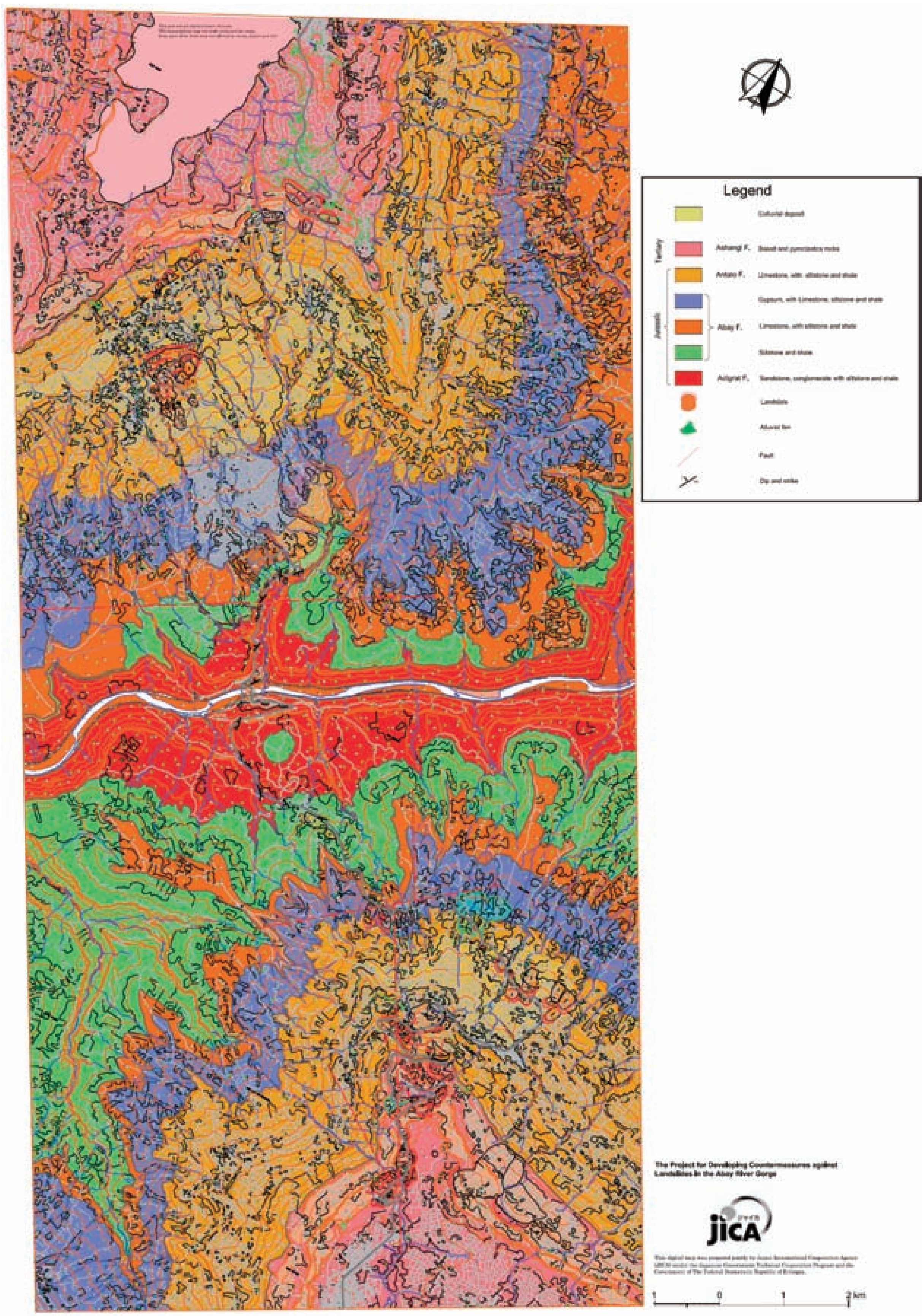


Figure 3.4.1 Geological map of Abay Gorge

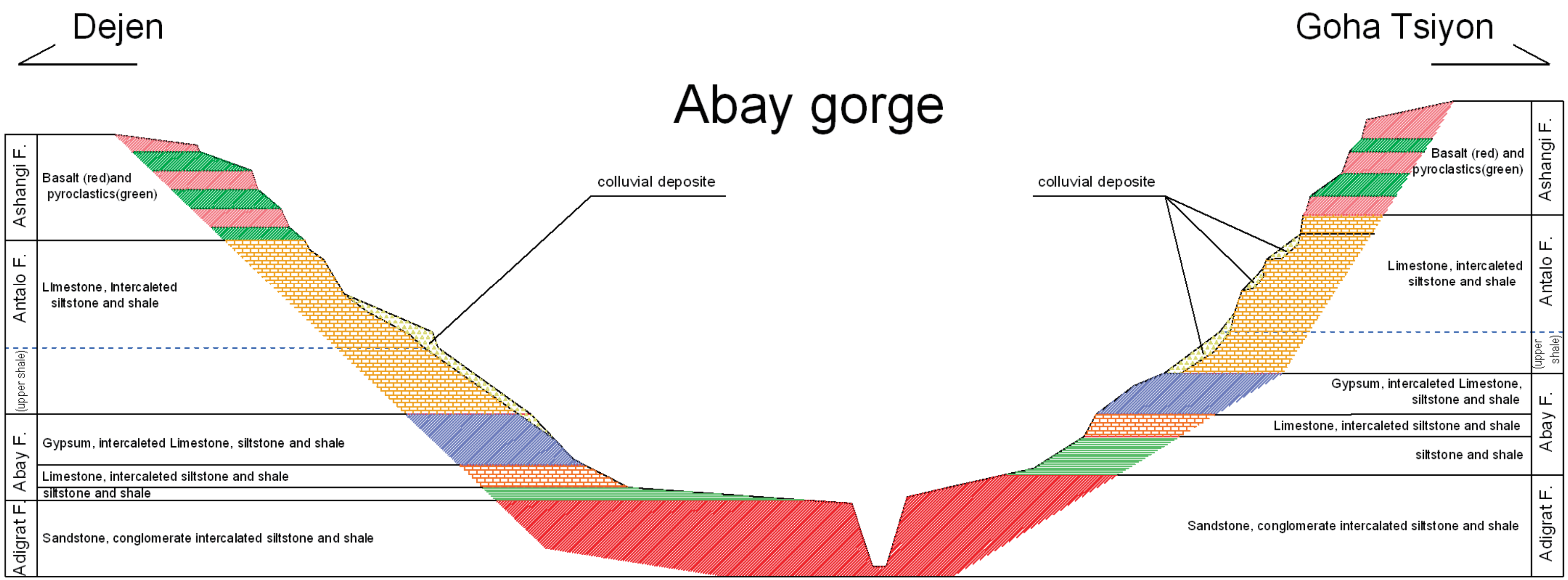


Figure 3.4.2 Geological schematic section of the Abay Gorge (not to scale)

3.4.2 Surface anomalies of the landslides

a. Surface anomalies of the landslide in L/S00 (ST.0+200 to 1+100)

In this area, several small landslide blocks can be classified as shown in following figure. The crack near the toe of the L/S00-1 block is conspicuous. From the fact that the lower part of the L/S00-1 is upthrusting and the surface is oppositely dipping as well as the inclination of the large rock block at the lower part, it can be estimated that the direction on the landslide is skewed to the southwest from the strike of the slope.

Relatively new cracks were observed in the two landslide blocks on the upper side of the road. Therefore several minor deformations seem to be still continuing.

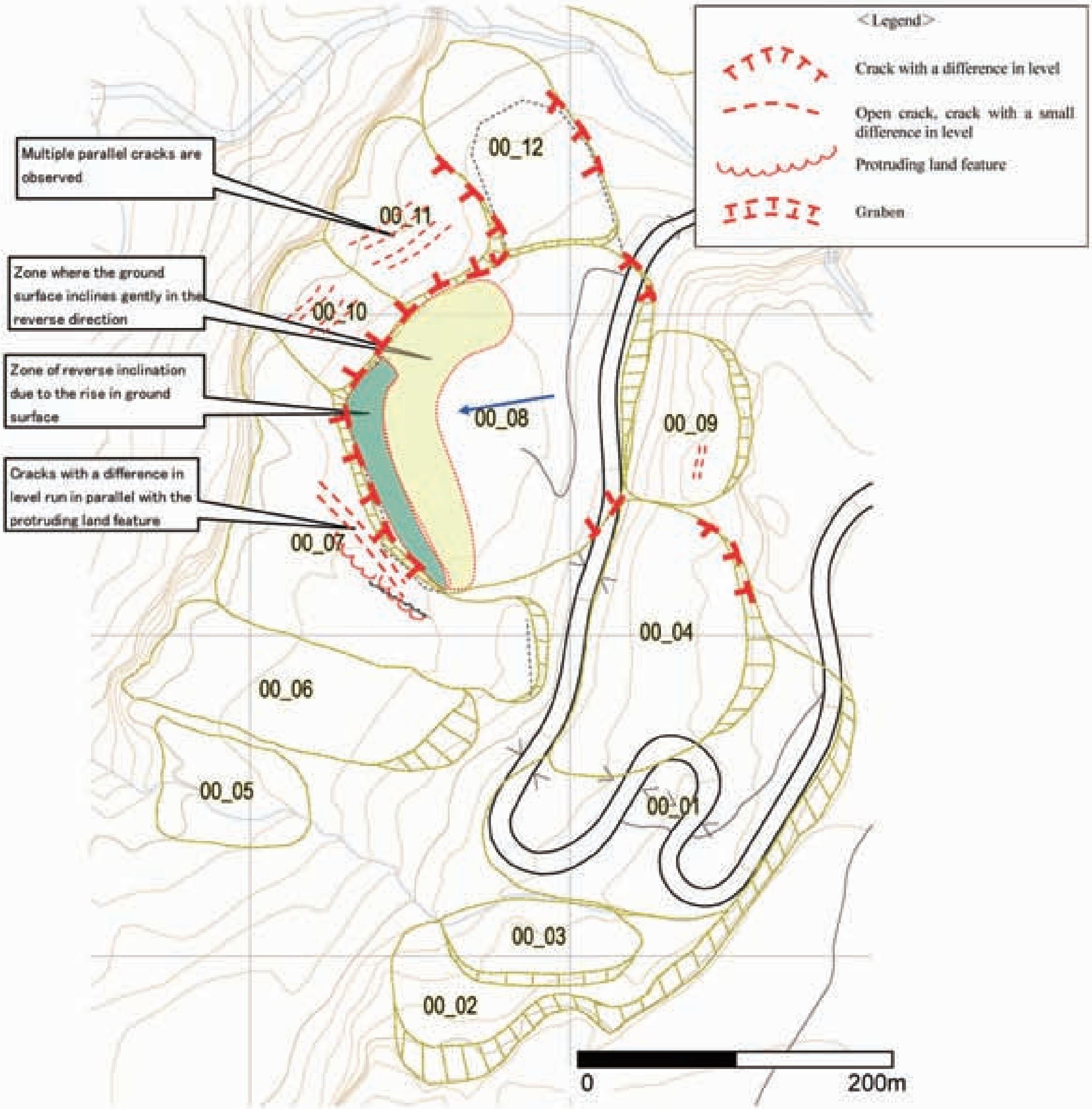


Figure 3.4.3 Surface anomalies in L/S00 (ST.0+200 to 1+100)

b. Surface anomalies of the landslide in L/S05 (ST.4+800 to 5+600)

In this area, soil and sand which have been collapsed from the crown of the L/S05-1 block have been piling up on the upper part of L/S05-1. The L/S05-2 on the valley side is made of the debris from the L/S05-1.

From new cracks along the old channel that crosses the upper part of L/S05-1 and small collapses on the lower part, it is considered that micro-displacements are still occurring in the L/S05-1.

New cracks at the top of the L/S05-2 on the valley side of the road indicate a continuing series of small collapses; therefore it is considered that small displacement is also occurring in this block.

c. Surface anomalies of the landslide in L/S22 (ST.21+600 to 22+300)

In this area, there are two blocks that are believed to have been active in recent years; a predominant displacement is the L/S22-1. This block could have resulted from events that occurred when the toe of the block has been eroded by surface water.

The main scarp and cracks 1 to 2 m in height on the valley side are quite close to the new road.

d. Surface anomalies of the landslide in L/S27 (ST.27+200 to 28+400)

In this area, multiple landslide blocks overlap. As indicated by the significant subsidence of the road in recent years, the activities in the L/S27-2 are most conspicuous in this area. It is possible that the L/S27-2 and the L/S27-3 are a continuous block from the viewpoint of the deformation on the road as of April 2009; however, because it was unable to find the reasonable factors through satellite image interpretation or reconnaissance, it is assumed here that they are separate blocks.

In the L/S27-1, where there is a broken church and a new church under construction, multiple displacements consisting of cracks by landslide activities are developing; however, the cracks are not new or clear.

In contrast, a new continuous crack, as well as the main scarp and graben, can be observed in the L/S28-1; a subsidence on the road can also be an extension of the deformation direction.

e. Surface anomalies of the landslide in L/S28 (ST.28+400 to 28+800)

This area is positioned at the head of a large landslide covering the whole region. There are continuous clear main scarps, and cracks, whose mountain side is sinking, that runs roughly in parallel with the main scarps. L/S28-2 is one of the multiple landslide blocks in the area.

However, as to whether the current L/S28-3 block is a part of the huge landslide or is independent from the big one, it is difficult to judge only through satellite image interpretation and reconnaissance. Considering the size of the subsidence, however, it can be estimated that a moving block is at least 300 m wide.

3.5 Monitoring

3.5.1 General devices for landslide monitoring

The methods of landslide monitoring are classified into two categories: measuring movement; and measuring inducing factors. Furthermore, the methods of measuring movement are classified into two categories: monitoring under the ground, or in boreholes; and monitoring on ground surface.

Inducing factor surveys contain precipitation observation, surface water observation, groundwater observation, seismic observation, which are usually conducted landslide monitoring simultaneously.

Table 3.5.1 Type of landslide monitoring

Location	Purpose	Method of monitoring
Borehole	Slip surface survey	**Borehole inclinometer measuring**
		Pipe strain gauge measuring
		Borehole extensometer measuring
	Groundwater survey	**Borehole water level measuring**
		Borehole pore pressure measuring
		Groundwater survey
		Groundwater quality investigation
Ground surface	Ground surface deformation survey	**Ground surface extensometer survey**
		Ground surface inclinometer survey
		Ground survey
		GPS survey
	Inducing factors survey	**Precipitation observation**
		Surface water observation
		Seismic observation
		Traffic census (landslide near roads)

Devices in **bold** were installed in the Project.

Figure 3.5.1 Various kinds of devices for landslide monitoring

3.5.2 Plan of monitoring devices installation

To grasp movements and characteristics on the landslide area, monitoring is undertaken at the five selected priority sites decided upon in discussions in advance, where warranted by the site conditions. The monitoring devices adopted in the Project are: 1) Extensometer, 2) Borehole extensometer, 3) Borehole inclinometer, and 4) Groundwater level meter as described in the following section. The devices 2) to 4) are installed with special casings and/or filling sand/gravel in each bore hole after completion of drilling to monitor condition in the ground at the landslide area, whereas the device 1) is set along the direction of landslide movement on the surface.

Table 3.5.2 Monitoring sites

No.	Location	Name	Monitoring			
			Extensometer	Borehole Extensometer	Borehole Inclinometer	Groundwater level meter
1	0+800～1+100	L/S00	1	1	3	3
2	4+800～5+500	L/S05	2	1	4	4
3	21+850～22+100	L/S22	0	0	1	0
4	27+500～27+900	L/S27	1	2	3	5
5	28+000～28+700	L/S28	2	3	4	6
Total			6	7	15	18

3.5.3 Landslide monitoring in Abay Gorge

a. Extensometer

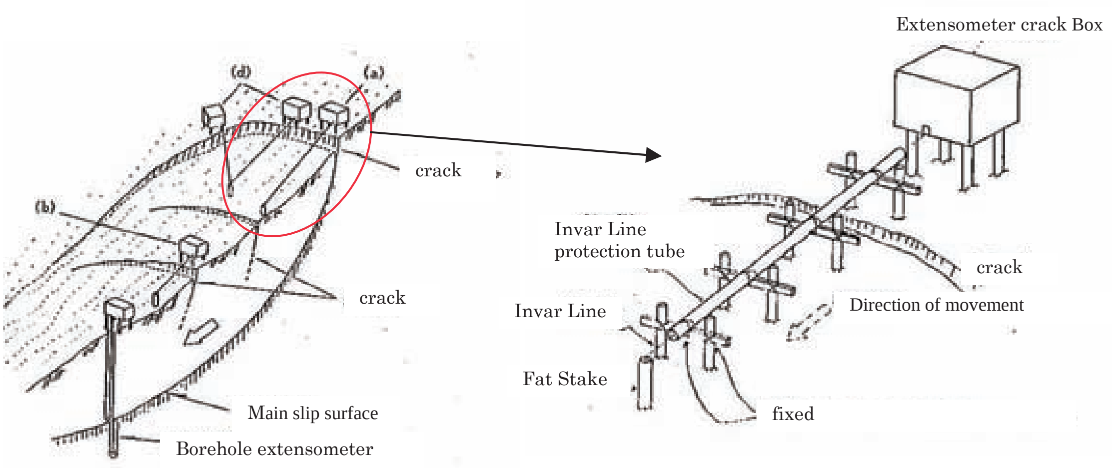


Figure 3.5.2 Conceptual diagram of Extensometer

To identify trigger/motion mechanisms of landslides, measurements were made with extensometers. These were installed along the direction of landslide movement and along each survey line to measure the amount of expansion/contraction in cracks and subsidence.

b. Borehole Extensometer

To measure movement of a slip surface in the ground, borehole extensometers were installed at drilled borehole points..

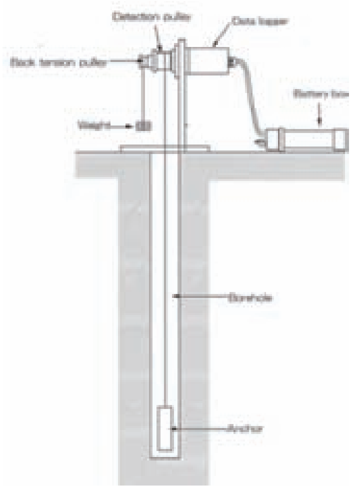


Figure 3.5.3 Conceptual diagram of Borehole Extensometer

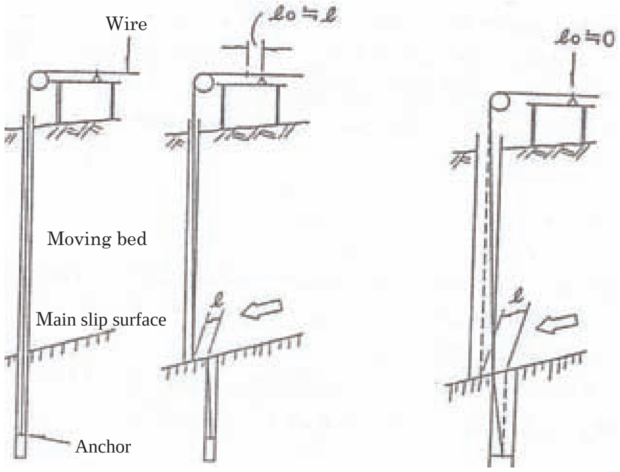


Figure 3.5.4 A principle of Borehole Extensometer

c. Borehole Inclinometer

The purpose of main slip surface survey is to determine the position of the slip surface. A borehole inclinometer measurement is one of the most important factors to determine it, and also quantitatively grasp the displacement of a landslide.

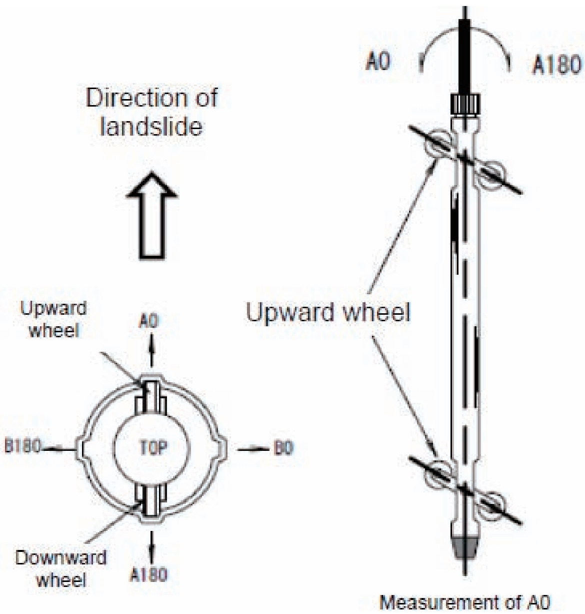


Figure 3.5.6 Borehole Inclinometer

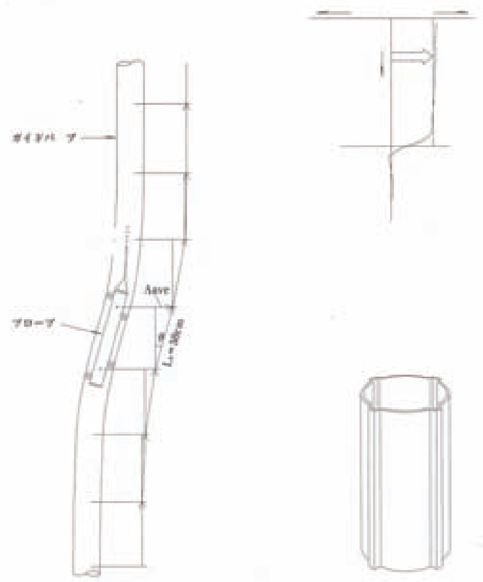


Figure 3.5.5 Measurement of Borehole Inclinometer

d. Groundwater Level Measurement

The groundwater level in boreholes is measured continuously by groundwater level meters, the correlation between groundwater level and precipitation is investigated, and also the relationship between groundwater level and landslide activity is considered.

3.6 Geophysical Exploration

3.6.1 Elastic wave Exploration

a. Purpose of Investigation

Elastic wave exploration is generally called as seismic exploration. Through generation of elastic wave into the ground, and measurement of the propagation velocity at the ground surface, the geological structure at the shallow ground near the ground surface can be clarified. In the landslide investigation, this method is used to estimate the weathered rock layer and the weathering degree, and to obtain the information about strata sequence and the distribution of fault and fracture zone. The exploration results can also be used as the fundamental information for groundwater draining work design. Generally, the measuring lines for elastic wave exploration are set parallel to the motion direction of the landslide, and the dip direction of the strata. The length of the measuring line should be longer than 6-7 times of the exploration depth, and be controlled in 15 times of the designed exploration depth.

b. Exploration method

In general, the elastic wave velocity is associated with geotechnical conditions closely such as the following factors:

- generation age
- components
- degree of alteration
- cracks
- moisture content

Its velocity value is high in the well-consolidated base rock, however, even though the degree of consolidation is the same, the more cracks and alterations in the base rock, the slower the elastic wave velocity gets.

c. Analysis method

Analysis is conducted with a method using travel-time curve. Arrival time (travel-time) of initial motion of the elastic wave from shot point to each vibration-receiving point (sample rate / sampling interval 500 μs) is read from measurement records in units of 1/1000 seconds to create the travel-time curve.

Shape of travel-time curve reflects the velocity structures, equivalent of velocity distributions of the underground. Gradient of travel-time curve represents the amplitude of apparent elastic wave velocity (the smaller the gradient of curve is, the bigger the velocity value is). The range of same layers that appear on the travel-time velocity varies corresponding to the layer thickness of said velocity layer. This change in the travel-time curve allows the velocity structure to be estimated by means of analysis.

d. Results of exploration

All travel-time curves and velocity profiles of the each line in the Project are shown in the Appendix.

The changes in velocity are depicted as color isograph. The velocity ranges from 0.30 to 3.00km/s, and the velocity interval is 0.15km/s. The analysis is conducted using the travel-time curve with the stripping method, and the velocity section is obtained using the tomographic method. It should be noted that the method assumes that the velocity increases with the depth when using the tomographic method.

3.6.2 Two-Dimensional Resistivity Exploration

a. Purpose of Investigation

Through applying DC electrical currents to the ground, resistivity exploration is to measure generated electrical potential and to estimate the resistivity distribution under the ground. Because the electrical behavior varies by rock composition, type and geological condition, groundwater properties and geological structures can be estimated through the measurement of the electrical resistivity under the ground.

During landslide investigation, based on the two dimensional distribution of the electrical resistivity, the weathered layer, bedrock, permeable layers and their continuity, existing situation of the faults and their continuity under the landslide slope can be estimated. The results can be used as fundamental information for the design of groundwater drainage.

In the two dimensional resistivity exploration, high density electrical potential is measured by placing the electrodes in an interval of 5m. Then through inverse analysis on a computer using the obtained electrical potential data, resistivity distribution is determined.

b. Exploration method

In general, the ground resistivity shows the following trends.

- The resistivity value of pelitic origin rocks is small while the resistivity value of rocks consisting of coarse grained minerals such as granite is large.
- The resistivity value of weathered and altered rocks is smaller than that of unweathered rocks with the same geology.
- The resistivity value decreases as water content increases.
- The resistivity value of fault and crush area or altered area is smaller than the resistivity value of their peripheries.
- The resistivity value of gravel layer is larger than that of clay layer.

Although these trends are seen, the ground resistivity generally depends on many factors such as content of conductive minerals (including clay mineral), porosity, water content and saturation, water quality of pore water (resistivity), and temperature. Furthermore, the resistivity simply indicates lithofacies changes in the same geological layer/rock, degree of weathering/hydrothermal alteration, and water content status in many cases in addition to differences in geological layers and rocks.

c. Analysis method

An inverse analysis (inversion) is made using the nonlinear least-squares method to obtain a color underground resistivity sectional view from a great deal of measured potential data. For analyzing the result, we used a 2D Earth Imager of AGI. エラー! 参照元が見つかりません。 shows a resistivity inversion analysis flow.

d. Results of exploration

All resistivity sectional views of the each line in the Project are shown in the Appendix.

3.7 Drilling Survey

3.7.1 Drilling plan

The drilling survey is implemented by taking direct samples from the ground to find the main slip surface and the geology and geological structure. In the Project, the drilling survey employs all-core sampling and a diameter of 63.5 mm. Further, the drilling use GSE's equipment, and the operator at GSE is directly instructed by the Study Team members. The specification of the drilling machine is as follows.

[Machine]	[Engine]	[Pump]
Crysten Rig, Top200 Rig	Crystensen	Triplex Pump Duplex Pump

The plan of the drilling quantities is shown in Table 3.7.1. The locations of the drilling and the monitoring at the selected priority sites are shown in Figure 3.7.1-3.7.4.

Table 3.7.1 Quantities for the drilling and monitoring

No.	Location	Name	Drilling survey			Monitoring			Preparation
			No.	Core drilling (m)	Standard penetration test (times)	Automatic water level meter (m)	Borehole inclinometer (m)	Borehole extensometer (m)	Construction of access road (m)
1	0+800～1+100	L/S00	B00-11	50	0			50	
			B00-12	35	1		35		
			B00-13	38	0				
			B00-14	30	5	30			1
			B00-15	30	20		30		190
			B00-16	25	15	25			70
			B00-21	30	0	30			
			B00-22	21	0		11		
2	4+800～5+500	L/S05	B05-10	30	5	30			190
			B05-11	35	0			35	
			B05-12	32	0	32			
			B05-13	35	5	35			80
			B05-20	35	5		35		40
			B05-21	35	0		35		
			B05-22	30	0		30		
			B05-23	35	5		35		80
			B05-31	35	0	35			
			B05-32	30	0				
3	21+850～22+100	L/S22	B22-11	20	0		20		
4	27+500～27+900	L/S27	B27-09	40	40	40			200
			B27-10	25	25	25			200
			B27-11	25	0		25		
			B27-12	25	0			25	
			B27-13	25	25			25	110
			B27-20	40	40		40		100
			B27-21	25	0	25			
			B27-22	27	0		27		
			B27-23	25	0	25			
			B27-24	25	25	25			70
5	28+000～28+700	L/S28	B28-10	40	40	40			250
			B28-11	25	0		25		
			B28-12	30	30			30	150
			B28-13	30	30		30		10
			B28-21	25	0	25			
			B28-22	30	30	30			130
			B28-23	25	25	25			10
			B28-31	25	0		25		
			B28-32	40	0		40		
			B28-33	30	30	30			180
			B28-34	25	25	25			220
			B28-41	45	0			45	
			B28-42	30	30			30	180
2010 sites				22	22	6	10	4	
2010 length (m)				678	1	172	273	155	
2011 sites				20	20	12	5	3	20
2011 length (m)				615	455	360	170	85	2,461
Total sites (2010-2011)				42	42	18	15	7	
Extension length (m)				1293	456	532	443	240	

(shaded)	2010 drilling
(white)	2011 driiling

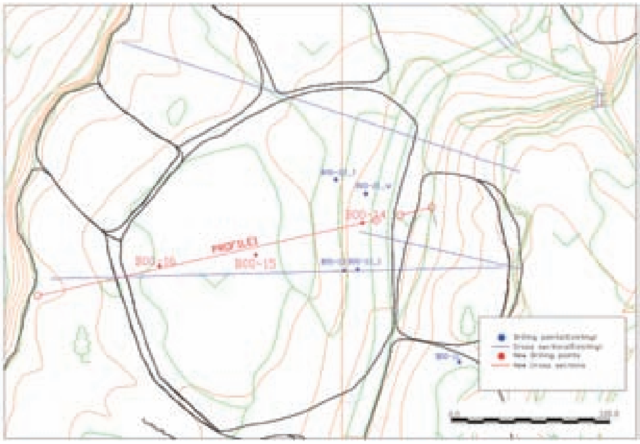


Figure 3.7.1 Survey locations in L/S00

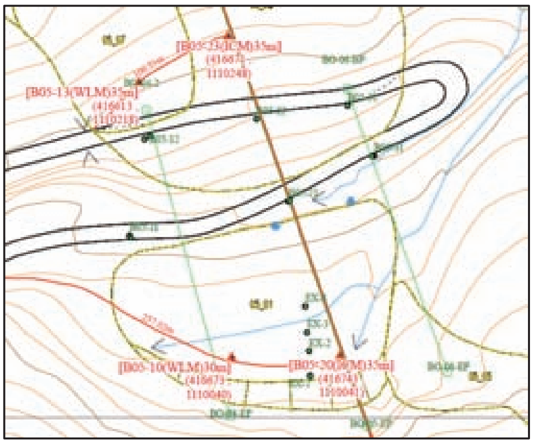


Figure 3.7.2 Survey locations in L/S05

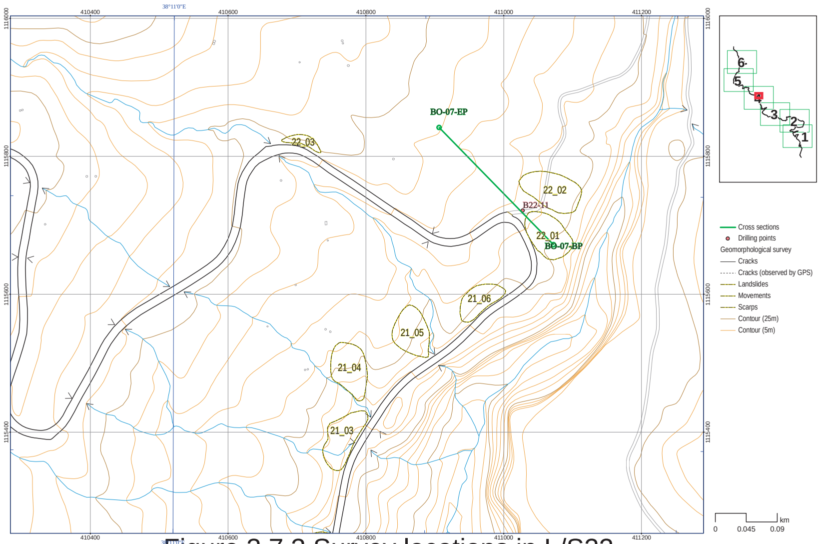


Figure 3.7.3 Survey locations in L/S22

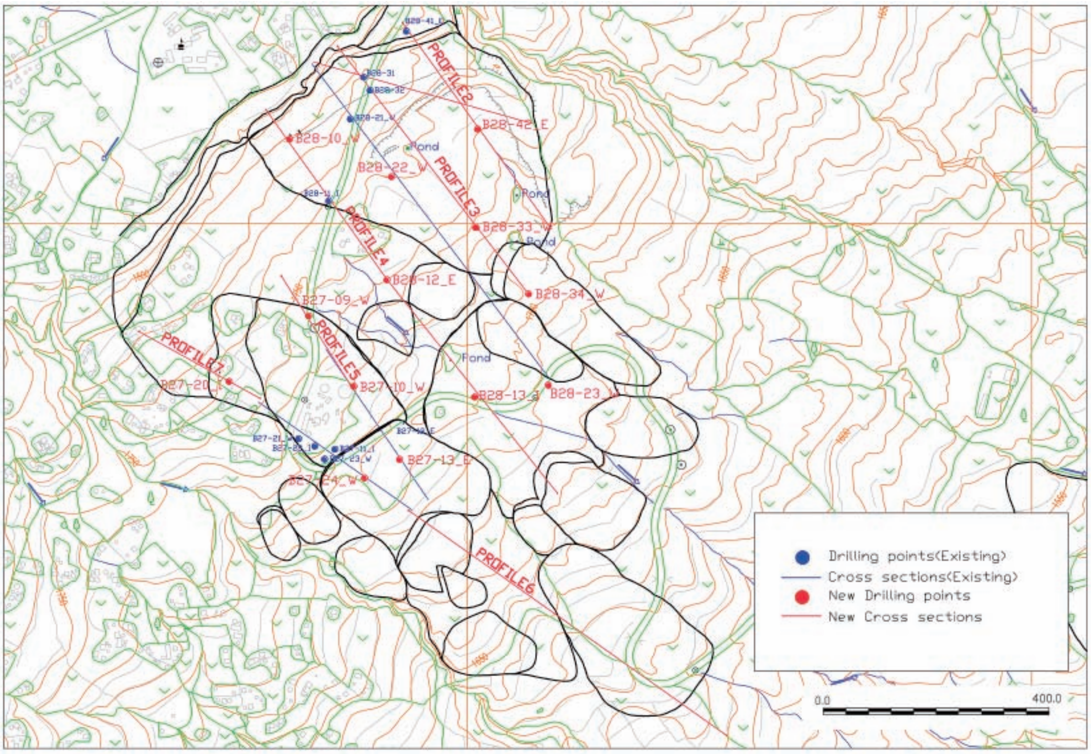


Figure 3.7.4 Survey locations in L/S27, L/S28

3.7.2 Drilling results

The result quantities for the core drilling are shown in the table below.

Table 3.7.2 The quantities for the core drilling

No.	Location	Name	Drilling survey			Monitoring installation			Preparation
			No.	Core drilling (m)	Standard intrusion test (times)	Automatic water level meter (m)	Borehole inclinometer (m)	Borehole extensometer (m)	Construction of access road (m)
1	0+800～1+100	L/S00	B00-11	50	0			50	
			B00-12	35	1		35		
			B00-13	38	0				
			B00-14	30	0	30			30
			B00-15	30	20		30		190
			B00-16	25	15	25			70
			B00-21	30	0	30			
			B00-22	21	0		11		
2	4+800～5+500	L/S05	B05-10	30	5	30			190
			B05-11	35	1			35	
			B05-12	32	0	32			
			B05-13	35	0	35	35		35
			B05-20	35	5		35		40
			B05-21	35	1		35		
			B05-22	30	0		30		
			B05-23	40	0		40		40
			B05-31	35	0	35			
			B05-32	30	0				
3	21+850～22+100	L/S22	B22-11	20	0		20		
4	27+500～27+900	L/S27	B27-09	50	0	50	50		50
			B27-10	25	0	25			50
			B27-11	25	0		25		
			B27-12	25	0			25	
			B27-13	25	25			25	110
			B27-20	40	40		40		100
			B27-21	25	0	25			
			B27-22	27	0		27		
			B27-23	25	0	25			
			B27-24	25	25	25			70
5	28+000～28+700	L/S28	B28-10	40	40	40			250
			B28-11	25	0		25		
			B28-12	30	30			30	150
			B28-13	30	0		30		30
			B28-21	25	0	25			
			B28-22	30	30	30			130
			B28-23	30	0	30			30
			B28-31	25	0		25		
			B28-32	40	0		40		
			B28-33	30	30	30			180
			B28-34	25	25	25			220
			B28-42	30	30			30	180
			B28-41	45	0			45	
2010 sites				22	22	6	10	4	
2010 length (m)				678	3				
2011 sites				7		5	4		7
2011 length (m)				240					240
Total				918	22	11	14	4	

this site will be implemented by GSE

3.8 Rockfall Survey/Debris Flow Survey

3.8.1 Rockfall Survey

Generally speaking, rockfalls are characterized by bedrock becoming unstable through groundwater and erosion which eventually cause falling of rock fragments under gravity. The velocity of the fall is great compared to other types of mass movement. The "rock mass failure" due to toppling (rock topple) is handled as one of the types of rockfalls in the Project.

The rockfall survey in the Project was conducted in order to identify topographic conditions, geological conditions and rockfall characteristics along a 40 km stretch of road between Goha Tsiyon and Dejen. The locations were selected based on the interpretations of topographic maps and satellite photographs. Many rockfall hazard locations exist in this area with high and steep slopes. Therefore, the surveys were conducted at areas with great potential of rockfalls.

The slope shapes are divided into the following three types: natural slope, cut slope, and composite slope which is a combination of the first two. Rockfall characteristics are related to the geological and geomorphic factors. The types of rockfall are dependent on the geology.

A table shown in the next page describes the rockfall hazard locations chosen for survey along the 40 km.

Slope gradients and heights of rockfall hazard locations were obtained by performing a basic topographic measurement on a set of representative areas. Although the survey did not cover the entire slope, it serves to obtain representative cross sections of rockfall hazard locations to be used for rockfall simulation analysis.

Based on the survey, the rockfall hazard locations were divided into 16 areas (RF00-1－RF35-1).

Table 3.8.1 Rockfall Hazard in each segment

RockFall			Topography	Soil and geological properties		Surface condition			Slope gradation and vertical height		Deformation of artificial and natural slope	Existing counter structures and effectiveness		History		Locations of rockfall occurrence during rain season		Note
No.	Station.No.	Slope Type	Topo. features indicating slope failure	Geology	Properties indicating slope failure	Surface soil, fallen stone and detached rock	Spring	Land cover	Slope gradation i(°)	Height H(m)		Structure type	Effectiveness	Frequency and scale of damage	Fallen rock diameter (m)	Rainy season in 2010	Rainy season in 2011	
RF00 -1	0+150 ～ 0+380	cut slope	Plateau base	Weatherd Basalt	Number of cracks per area is high which many of them open cracks	Somewhat unstable	No	Bare ground to vegetated land	-	H<15	Open crack	-	-	Small to medium rockfall within the artificial slope and before slope tips.	0.1～1.0		ST.0+350	This area has predominantly small rockfall developing cracks in the entire base rock. It has experienced rockfall in the rain season of 2011.
		natural slope	Significant topogoraphic discontinuities/ plateau base	Baslt/Weatherd Basalt	Number of cracks per area is high which many of them open cracks. In addition, occasional overhangs of rocks are seen.	Somewhat unstable	No	Bare ground to vegetated land	45≦i<70	15≦H<30	Open crack	-	-					
RF00 -2	0+740 ～ 1+080	cut slope	Plateau base/ erosion at slope foot	Weatherd Basalt/Tuff	Spring was seen at the boundary of tuff and weathered basalt. Tuff is prone to weathering.	Somewhat unstable	Permeated to surface	Bare ground to vegetated land	-	H<15	Gully erosion	Gabion (partially)	Not effective	Relatively large rockfall occasionally reaching roads.	0.1～4.0	ST.0+900 ST.1+000	ST.0+820 ST.0+930 ST.1+080	Surface of cut slope has tuff and on top of it has outcrop of basalt. Frequent rockfall indicents during rain season are common and in the year 2011 when it had large-scale rockall, a piece of basalt slipped through natural slope. The area has great rick of rockfall hazard as well as landslide hazard.
		natural slope	Plateau base/ erosion at slope foot	Baslt/Weatherd Basalt	Number of cracks per area is high which many of them open cracks. In addition, occasional overhangs of rocks are seen.	Unstable	No	Bare ground to vegetated land	45≦i<70	30≦H<50	Cracks/bed wash	-	-					
RF01 -1	1+160 ～ 2+000	cut slope	-	-	-	-	-	-	-	-	-	Gabion (partially)	Not effective	Relatively large rockfall occasionally reaching roads.	0.1～3.0		ST.1+820	Plateau base is the source of rockfall. Although large boulders are scattered across the slope, only few fallen rocks have reached the road as it has a good distance between the road and the slope. In addition, this section also has a history of frequent slope failures so that a gabion has been newly installed to protect against rockfall and slope failure hazards.
		natural slope	Plateau base/ overhanging rocks	Baslt/Weatherd Basalt	Number of cracks per area is high which many of them open cracks. In addition, overhangs of rocks continues along slope top.	Somewhat unstable	No	Bare ground to vegetated land	45≦i<70	H≧50	Open crack	-	-					
RF02 -1	2+080 ～ 2+780	cut slope	-	Weatherd Basalt	Number of cracks per area is high with varying orientations while cracks develop throughout the the entire slope.	Unstable	No	Bare ground to vegetated land	-	15≦H<30	Open crack/small-scale rockfall	-	-	Small to medium rockfall within the artificial slope and before slope tips.	0.1～0.3	ST.2+160 ST.2+250 ST.2+600	ST.2+240 ST.2+510	Scale of rockfall hazard in this section is amall but frequency of occurrence is high. Cracks develop in basalt and cubes of small rock fragments scatter in the area. Kinetic energy of rockfall may be small but bouce height is high.
		natural slope	-	Weatherd Basalt	Number of cracks per area is high with many open cracks.	Unstable	No	Bare ground to vegetated land	45≦i<70	15≦H<30	Open crack/small-scale rockfall	-	-					
RF03 -1	3+920 ～ 4+880	cut slope	-	-	-	-	-	-	-	-	-	-	-	Relatively large rockfall occasionally reaching roads.	0.1～3.1			This section has a number of fragments of basalt rocks with open cracks developing on the surface. Type of failing is toppling and when it happens the impact is great.
		natural slope	Significant topogoraphic discontinuities/ plateau base	Baslt/Weatherd Basalt	Large boulders distributed across the area. It has also developed open cracks.	Somewhat unstable	No	Bare ground to vegetated land	45≦i<70	30≦H<50	Open crack/small-scale rockfall	-	-					
RF05 -1	5+400 ～ 6+240	cut slope	-	-	-	-	-	-	-	-	-	-	-	Relatively large rockfall occasionally reaching roads.	0.1～4.5	ST.5+820 ST.5+950 ST.6+020		A number of fallen rocks are scattered within the slope some of which are overhanging. Although slope gradient becomes gradual toward the end of the section, risk of rockfall hazard is high up in the ridges. Establishment of shrubs and grass within the slope allow catching some of bouncing or rolling rocks.
		natural slope	Significant topogoraphic discontinuities/ overhanging rocks	Limestone/Weatherd Limestone	Limestone with developed cracks in the upper slope while weathered limestone in the mid to lower slope.	Somewhat unstable	No	Bare ground to vegetated land	45≦i<70	H≧50	Open crack/bed wash	-	-					
RF06 -1	6+340 ～ 6+800	cut slope	-	Weatherd Limestone	Weathering has progressed which has partially become soils.	Somewhat unstable	No	Bare ground	-	15≦H<30	Small-scale rockfall/ gully	-	-	Small to medium rockfall within the artificial slope and before slope tips.	0.1～0.7	ST.6+520 ST.6+600 ST.6+680	ST.6+680	In this section, small rockfall occur from the surface of cut slope that have fallen in the side ditch.
		natural slope	-	Weatherd Limestone	Weathering has progressed in the entire slope which is prone to erosion.	Somewhat unstable	No	Bare ground to vegetated land	45≦i<70	15≦H<30	Small-scale rockfall/ gully	-	-					
RF13 -1	13+520 ～ 13+680	cut slope	Taulus/ erosion at slope foot	Talus	Prone to erosion developing gully	Somewhat unstable	Permeated to surface	Bare ground to vegetated land	i≦ standards, H<15	-	Small-scale rockfall/ gully erosion	-	-	Small to medium rockfall within the artificial slope and before slope tips.	0.1～1.5			The slope is composed of taulus deposit and fall-through type rockfall is observed. Scale of rockfall is not enough to reach the road.
		natural slope	-	-	-	-	-	-	-	-	-	-	-					
RF13 -2	13+680 ～ 14+120	cut slope	-	Weatherd Limestone	Weathering has progressed which has partially become soils.	Unstable	No	Bare ground to vegetated land	-	15≦H<30	Small-scale rockfall/ gully erosion	Concrete retaining wall (partially)	Not effective	Relatively large rockfall occasionally reaching roads.	0.1～3.5	ST.14+180	ST.13+820 ST.13+940 ST.14+060	Earth wall is installed to protect from rockfall although it is 1 meter high. Fragments of rocks are seen on both sides of the wall. Furthermore, mining of gypsum is ongoing in the upper slope further increasing risk of rockfall hazard.
		natural slope	-	Weatherd Limestone/Gypsum	Weathering has progressed in the entire artificial slope which is prone to erosion.	Unstable	No	Bare ground to vegetated land	45≦i<70	30≦H<50	Small-scale rockfall/ gully erosion	-	-					
RF16 -1	16+680 ～ 18+860	cut slope	Significant topogoraphic discontinuities/ erosion at slope foot	Sandstone/Weatherd Sandstone	Significant partial weathering and differentiatial erosion.	Unstable	No	Bare ground to vegetated land	-	H<15	Small-scale rockfall/ gully erosion	Gabion (partially)	Not effective	Relatively large rockfall occasionally reaching roads.	0.1～3.6	ST.17+620 ST.17+860 ST.17+960 etc.	ST.17+120 ST.17+680 ST.17+890 etc.	It is frequent rockfall hazard area and diameters of fallen rocks can be large. Although cliff of plateau base is the source of rockfall, cut slope surface is also another source where fall-through type rockfall has occurred. From ST.18+080 toward the section end, relatively gradual slope continues but the vertical height of the slope is high which increases the chance of fallen rocks reaching the road.
		natural slope	Plateau base/ overhanging rocks	Sandstone	Number of cracks per area is high which many of them are open cracks. In addition, occasional overhangs of rocks are seen.	Unstable	No	Bare ground to vegetated land	45≦i<70	H≧50	Cracks/ open crack	-	-					
RF19 -1	19+900 ～ 20+520	cut slope	Significant topogoraphic discontinuities/ erosion at slope foot	Sandstone/Weatherd Sandstone	Significant partial weathering and differentiatial erosion.	Unstable	Permeated to surface	Bare ground to vegetated land	-	H<15	Small-scale rockfall/ gully erosion	-	-	Relatively large rockfall occasionally reaching roads.	0.1～2.8	ST.20+280 ST.20+460	ST.20+210 ST.20+290 ST.20+400 etc.	This section is another frequent rockfall hazard area and diameters of fallen rocks are also large. Although cliff of plateau base is the source of rockfall, cut slope surface is also another source where fall-through type rockfall has occurred. From ST.18+080 toward the section end, slope becomes steep increasing the rate of rockfall occurrence in this area.
		natural slope	Plateau base/ overhanging rocks	Sandstone	Number of cracks per area is high which many of them are open cracks. In addition, occasional overhangs of rocks are seen.	Unstable	No	Composite type	45≦i<70	H≧50	Cracks/ open crack	-	-					
RF20 -1	20+560 ～ 21+360	cut slope	Significant topogoraphic discontinuities/ erosion at slope foot	Sandstone/Weatherd Sandstone	Significant partial weathering resulting in smaller particles of weathered rocks.	Unstable	Permeated to surface	Bare ground to vegetated land	-	H<15	Small-scale rockfall/ gully erosion	-	-	Relatively large rockfall occasionally reaching roads.	0.1～1.5	ST.20+720 ST.21+000 ST.21+100 etc.	ST.20+740 ST.20+820 ST.20+910 etc.	This section is another frequent rockfall hazard area and diameters of fallen rocks are also large. Sources of the rockfall are plateau base cliff and cut slope surface. Though vertical height of the slope decreases toward the section end, detached-type rockfall occur.
		natural slope	Plateau base	Sandstone	Number of cracks per area is high which many of them open cracks.	Unstable	No	Composite type	45≦i<70	30≦H<50	Cracks/ open crack	-	-					
RF30 -1	30+450 ～ 30+700	cut slope	-	-	-	-	-	-	-	-	-	-	-	Small rockfall within the artificial slope and before slope tips.	0.1～0.6	ST.30+560	ST.30+600	Rockfall occurs throughout the slope. Diameters of rocks are relatively small but some of them have reached the road. Meanwhile, rockfall occurs within the landslide area but it is excluded from the rockfall hazard area.
		natural slope	Plateau base	Limestone/Weatherd Limestone	Number of cracks per area is high which many of them open cracks.	Somewhat unstable	No	Bare ground to vegetated land	45≦i<70	15≦H<30	Cracks/ open crack	-	-					
RF32 -1	32+000 ～ 32+460	cut slope	-	Weatherd Limestone	Entire artificial slope has weathered which partially become soils. Gullies have also developed.	Unstable	No	Bare ground	-	15≦H<30	Small-scale rockfall/ gully erosion	-	-	Small rockfall within the artificial slope and before slope tips.	0.1～0.6	ST.32+100	ST.32+370	Cut slope surface is the source of predominantly small scale rockfall in this area and many fallen rocks have reached the side ditch. Weathering process is fast and slope failures are also observed.
		natural slope	-	-	-	-	-	-	-	-	-	-	-					
RF34 -1	34+020 ～ 34+620	cut slope	Plateau base	Baslt/Weatherd Basalt	Number of cracks per area is high with varying orientations while cracks develop throughout the the entire slope.	Unstable	No	Bare ground to vegetated land	-	H<15	Exfoliation/ cracks	-	-	Occasional rockfall reaching roads.	0.1～0.7	ST.34+350 ST.34+500	ST.34+280 ST.34+370 ST.34+420	Cut slope surface is the source of frequent rockfall. In addition, fallen rocks are scattered in the slope above. This section is also frequent rockfall hazard area.
		natural slope	Plateau base	Baslt/Weatherd Basalt	Number of cracks per area is high which many of them open cracks.	Somewhat unstable	No	Bare ground to vegetated land	45≦i<70	15≦H<30	Cracks/ open crack	-	-					
RF35 -1	35+300 ～ 35+600	cut slope	Plateau base	Baslt/Weatherd Basalt	Number of cracks per area is high which many of them open cracks.	Somewhat unstable	No	Bare ground to vegetated land	-	15≦H<30	Cracks/ open crack	-	-	Small rockfall within the artificial slope and before slope tips.	0.1～0.3		ST.35+560	Cut slope surface is the source of fequent rockfall. Diameters of rocks are relatively small.
		natural slope	-	-	-	-	-	-	-	-	-	-	-					

3.8.2 Debris Flow Survey

A debris flow is very damaging, transporting large boulders and debris mixed in with mud from steep slopes and down through river systems. Furthermore, its flow has significant velocity which usually causes devastation as it passes. Debris flows generally occur in and flow down along valleys, which causes damage to areas along those valleys as well as their outlets. Damage done by debris flows can be divided into two types: 1) direct hitting by the head flow (bouldery front), and 2) flooding by subsequent flows (slurry flow and/or hyperconcentrated flow).

Hitting by bouldery fronts causes serious damage, because it literally contains large boulders. Subsequent flow (slurry flow and hyperconcentrated flow) causes flooding in the surrounding area after sedimentation of the boulders take place.

The diagram below illustrates the concept of large-scale debris flow flooding.

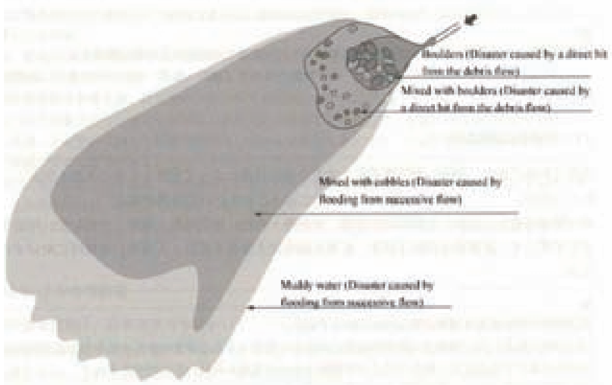


Figure 3.8.1 Conceptual diagram of debris flow flooding

The characteristics of each stream channel are shown in Table 3.8.2 and 3.8.3 with risk of debris flow and sediment runoff.

Basic topographic measurement was implemented on those streams in Filiklik Village that has many important facilities such as houses and churches within the hazard zone as well as streams with history of multiple sediment runoffs. The channels which are designated debris flow hazard areas were also measured as well. During the measurement, channel bed gradient and cross-section shape were measured.

In general, channels are determined as “high risk debris flow channels” based on the bed gradient and the importance of conservation facilities within the area. However, the channel bed gradient which crosses Route No.3 in the target area is over 2 degrees; in addition, when debris flows occur, sediment would likely to outflow and be deposited on the road.

Those channels with high risk of debris flow were selected based on their size of basin area and amount and condition of sediment deposit as well as histories of sediment runoffs.　As a result, smaller channels such as S08-2 and S32-1 tend to have greater risk of debris flow hazard. In addition, great amount of unstable sediment accumulated upstream in those channels is likely overflow with intense precipitation even for short period of time and eventually cause damage to roads and traffic.

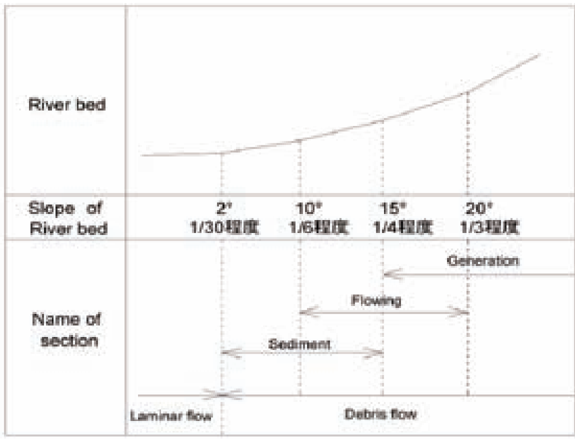


Figure 3.8.2 Sediment forms based on bed gradients

Table 3.8.2 List of Channels with Risks of Debris Flow and Sediment Runoff (1)

Stream.ID	Station	Characteristics of stream					Characteristics of slope			Existing counter structures and level of deposit		Road structures			History	Note
		Basin area	Stream length	Areas w/ bed gradient >=15°	Max. gradient	Bed gradient near roads	Areas w/ slope gradient >=30°	Vegetated area (shrubs & grass)	Construction sites with unstable debris	Type	Level of deposit	Type	Stream width (m)	Vertical clearance (m)	Sediment runoff	
		(km2)	(km)	(km2)	Class	(°)	(km2)	(km2)								
S01 -1	1+130	12.318	33.13	0.003	<30°	20.9	0.000	0.71	-	Check dam	Full	Bridge	>=10m	>=5m	Frequent	Check dam is installed in the upper stream which becomes waterfall during the rain season resulting in sediment runoff.
S01 -2	1+760	0.004	0.85	0.004	30-40°	17.5	0.002	0.00	-	-	-	Box culvert	<3m	1m～2m	Seldom	Surface runoff during the rain season
S02 -1	2+080	0.002	0.62	0.002	30-40°	10.3	0.000	0.00	-	-	-	Box culvert	<3m	1m～2m	Seldom	Surface runoff during the rain season
S06 -1	6+930	0.005	0.12	0.003	<30°	8.6	0.000	0.00	-	-	-	Box culvert	<3m	1m～2m	Seldom	Surface runoff during the rain season
S07 -1	7+190	0.025	0.48	0.018	30-40°	10.4	0.001	0.01	-	-	-	Box culvert	<3m	1m～2m	Seldom	Surface runoff during the rain season
S08 -1	8+230	0.008	0.25	0.000	<30°	6.2	0.000	0.00	-	-	-	Box culvert	<3m	1m～2m	Occasional	Many rock fragments are accumulated in the box culvert.
S08 -2	8+980	0.074	2.48	0.068	<30°	9.2	0.001	0.04	-	-	-	Box culvert	<3m	<1m	Frequent	Box culvert is blocked with accumulated debris. In the rain season of 2010, sediment runoff occurred.
S09 -1	9+220	4.203	10.64	1.681	>=40°	3.2	0.126	1.01	-	-	-	Box culvert	3m～5m	>=5m	Frequent	Previous debris flow has damaged cross drainage structure in the upper stream.
S10 -1	10+810	6.206	8.59	2.627	>=40°	4.2	0.213	1.83	-	Check dam (downstream of road)	Full	Box culvert	3m～5m	2m～3m	Frequent	Check dam is installed in the downstream of the road. Basin area is relatively large.
S11 -1	11+030	0.186	1.91	0.000	<30°	4.5	0.000	0.06	-	-	-	Box culvert	<3m	2m～3m	Occasional	It is a small tributary with developed gullies. Gabions are currently being installed at the flow end.
S11 -2	11+440	0.036	0.06	0.001	<30°	4.6	0.000	0.01	-	-	-	Box culvert	<3m	2m～3m	Frequent	It is a small tributary with developed gullies. Debris and rock fragments accumulate in the box culvert.
S11 -3	11+790	0.192	0.32	0.033	<30°	6.9	0.000	0.06	-	-	-	Box culvert	<3m	2m～3m	Seldom	It is another small tributary with developed gullies.
S12 -1	12+000	0.075	1.34	0.000	<30°	6.1	0.000	0.02	-	-	-	Box culvert	3m～5m	3m～5m	Occasional	It is a small tributary with developed gullies. Debris and rock fragments accumulate in the box culvert.
S12 -2	12+320	0.010	0.07	0.000	<30°	6.3	0.000	0.00	Debris entering from mining site	-	-	Box culvert	<3m	2m～3m	Seldom	Sediment enters from the mining site.
S12 -3	12+740	0.015	0.47	0.001	<30°	9.0	0.000	0.01	Debris entering from mining site	-	-	Box culvert	<3m	1m～2m	Frequent	Sediment enters from the mining site.
S13 -1	13+370	0.511	2.01	0.108	<30°	8.7	0.000	0.18	-	-	-	Box culvert	<3m	3m～5m	Seldom	Although large boulders scatter upstream of the road, there is no sediment accumulation in the box culvert.
S13 -2	13+430	0.101	0.66	0.034	<30°	8.6	0.000	0.05	-	-	-	Concrete pipe	<3m	1m～2m	Seldom	It is another small tributary with developed gullies.
S13 -3	13+620	1.207	3.02	0.692	>=40°	11.5	0.107	0.39	-	-	-	Box culvert	3m～5m	3m～5m	Occasional	Although large boulders scatter upstream of the road, there is no sediment accumulation in the box culvert.
S13 -4	13+660	0.035	0.56	0.028	30-40°	16.5	0.004	0.01	-	-	-	Concrete pipe	<3m	1m～2m	Seldom	It is a small tributary with developed gullies. Further bank erosion is ongoing.
S14 -1	14+120	0.088	0.42	0.054	30-40°	28.7	0.002	0.03	-	-	-	Box culvert	<3m	2m～3m	Seldom	It is a small tributary with developed gullies. Stream bed gradient is steep.
S14 -2	14+700	0.095	0.82	0.056	30-40°	15.4	0.005	0.03	Debris entering from mining site	-	-	Concrete pipe	<3m	<1m	Occasional	Sediment enters from the mining site.
S15 -1	15+890	0.024	0.25	0.000	<30°	1.7	0.000	0.01	-	-	-	Concrete pipe	<3m	<1m	Seldom	Slope of stream bed is gradual and flow path is difficult to deliniate.
S16 -1	16+660	0.136	1.29	0.002	<30°	4.2	0.000	0.05	-	-	-	Box culvert	<3m	3m～5m	Seldom	Slope of stream bed is gradual and surface runoff occurs during the rain season,

Table 3.8.3 List of Channels with Risks of Debris Flow and Sediment Runoff (2)

Stream.ID	Station	Characteristics of stream: Basin area (km2)	Stream length (km)	Areas with bed gradient >=15° (km2)	Steepest section Class	Bed gradient near roads (°)	Characteristics of slope: Areas with slope gradient >=30° (km2)	Vegetated area (shrubs & grass) (km2)	Construction sites with unstable debris	Existing counter structures and level of deposit: Type	Level of deposit	Road structures: Type	Stream width (m)	Vertical clearance (m)	History: Debris runoff	Note
S20 -1	20+530	7.829	26.14	1.242	>=40°	9.9	0.207	1.31	-	Check dam	full	Box culvert	3m～5m	>=5m	Frequent	Check dam with damaged wings in the upper stream is full. Basin area is large.
S20 -2	20+980	0.109	0.31	0.005	30-40°	32.2	0.000	0.01	-	-	-	-	<3m	-	Occasional	Runoff that exceeds the capacity of side ditch enters the road. The stream has water flow during the rain season.
S21 -1	21+280	0.027	0.52	0.004	30-40°	55.7	0.001	0.00	-	-	-	-	<3m	-	Seldom	Channel becomes a water fall by the road. It has surface runoff during the rain season.
S21 -2	21+470	0.025	0.62	0.003	30-40°	30.0	0.000	0.00	-	-	-	-	<3m	-	Seldom	Runoff that exceeds the capacity of side ditch enters the road.
S21 -3	21+600	0.185	0.60	0.005	<30°	13.7	0.000	0.03	-	-	-	Box culvert	<3m	1m～2m	Seldom	Runoff that exceeds the capacity of side ditch enters the road. The stream has water flow during the rain season.
S21 -4	21+640	0.010	0.34	0.002	<30°	11.5	0.000	0.00	-	-	-	-	<3m	-	Seldom	Runoff that exceeds the capacity of side ditch enters the road. The stream has water flow during the rain season.
S21 -5	21+770	3.413	16.67	0.590	>=40°	10.4	0.093	0.64	-	-	-	Box culvert	3m～5m	3m～5m	Frequent	Stream length is relatively long which accelerates sediment production.
S30 -1	30+060	1.319	0.70	0.248	>=40°	8.5	0.047	0.17	-	-	-		<3m	1m～2m	Seldom	Surface runoff during the rain season
S30 -2	30+420	0.041	0.96	0.033	>=40°	20.7	0.008	0.02	-	Concrete retaining wall	Damaged	Box culvert	<3m	<1m	Frequent	Box culvert is full. In the rain season of 2011, sediment runoff occurred in the lower stream.
S30 -3	30+720	0.088	0.62	0.041	>=40°	34.9	0.016	0.02	-	-	-	-	<3m	-	Frequent	Stream gradient is somewhat steep and fragments of rocks accumulate by the road.
S30 -4	30+950	0.123	1.35	0.091	30-40°	14.7	0.003	0.02	-	-	-	Box culvert	<3m	2m～3m	Frequent	Base of the channel structure is damaged.
S31 -1	31+260	0.282	1.45	0.193	30-40°	13.9	0.044	0.06	-	-	-	Box culvert	<3m	<1m	Frequent	Large amount of debris accumulates in the box culvert.
S31 -2	31+580	0.021	0.73	0.016	30-40°	16.8	0.002	0.01	-	Check dam	Full	Box culvert	3m～5m	1m～2m	Frequent	Sediment runoff occurred in the rain season of 2008 as well as in 2011 affecting the traffics.
S31 -3	31+790	—	—	—	—	—	—	—	-	-	-	Concrete pipe	<3m	1m～2m	-	Unable to delineate the extent of the basin.
S32 -1	32+320	0.011	0.25	0.010	<30°	25.3	0.000	0.00	-	-	-	Concrete pipe	<3m	1m～2m	Seldom	Channel becomes a water fall by the road. It has surface runoff during the rain season.
S32 -2	32+800	12.487	12.11	0.610	30-40°	17.8	0.030	0.77	-	-	-	Box culvert	5m～10m	>=5m	Frequent	Basin area is large and large boulders scatter upstream of the road.
S33 -1	33+200	0.629	6.12	0.161	30-40°	6.0	0.012	0.12	-	-	-	Box culvert	3m～5m	1m～2m	Occasional	Stream gradient is gradual and it has surface runoff during the rain season.
S33 -2	33+500	0.028	0.34	0.014	30-40°	1.7	0.002	0.01	-	-	-	Concrete pipe	<3m	<1m	Seldom	Drainage pipe is blocked.
S33 -3	33+860	0.016	0.07	0.015	<30°	8.8	0.000	0.00	-	-	-	Concrete pipe	<3m	1m～2m	Seldom	It has surface runoff during the rain season.

3.9 GIS/Database

The purpose is to collect data on which to base the GIS database and slope disaster hazard maps that will be made in the second year. This chapter reports on the following contents:

- Data collection of GIS/Database and information related to the study
- Organizing/preprocessing/compilation of the collected data

The implementation procedure for the above is given below.

- Reviewing existing GIS data, documents and materials, collecting/organizing related information in Japan
- Requesting meetings for investigation and providing related data/information with GIS/DB to the C/P
- Checking the collected data, and organizing, preprocessing for GIS, compilation as a GIS/Database

3.10 Preliminary interpretation for each landslide

3.10.1 Location L/S 00

Figure 3.10.1 summarized the survey results at the site. Table 3.10.1 summarized the seismic velocity of colluvial deposit/embankment and the drilling survey in the landslide.

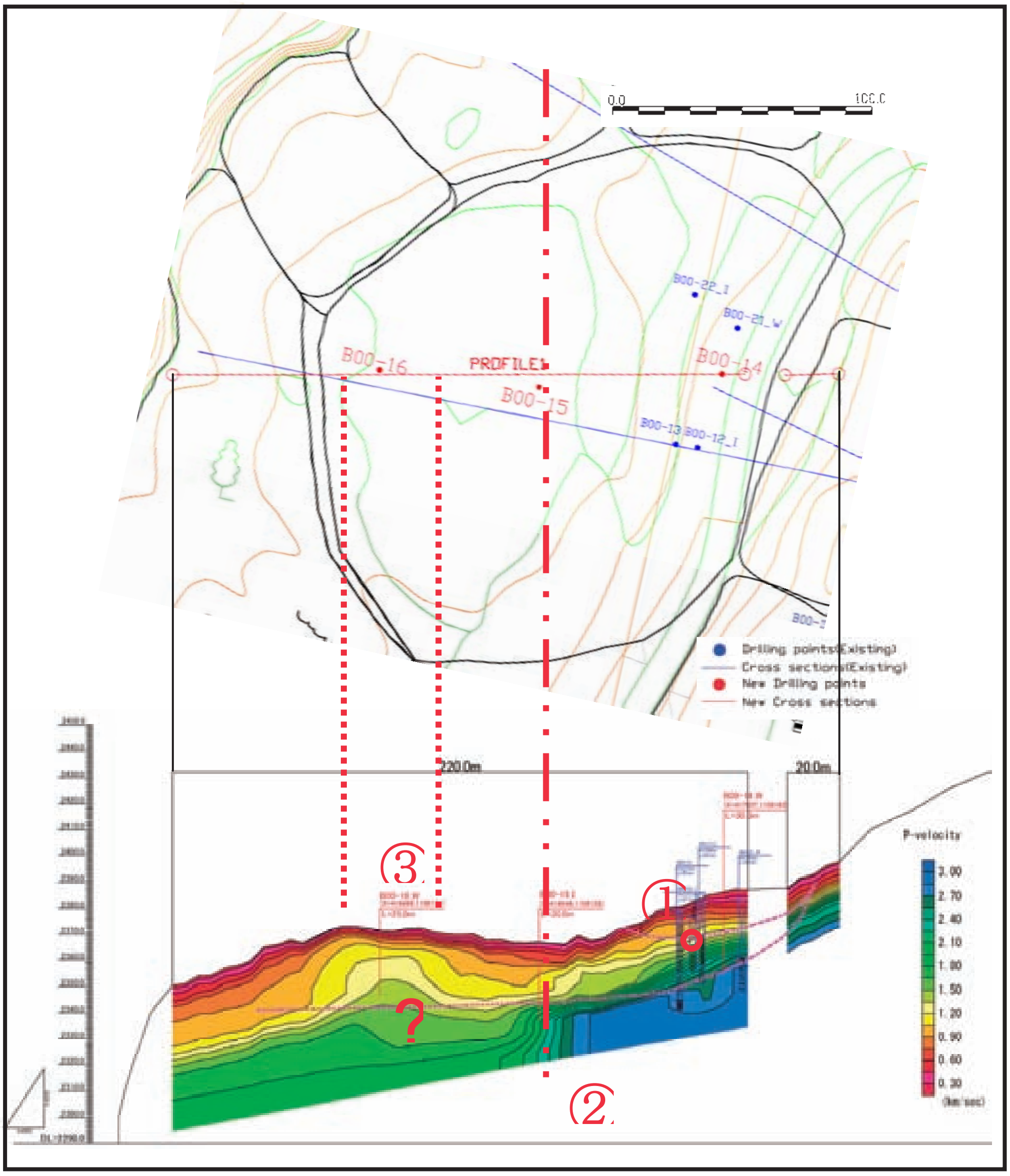


Figure 3.10.1 Relationship between plain map and geophysical cross section on L/S00

Table 3.10.1 Comparison of seismic exploration and drilling survey on L/S00

		boundary of seismic velocity (km/sec)			Borehole NO.	existance depth(m)				
						sliding mass				basement layer
		～1	1～3	3～		surface soil	embankment	colluvial dep.		
L/S00	Profile 1	10 – 15m	10 – 30m	25 – 30m	B00-21	–	0.00 – 22.10m		22.10 –25.50m	25.50 – 30.00m
					B00-12	–	0.00 – 16.60m		16.60 – 31.50m	31.50 – 35.00m
					B00-22	–	0.00 – 11.30m	11.30 – 21.40m	–	–
					B00-13	–	0.00 – 5.00m	5.00m – 23.50m	23.50 – 34.45m	34.45 – 38.00m
					B00-14	to be continue				
					B00-15	post pone				
					B00-16	post pone				

The boundary of colluvial deposit and sliding mass is considered seismic velocity 2.0km/sec on near road (12-25m depth)

3.10.2 Location L/S 05

Figure 3.10.2 summarized the survey results at the site.

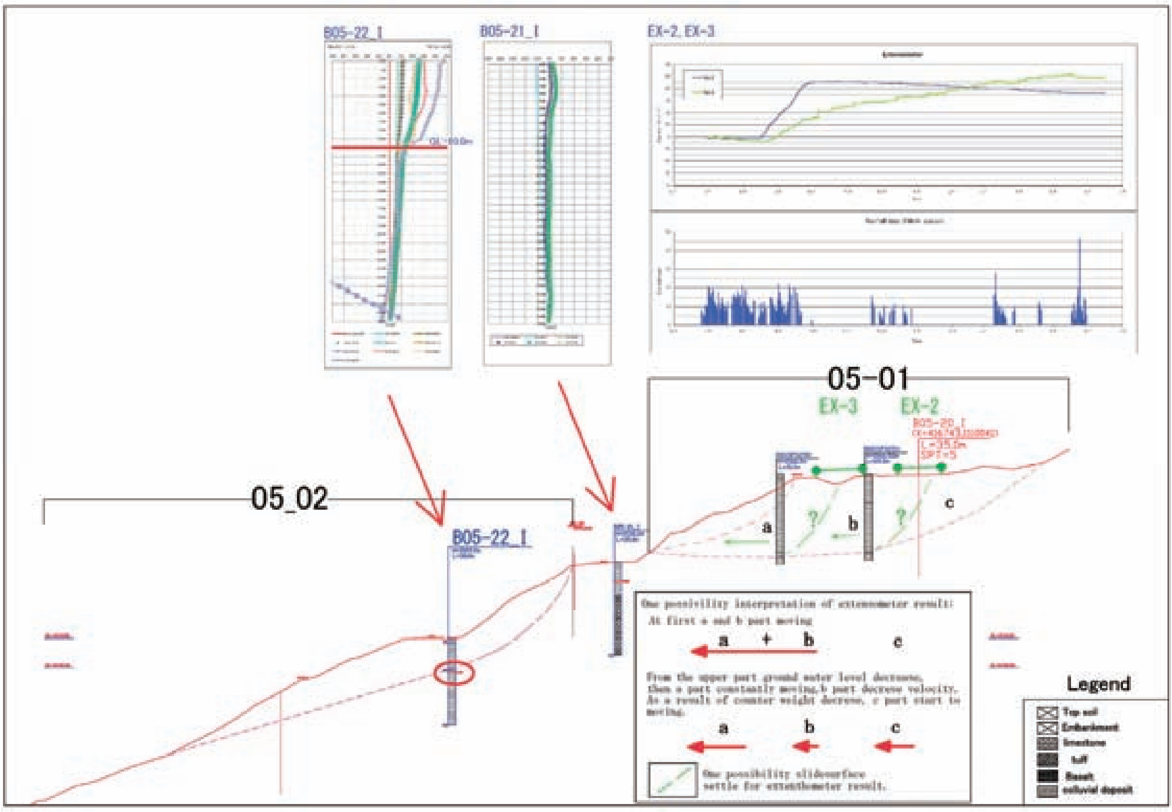


Figure 3.10.2 Summarized cross section on L/S05

3.10.3 Location L/S 22

On the field observation, the area is included an old large landslide block. The boundary of sandstone and colluvial deposit is considered as a slip surface. The ground water springs out from the upper part of the slip surface. (Photo 3.10.1)

Photo 3.10.1 Landslide 22-01 from opposite side terrace cliff.

3.10.4 Location L/S 27

As results of the seismic survey and the drilling survey (Table 3.10.2), it was confirmed accordance between the deposit and the seismic velocity; the depth of colluvial deposit accord with the velocity <1.0km/sec (brown box in the table), and the depth of sliding mass is the velocity 1.0-3.0km/sec (orange box in the table).

Table 3.10.2 Comparison of seismic exploration and drilling survey on L/S27

		boundary of seismic velocity (km/sec)			Borehole NO.	existance depth(m)				
						sliding mass				basement layer
		~1	1~3	3~		embankment	surface soil	colluvial dep.		
L/S27	Profile 5	10 - 15m	10m - (less than 2km)	-	B27-09	0.00 - 3.90m	-	3.90 - 24.60m	24.60 - 30.00m	30.00 - 50.00m
					B27-10	-	0.00 - 2.20m	2.20 - 13.30m	13.30 - 21.30m	21.30 - 30.00m
					B27-12	-	0.00 - 0.90m	0.90 - 13.40m	13.40 - 25.00m	
	Profile 6	5 - 10m	5- 30m	20 - 35m		-				
	Profile 7	5 - 15m	5m - (less than 2km)	-	B27-20	post pone				
					B27-21	-	0.00 - 0.30m	0.30 - 12.40m	12.40 - 25.00m	-
					B27-22	-	0.00 - 1.70m	1.70 - 15.40m	15.40 - 27.00m	-
					B27-23	-	0.00-9.00m		9.00-25.00m	-
					B27-11	-	0.55 - 8.90m		8.90 - 25.00m	-
					B27-24	post pone				

3.10.5 Location L/S 28

As results of seismic survey and the drilling survey (Table 3.10.3), it was confirmed accordance between the deposit and the seismic velocity; the depth of colluvial deposit accord with the velocity <1.0km/sec (brown box in the table), and the depth of sliding mass is the velocity 1.0-3.0km/sec (orange box in the table).

Table 3.10.3 Comparison of seismic exploration and drilling survey on L/S28

		boundary of seismic velocity (km/sec)			Borehole NO.	existance depth(m)				
						sliding mass				basement layer
		~1	1~3	3~		embankment	surface soil	colluvial dep.		
L/S28	Profile 2	5 - 15m	5 - 45m	30 - 45m	B28-41	0.00 - 5.30m	-	5.30 - 9.80m	9.80 - 34.50m	-
	Profile 3	5 - 20m	5m -	-	B28-31	-	0.00 - 14.00m		14.00 - 25.00m	-
					B28-32	-	0.00 - 0.70m	0.70 - 11.80m	11.80 - 32.05m	32.05 - 40.00
					B28-33	post pone				
					B28-34	post pone				
	Profile 4	5 - 10m	5m -	-	B28-10	post pone				
					B28-11	-	0.00 -0.40m	0.40 -13.95m	13.95 25.00m	-
					B28-12	post pone				
					B28-13	-	0.00 - 23.00m		23.00-26.35m	26.35m-30.00m
					B28-14	post pone				

Chapter 4

Landslide Analysis and Interpretation

4 Landslide Analysis and Interpretation

4.1 Hydrological Interpretation

4.1.1 Characteristics of rainfall

The record of the rain gauges installed in the Abay Gorge area could be described as follows.

- The mean annual rainfall is relatively low at about 1,200-1,400mm.
- It rains intensively, 600mm - 700mm, for two months, July and August of the rainy season, when about 50% of annual rainfall is recorded.
- It rains at least once a day on most days in July and August. Monthly rainfall exceeds 300mm and the average for July is about 10mm per day.

4.1.2 Landslide occurrence and triggering mechanisms

Table 4.1.1 Landslide Occurrence in Abay Gorge

Station No.	Time	Observed damage
ST.0+700- ST.1+100	2008 rainy season	Road settlements Every rainy season
	2009 rainy season	ditto
	2010 rainy season	ditto
ST.4+900- ST.5+200	2006 Aug～Sep	Collapse of existing retaining wall
ST.21+850- ST.22+200	2008 rainy season	Collapse of retaining wall
	2009 rainy season	Landslide area expansion
ST.27+500- ST.27+800	2006 unknown Every rainy season	Old church destroyed New church under construction (cracks found) Road subsidence
ST.28+100- ST.28+600	Every rainy season	Road subsidence and cracks
ST.32+250	2009	Road culvert is damaged

JICA (2010)

There are many mechanisms that cause landslides, such as geomorphological features, geology, and other man-made and natural conditions. In the Abay Gorge, water is the direct and primary cause of a landslide. Since groundwater is fundamentally recharged by rain, the relation between a landslide and rain is close. According to Takano, 1960, landslides occur most easily when about 10 mm/day of rainfall continues for about five days. This is because rainfall of this level is most suitable for deep percolation. Otherwise rainfall heavier than this seldom permeates into the ground and becomes a surface flow.

Theoretically, when groundwater increases the pore water pressure also increased, and effective stress will decrease. As a result, shear resistance decreases and triggered a landslide.

4.1.3 Hydrological monitoring data interpretation

The locations of monitoring stations and specifications of the pressure type water gauges that are installed in the drilling holes since August, 2010 are shown in Table 4.1.2.

Table 4.1.2 Monitoring sites and parameters

No.	Location	Name	Drilling survey		Groundwater level meter	Monitoring started
			No.	Core drilling		
1	ST.0+800 - ST.1+100	L/S00	B00-14	30m	30m	21 Jul. 2011
			B00-21	30m	30m	3 Aug. 2010
2	ST.4+800 - ST.5+500	L/S05	B05-12	30m	30m	14 Aug. 2010
			B05-13	35m	35m	7 Jul. 2011
			B05-31	35m	35m	1 Sep. 2010
3	ST.27+500 - ST.27+900	L/S27	B27-09	50m	50m	29 Jun. 2011
			B27-10	25m	25m	15 Jun. 2011
			B27-11	25m	25m	24 Sep. 2010
			B27-23	25m	25m Data logger stolen(Nov.)	8 Oct. 2010 ＊stolen
4	ST.28+000 - ST.28+700	L/S28	B28-21	25m	25m Data logger stolen(Nov.)	9 Sep. 2010 ＊stolen
			B28-23	30m	30m	15 Jun. 2011

Two of the six data loggers, B27-23 and B28-21, were stolen after data was acquired on November 25, and since then there has been no measurement record. Monitoring is still being carried out at the other gauges, and the rainfall records of each station are summarized as graphs in Appendix.

At B00-14, the steady water level keeps about -23 to -24m after July 2011.At B00-21, the steady water level of -20 to -23m and the high water level of -18.1m from August 2010 to September 2010 were recorded. The steady water level keeps about -20m after October 2010.

At B05-12, the steady water level -31 to -32m and the high water level -31. 0m at August 15 was recorded. However, the data has not been recorded since October 9 because there has been no water in the hole. At B05-13, the data has not been recorded since the installation because there has been no water in the hole. At B05-31, the steady water level of -22 to -23m and the high water level of -21.8m on September 2011 were recorded.

At B27-09, the steady water level of -15 to -16m had been recorded. However, the monitoring has never been implemented since July 26, 2011 because of the landslide movement. At B27-10, the steady water level of -21 to -23m and the low water level of less than -25m at the end of July 2011 were recorded. At B27-21, the steady water level of -22 to -23m and the high water level of -21.9m on September 29 in the rainy season were recorded. The steady water level keeps about -23 to -24m in the dry season. At B27-23, the steady water level of -20 to -21m and the high water level of -20.3m on November 8 were recorded. However, there is no data after November 24 because the equipment was stolen.

At B28-21, both the steady water level and the high water level keep around -20m. However, there is no data after November 24 because the equipment was stolen. At B28-23, the rising up according to the rain and the high water level at -14.7m observed. The steady water level of -15 to -17m has been recorded after that.

Dalliance of installation of devices couldn't allow making full monitoring of water level changes during the rainy season (around July to September). However, future monitoring could reveal the relevance of rainfall to groundwater level variation.

4.2 Hydrographic System

4.2.1 Drainage network

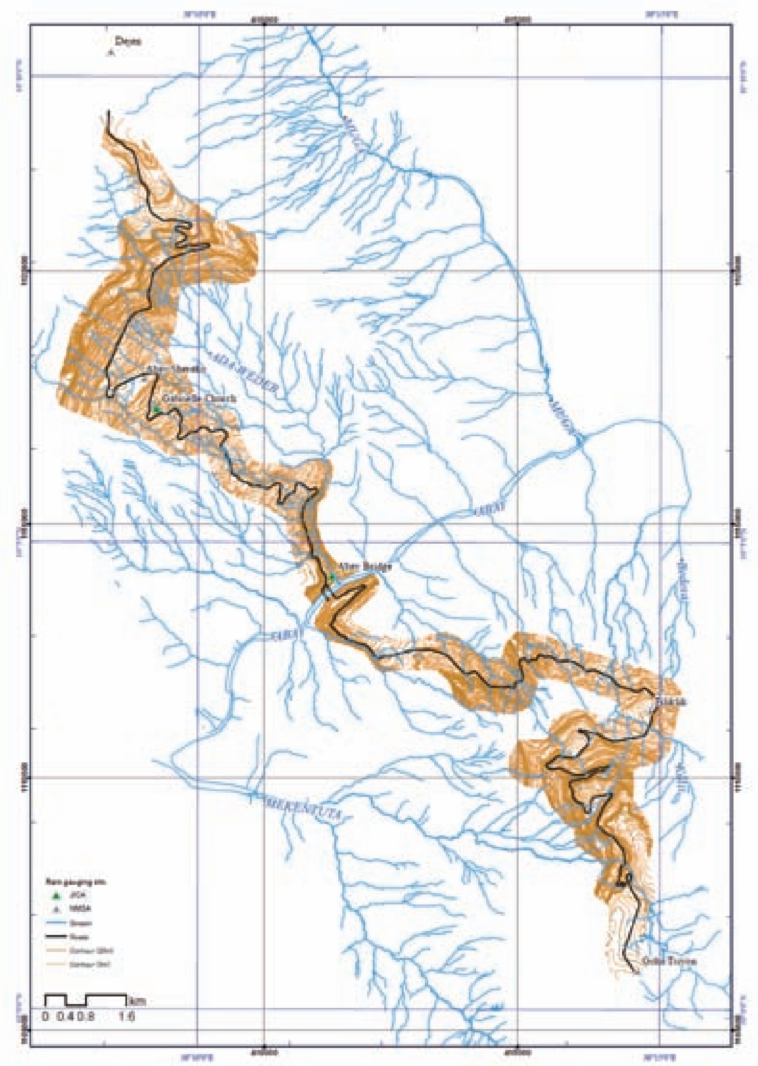


Figure 4.2.1 Drainage network

4.2.2 Groundwater distribution and flow

Although five landslide areas are applicable to the investigation this time, only four water level monitoring stations have been installed, meaning there is no conclusive data on the rainy season. Therefore, the relevance of rain and groundwater level can not be fully confirmed. However, if the geographical feature and the valley in the target landslide area are taken into consideration, it is clear that the water which flowed into the osmosis and the mountain streams of surface water by rain turned into groundwater, and has contributed to the rise of the groundwater level.

In addition, further water gauges are due to be added from now on. Therefore, it seems by grasping change of another amount of spring water the change of the groundwater level, the situation of spring water, the groundwater distribution and the flow situation becomes clear.

4.3 Landslide area Identification and Assessment

4.3.1 Satellite imagery interpretation

There are many large landslides, which probably are produced during the formation of the Abay Gorge. These old landslides can be clearly identified from satellite images.

Figure 4.3.1 shows the result of satellite imagery interpretation near L/S05-01. The horseshoe-shaped steep cliff surrounding the landslide block at L/S05-01 is the main scarp of the old huge landslide that formed this horseshoe-shaped cliff in ancient times. Thereafter, moving mass by a landslide that occurred on the upper part (L/S03-01, etc.) was piled up at the head of the lower landslide, and then a secondary landslide occurred. The secondary landslide can be interpreted as being at L/S05-01.

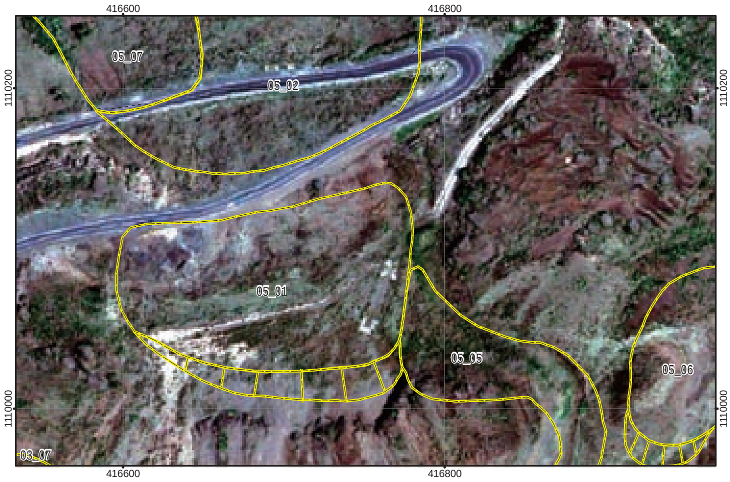


Figure 4.3.1 Examples of old landslides (L/S05-01)

The area from L/S26 to L/S28 has a widely distributed colluvial deposit and contains multiple landslides, these are distributed in multiple layers, so it is difficult to identify and extract single landslides. Among the landslide topographies that can be identified from satellite imagery, (1) the range where a landslide can be clearly identified and (2) the range where a moving block can be identified as an event on the ground surface, such as deformation of a road or formation of a new main scarp, are interpreted as a landslide block. Global Positioning System (hereafter GPS) measurements were used when the boundary between two landslide blocks was not clear only from interpretation of satellite imagery. The boundary between the blocks was determined using the road deformation and the crack distributions by GPS measurements.

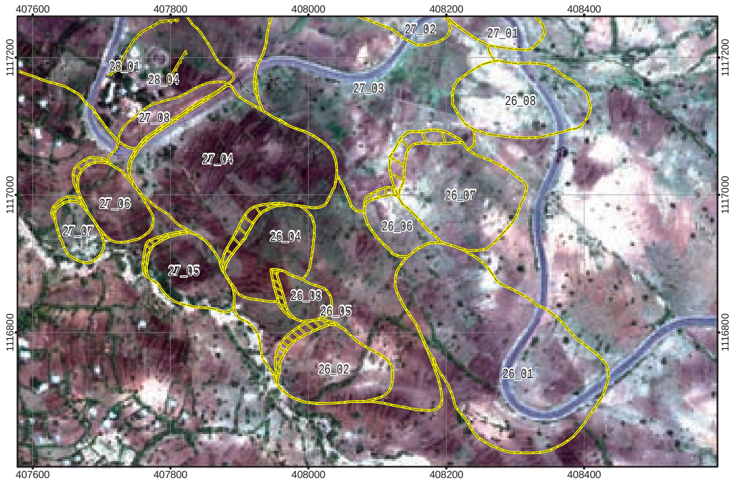


Figure 4.3.2 Satellite imagery interpretation and mapping of landslides (L/S26 to L/S27)

4.3.2 Landslide distribution

Landslides which are shown in the landslide distribution map are classified into blocks, according to the movement direction, scale, activity and mechanism.

The relationship between the landslides, altitude and basement geology was analyzed to study the distribution and trend of the landslides in the surveyed area.

a. Number of landslides by altitude

The data on landslide distribution and altitude were combined using GIS to study the relationship between the number of landslides and the altitude. With respect to the number of landslides for every 200m altitude, on the Goha Tsiyon side, the number is highest between 2,400 and 2,600 m, followed by 2,000 and 2,200 m, and 2,200 and 2,400 m. On the other hand, on the Dejen side, many landslides are observed between 1,800 and 2,000 m, while few are observed at other altitudes.

b. Number of landslides by geology

In general, colluvial deposits are accumulated essentially under scarps and on gentle slopes. The data on landslide distribution and geology of the bedrock were combined by GIS to study the relationship between the number of landslides and the bedrock geology. In terms of the number of landslides per km^2 area, the landslide frequency is the highest (17.45 per km^2) in the area of limestone, siltstone and shale of the Antalo Formation, followed by area covered with basalt and pyroclastic rock (12.62 per km^2). The frequency is low in the area with gypsum, siltstone and shale in the Abay Formation and the area with sandstone and conglomerate in the Adigrat Formation. Both formations are located at low altitudes in Abay Gorge.

Table 4.3.1 Landslide Density by Geology

Geology	Road length by geology [m]	Area of each geology [km^2]	Number of landslides [Landslides]	Density in each geology [Landslides/km^2]
Basalt and pyroclastic rocks	20659.56	5.39	69	12.81
Limestone, with siltstone and shale	9181.99	8.59	82	9.54
Gypsum, with Limestone, siltstone and shale	3827.89	1.74	7	4.03
Siltstone and shale	2023.25	1.08	3	2.77
Sandstone, conglomerate with siltstone and shale	5386.58	1.76	12	6.83

(Colluvial deposits have been excluded because some colluvial deposits are themselves landslide mass)

4.3.3 Characteristics of landslide blocks

Figure 4.3.3 summarizes the micro landforms of landslides. Landslides with significant movement clearly show in the landforms. The main scarp (or horse shoe shape scarp) is one such landform where landslides are most easily recognizable. Depression zones, tension cracks, ponds and swamps are observed at upper part on the landslide. Located middle to upper part on the landslide is small isolated hummocks. The bottom of the landslide protrudes from the surrounding slope and compression landforms such as compression cracks, pressure ridges and pressure wrinkles are observed. The tongue is pushed out forward and downward and it sometimes changes the course of a river.

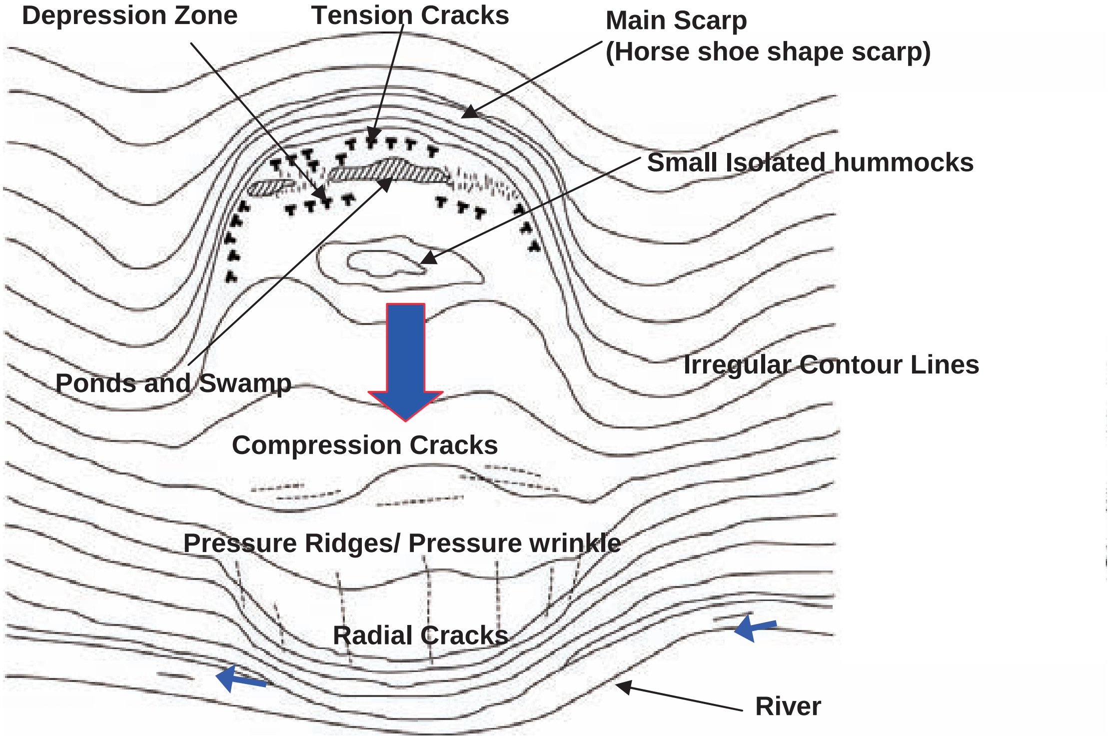
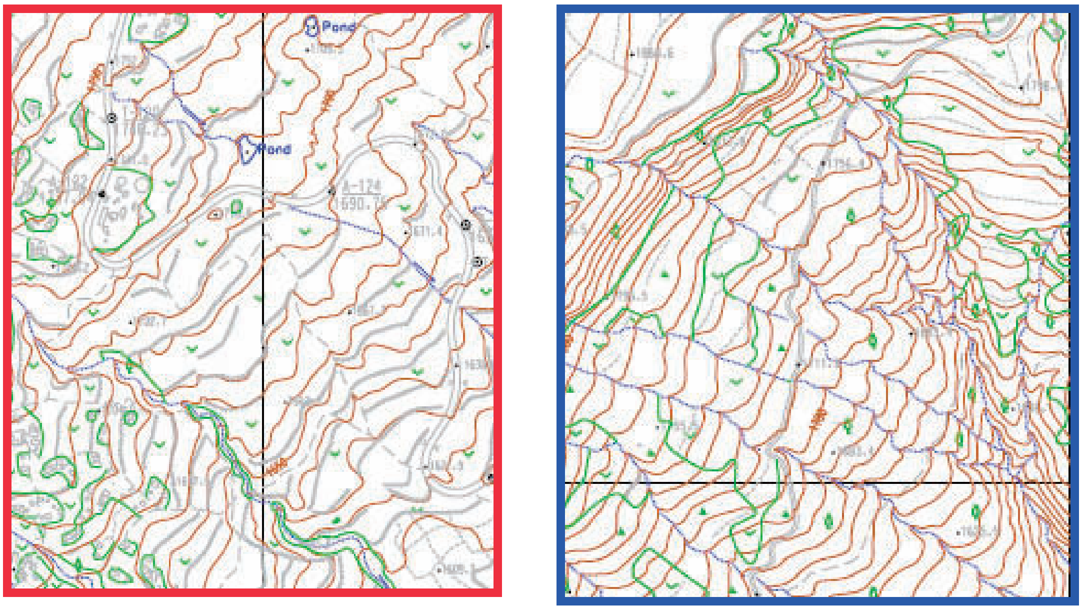


Figure 4.3.3 Schematic Diagram of Landslide Landforms

When interpreting topographic maps, it is possible to deduce the existence of landslides from the irregular contour lines. Figure 4.3.4 is a topographic map of the vicinity of Kurar Village on the Dejen side. The area to the left is not a landslide area. The contour lines are parallel and drawn in an orderly manner. The rivers flow relatively straight. On the other hand, the area to the right is a landslide area. The contour lines are irregular and the river courses are often interrupted. Since surface water easily permeates through cracks in a landslide area, the water spreads underground, making it difficult for rivers to form.



Landslide area **Non-landslide area**

Figure 4.3.4 Comparison of Contour Lines in Landslide Area and Non-landslide Area

4.3.4 Landslide hazard assessment

The results of the landslide hazard assessment, combined with those of rockfall and debris flow hazard assessment, will constitute a comprehensive "sediment disaster hazard map".

With respect to the assessment method, the score rating system commonly used in Japan is adopted, but the score rating of the system has been confirmed to make it suitable for the evaluation results by the experts, incorporating the characteristics of the landslides in the Abay Gorge area.

The sediment disaster hazard map is created using GIS to make it as easy to understand as possible so that it can serve as a basic reference when studying the priority of countermeasures and the road management in the future.

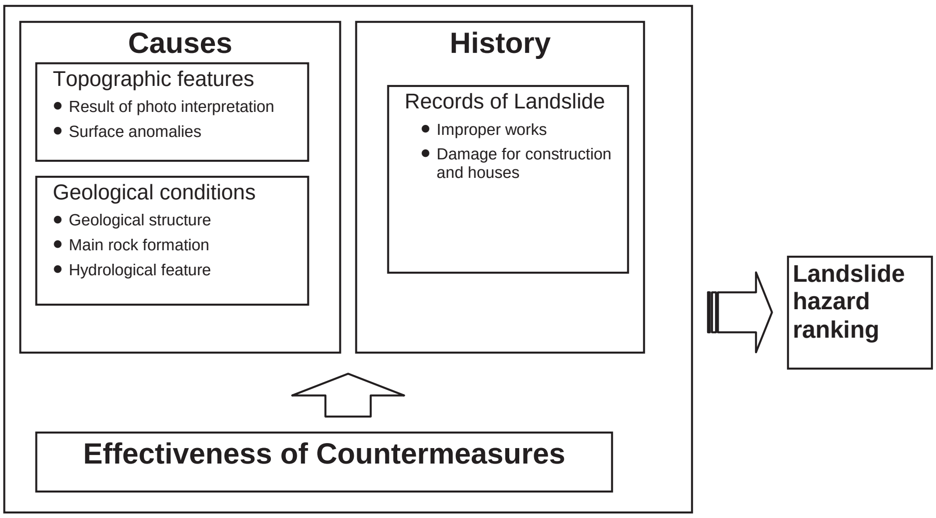


Figure 4.3.5 Flowchart of Landslide Hazard Assessment

Table 4.3.2 Landslide Hazard Assessment Categories and Scores

Category			4	2	1	0
A: Causes	Topographical factor	Result of photo interpretation	exist clearly	exist but partial and not clear	exist but not clear	
		Surface anomalies	large and new cracks, steps and subsidence	small and old cracks, steps and subsidence	slight deformation	no anomalies
	Geological conditions	Geological structure		step, fracture / dip slope	undip slope and others）	
		Main rock formation of landslide body	pyroclastic materials(Py)	colluvial deposit(Co) / siltstone(Si)	basalt(Ba) / shale(Sh)/ limestone(Lm)	sandstone(Ss)/ gypsum(Gy)
		Hydrological feature	much springs / seepage	little springs /little seepage	surface water /trace of water	no water observed
B: History	Records of Landslide	Improper works		obvious	slight	not exist
		Damage on construction and houses	obvious	slight		no indication/ no constructions）
C: Effectiveness of Countermeasure			No countermeasure: ± 0	No effect: ± 0	Some effect: -2	High effect: -4

In addition, the landslide risk for the road was assessed in qualitative terms, taking into consideration the landslide hazard and the impact on the road. The impact on the road was determined based on the positional relationship between the landslide and the road and whether or not the landslide phenomenon affects the road. The higher the landslide hazard rank and the greater the impact on the road, the higher the landslide risk for the road. A summary of the risk assessment results is provided in Appendix.

Table 4.3.3 Landslide Risk Assessment of the Road

		Influence on the road			
		A	B	C	D
Landslide hazard	A	I	II	III	IV
	B	II	III	IV	IV
	C	III	IV	IV	IV

4.3.5 Priority landslides

According to the results of landslide risk assessment of roads, landslides of rank I (extremely high risk to the road) and rank II (high risk to the road) should be regarded as high priority landslides. ERA has already carried out construction work as a countermeasure for some sections of the high priority landslide. Drilling survey, monitoring and geophysical exploration have been conducted in several sections of the high priority landslide as part of the Project.

Of the high priority landslides, 22 landslides (or slopes) are of rank I (extremely high risk to the road) and 40 are of rank II (high risk to the road). It was determined that a total of 62 landslides (or slopes) should be given high priority for countermeasures.

4.4 Landslide Block Interpretation

4.4.1 Geological character of landslides by block

a. Geology of the landslide in L/S00 (ST.0+200 to 1+100)

The area is located in basalts and pyroclastic rocks representing the Ashangi Formation. The main road was constructed on the bedrocks, and the embankment runs through the boundary of the cliff and the flat plane. Schematic geological column of this area is shown in Figure 4.4.1.

Column	Geology	Remarks	Borehole
	Basalt (1)	Flat plane of Goha Tsiyon village.	BH00-11
	Pyroclastic rock (1)	Sandy tuff to tuffaceous sandstone. 2-5 m thickness. Flat plane on top of the basalt (2).	BH00-11
	Basalt (2)	Massive with pillow lava. Cliffs on road side.	BH00-11
	Pyroclastic rock (2)	Fine tuff to lapili tuff with mudstone-like tuff. Widely exposed at the road side.	BH00-11
	Basalt (3)	Highly weathered porous basalt. Very soft and brittle.	BH00-12, BH00-21
	Pyroclastic rock (3)	Fine tuff to lapili tuff. As deeper, Fresh rod-like mudstone.	BH00-12, BH00-13, BH00-21
	Basalt (4)	Escarpments over 100 m thick below the area. Developed columnar joints	

Figure 4.4.1 Schematic geological column in the landslide in L/S00

b. Geology of the landslide in L/S05 (ST.4+800 to 5+600)

The area is located around the boundary of the basalts in the Ashangi Formation and the limestone in the Antalo Formation. The main road was constructed on the limestone. Copious amount of debris from the basalt cliff, which affects the road in rainy season, is piled up on the mountainous side of the road. Schematic geological column in this area is shown in Figure 4.4.2.

Column	Geology	Remarks	Borehole
	Basalt	Massive. The phenocryst is small, like mudstone.	
	Tuff (highly weathered basalt ?)	Sand or mud of soft particles prone to liquefying. A few m thickness.	
	Upper limestone	Thick limestone beds and minor intercalation. Steep slopes and escarpments. Pale grey in color.	BH05-11, BH05-21, BH05-31
	Lower limestone	Thick limestone beds and tuffaceous beds. Gentle slopes. Grey white to white in color.	BH05-12, BH05-22, BH05-32

Figure 4.4.2 Schematic geological column in the landslide in L/S05

c. Geology of the landslide in L/S22 (ST.21+600 to 22+300)

The area is located on the sandstone in the Adigrat Formation. The main road was constructed on the colluvial deposit/embankment on the sandstone. The collapse of the colluvial deposit would be a trigger of a big road failure. Schematic geological column in this area is shown in Figure 4.4.3.

Column	Geology	Remarks	Borehole
	Colluvial deposit/embankment	Tuffaceous gravel, sandy gravel, mud and clay mixed with basalt, tuff and limestone. 15-20 m thickness.	BH22-11
	Sandstone	Highly consolidated sandstone. Horizontal bedding plane.	BH22-11

Figure 4.4.3 Schematic geological column in the landslide in L/S22

d. Geology of the landslide in L/S27-28 (ST.27+200 to 28+800)

The area is considered to be located on the siltstone, the shale and the limestone in the Abay Formation. Landslide activities are frequently observed in this area, especially in the rainy season. Hence the boundary of the base rock, which consists of the siltstone, and the sliding soil mass cannot be clearly identified. Schematic geological column in this area is shown in Figure 4.4.4.

Column	Geology	Remarks	Borehole
	Limestone	Thick limestone beds and tuffaceous beds. Steep cliff including overhung. Grey white to white in color.	
	Silt and shale	Siltstone and shale with limestone mixed with sliding soil mass. Gentle slope. Landslide forms.	BH27-11,12,21,22,23, BH28-11,21,31,32,41

Figure 4.4.4 Schematic geological column in the landslide in L/S27-28

4.4.2 Cross sectional interpretation

a. Geology of the landslide in L/S00 (ST.0+200 to 1+100)

In this area, three kinds of landslide classification were exposed. The biggest one is a weathered rock landslide that was initially a rockslide. This landslide body is mainly composed of colluvial deposits. And its slip surface was within a pyroclastic rock layer. Second landslide was a part of a former landslide. This block is classified as a debris movement of past landslide materials, and is composed of colluvial deposits.

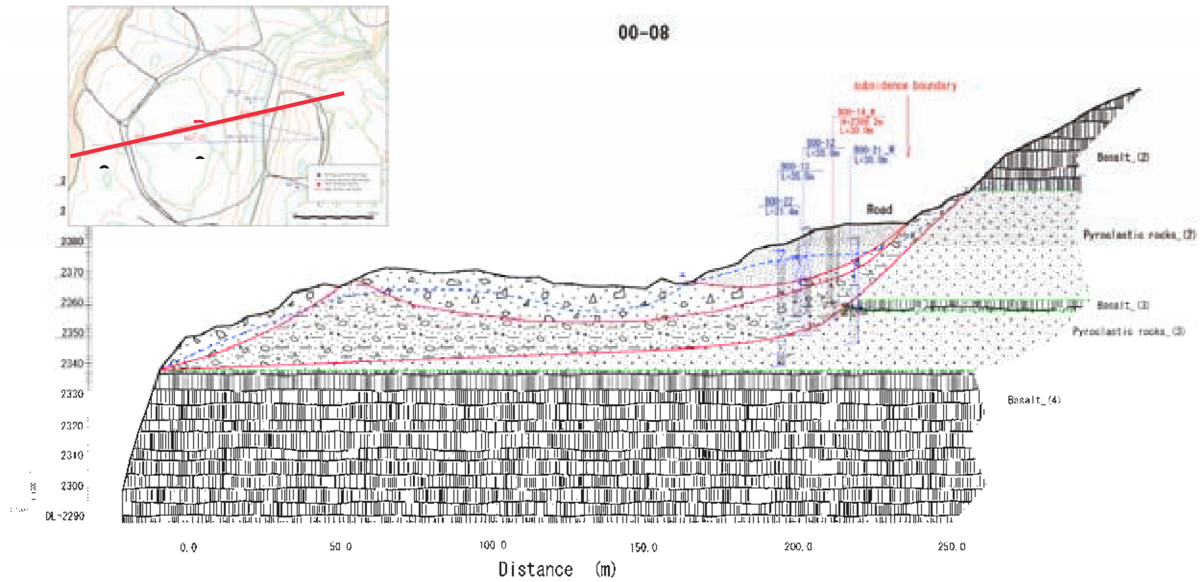


Figure 4.4.5 Geological cross section in L/S00 (B0-12)

b. Geology of the landslide in L/S05 (ST.4+800 to 5+600)

In this area, two kinds of landslide were identified. Landslide 05-01, located on the upper slope, is classified as a debris movement of past landslide materials. It was initially a rockslide during basaltic material and limestone. And the other (05-02, 05-07) located on the lower slope were classified as debris material landslide derived from upper slopes colluvial deposits.

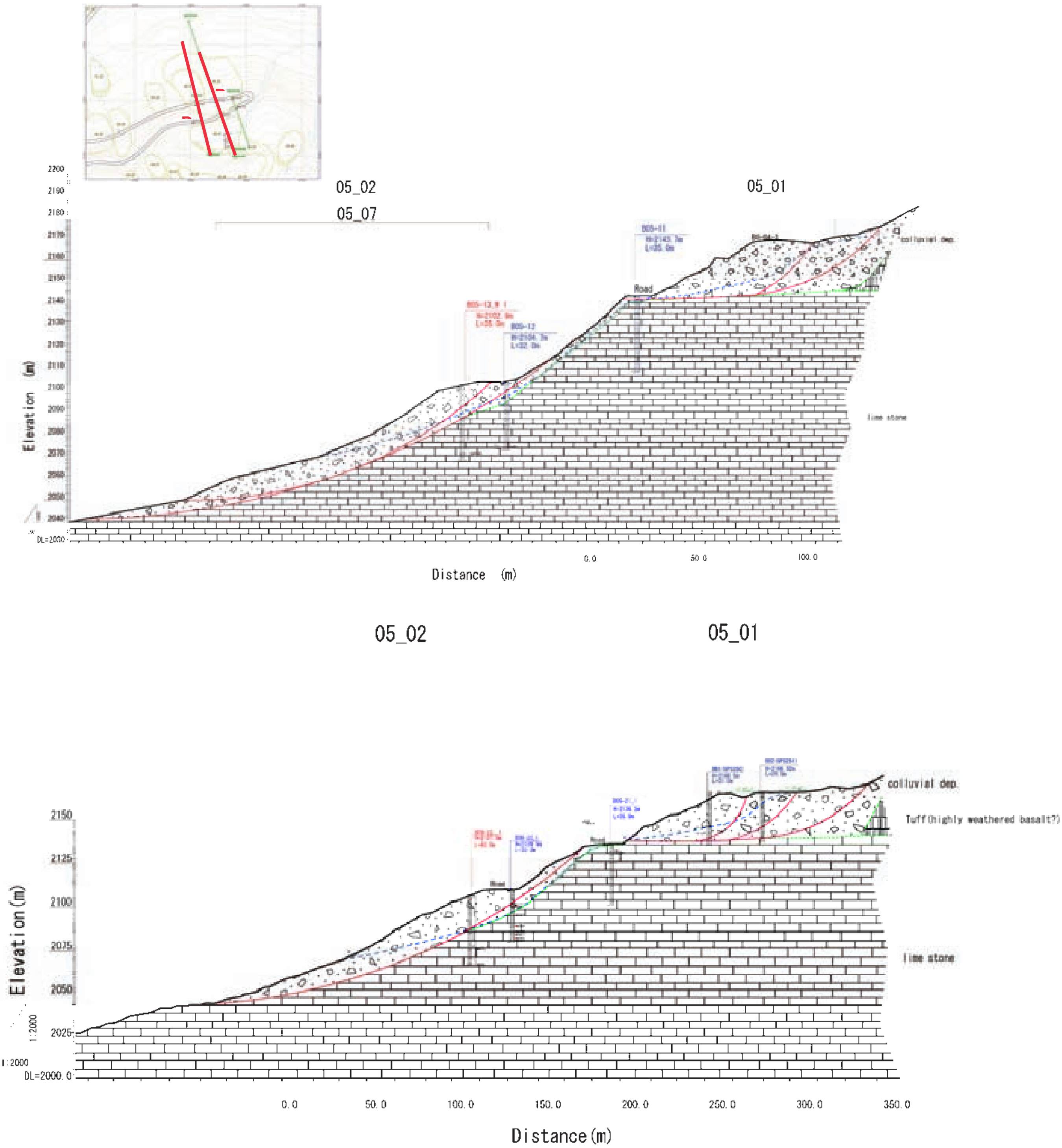


Figure 4.4.6 Geological cross section in L/S05 (above:B0-04, bottom: B0-05)

c. Geology of the landslide in L/S27-28 (ST.27+200 to 28+800)

In this area, two kinds of landslide were classified. Initial landslide is classified as weathered rock landslide that is considered as initially rockslide and debris movement which covered the entire landslide area of L/S27-28. In this area, the basement rocks are not exposed due to weathering or erosion, and are covered by colluvial. Therefore the area is mostly flat planes and/or gentle slopes.

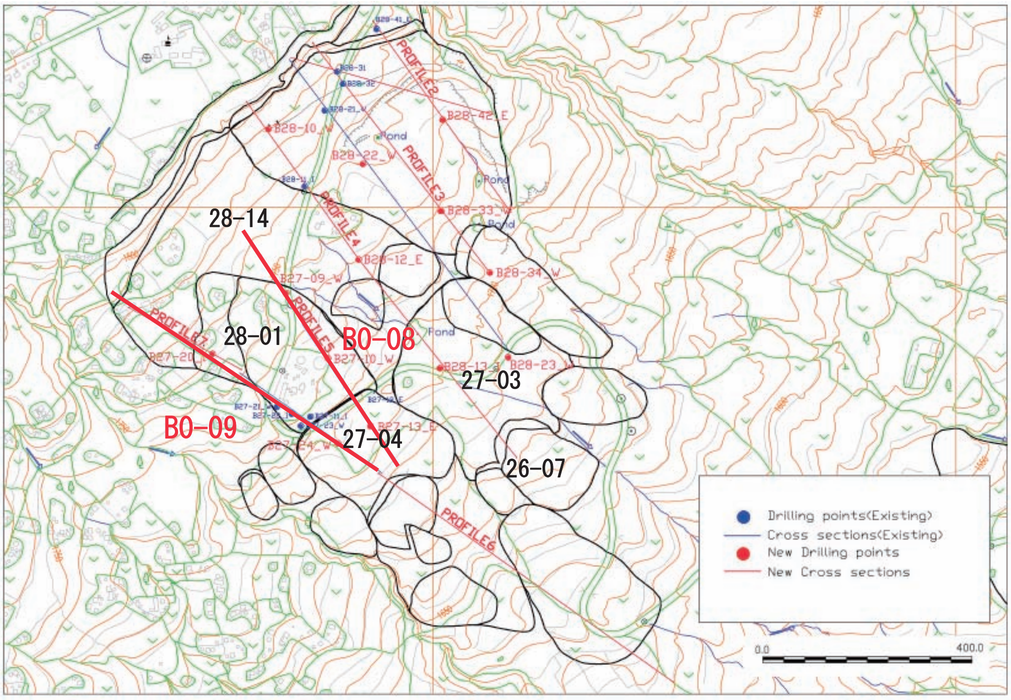


Figure 4.4.7 Survey locations in L/S27

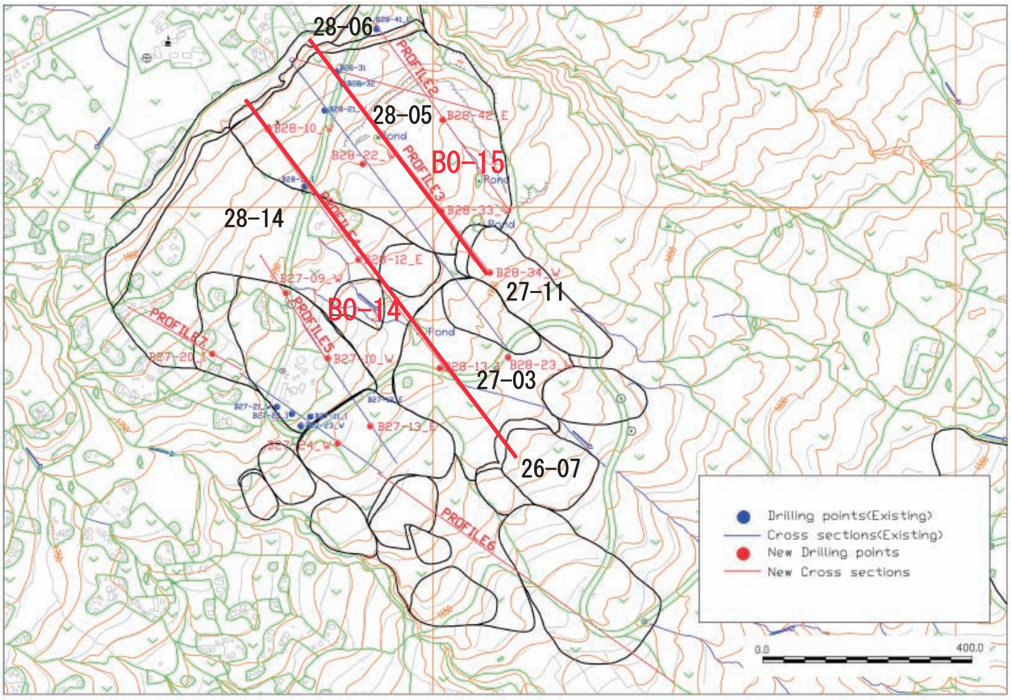


Figure 4.4.8 Survey locations in L/S28

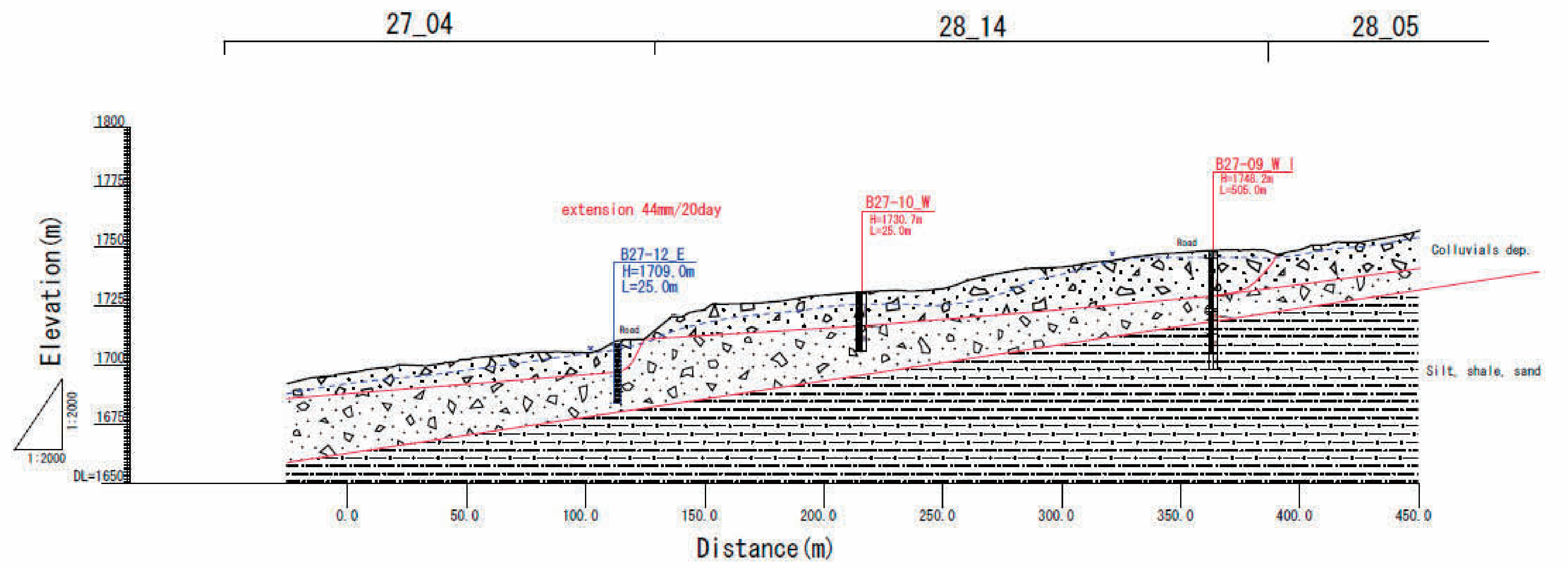


Figure 4.4.9 Geological cross section in L/S27/28 (B0-08)

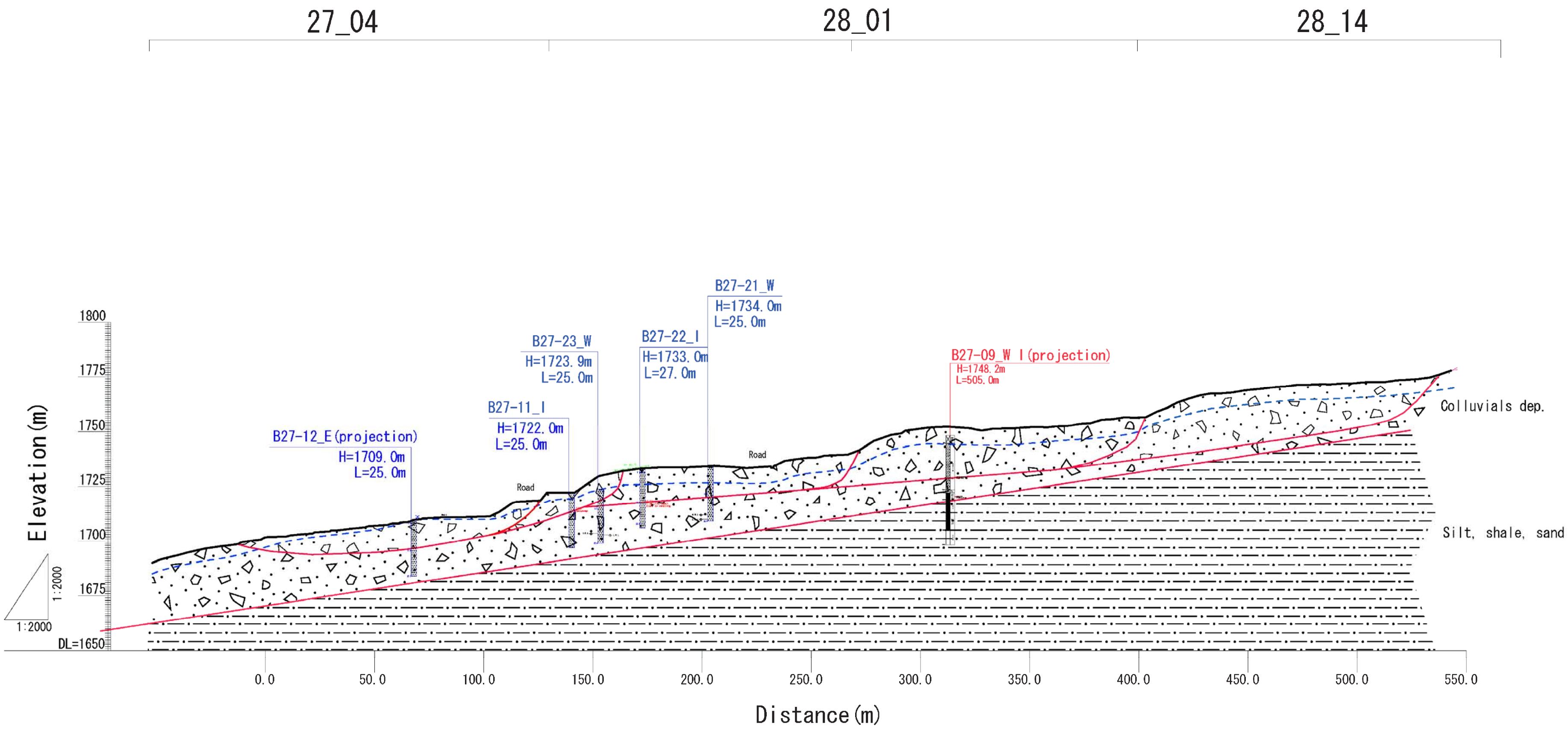


Figure 4.4.10 Geological cross section in L/S27/28 (B0-09)

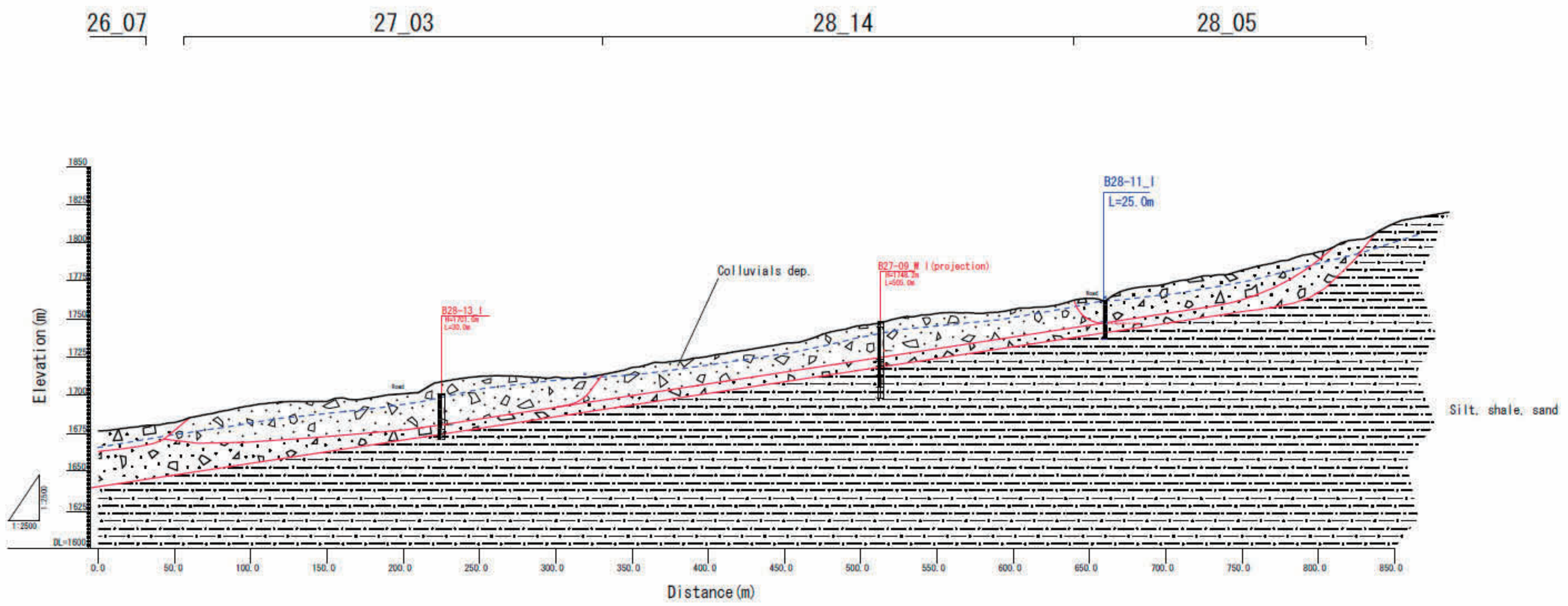


Figure 4.4.11 Geological cross section in L/S27/28 (B0-14)

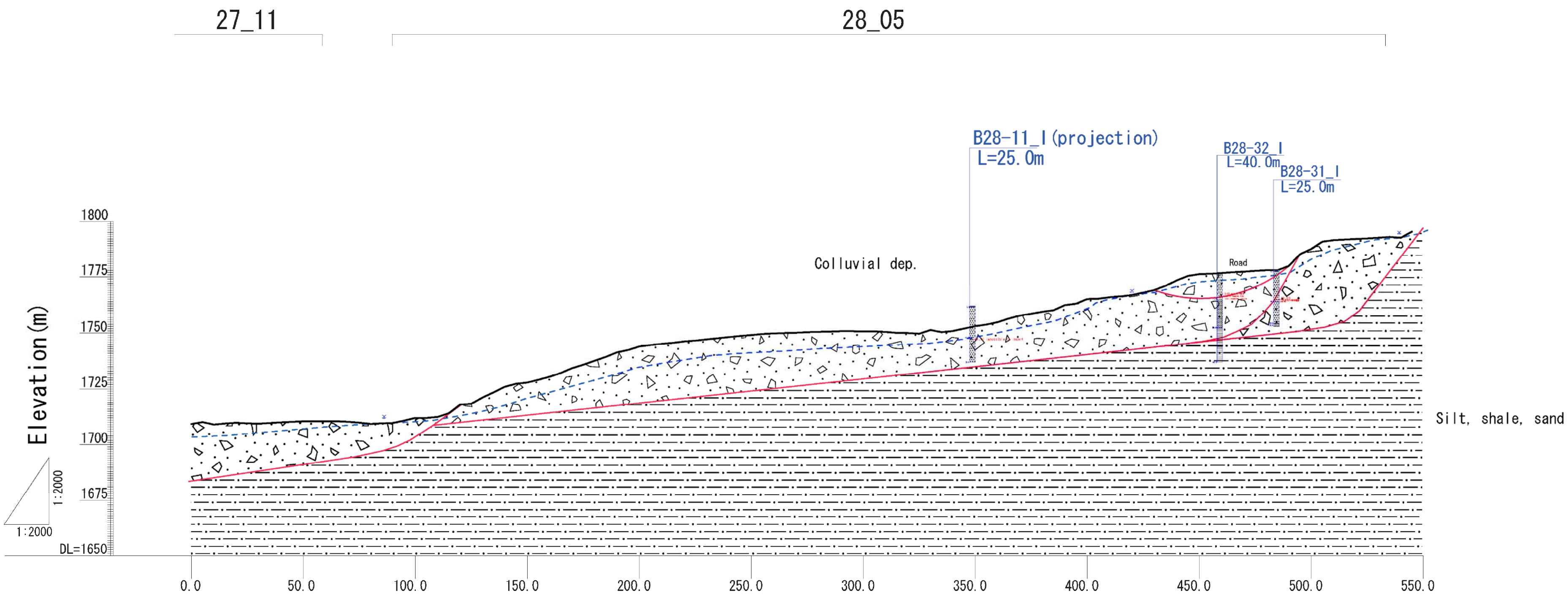


Figure 4.4.12 Geological cross section in L/S27/28 (B0-15)

4.4.3 Monitoring data interpretation

The results of the observation and monitoring with the equipment which was installed in 2010 and 2011 are summarized in this section. The assumed activities of the landslides were examined. It is vital to continue the monitoring to accurately identify the movements of the landslides. The monitoring equipment which was installed is extensometer, borehole extensometer, borehole inclinometer and water level meter.

Table 4.4.1 Outline of the monitoring results

Location	Extensometer		Borehole extensometer		Borehole inclinometer		Water level meter	
L/S00	EX-1	42.4mm (Compression 26.6mm)	B00-11	0.1mm	B00-12	16.2m	B00-14	-23 to -24m Highest-22.7m
					B00-22	10.5m	B00-21	-20 to -23m Highest-18.1m
L/S05	EX-2	45.5mm (Compression 1.9mm)	B05-11	7.5mm	B05-13	12.5m (minute movement)	B05-12	-31 to -32m Highest-30.9m
					B05-21	7.5m (minute movement)	B05-13	nothing
	EX-3	57.6mm (Compression 3.8mm)			B05-22	11.0m (minute movement:29.0m)		
					B05-23	17.0m (minute movement:30.0m)	B05-31	-22 to -23m Highest-21.8m
L/S22					B22-11	18.0m (minute movement:5.5m)		
L/S27	EX-4	99.2mm (Compression 0.9mm)	B27-12	48.9mm	B27-09	GL-19.2m measurement impossibility	B27-09	-15 to -16m Highest-15.0m
					B27-11	8.9m	B27-10	-21 to -25m Highest-20.6m
	EX-5	415.2mm			B27-22	15.4m	B27-21	-22 to -24m Highest-21.9m
							B27-23	-20 to -21m Highest-20.3m
L/S28	EX-6	294.9mm (Compression 0.1mm)	B28-41	0.1mm	B28-11	14.7m	B28-21	-20m Highest-20.0m
					B28-13	GL-9.6m measurement impossibility		
					B28-31	14.0m	B28-23	-15 to -17m Highest-14.7m
					B28-32	24.5m		

4.4.4 Rock and soil properties

a. Bulk density test

Rock and soil are generally composed of silicate minerals, calcareous matters and organic matters etc. The density of general silicate minerals and calcareous matters is 2.5-2.8 g/cm^3 while the density of organic matters is 1.4-2.4 g/cm^3. The bulk densities of the rocks and soils in the area are around 2.2-3.0 g/cm^3, therefore, it is considered to be rich for silicate and calcareous minerals and less organic matters.

b. Grain size analysis

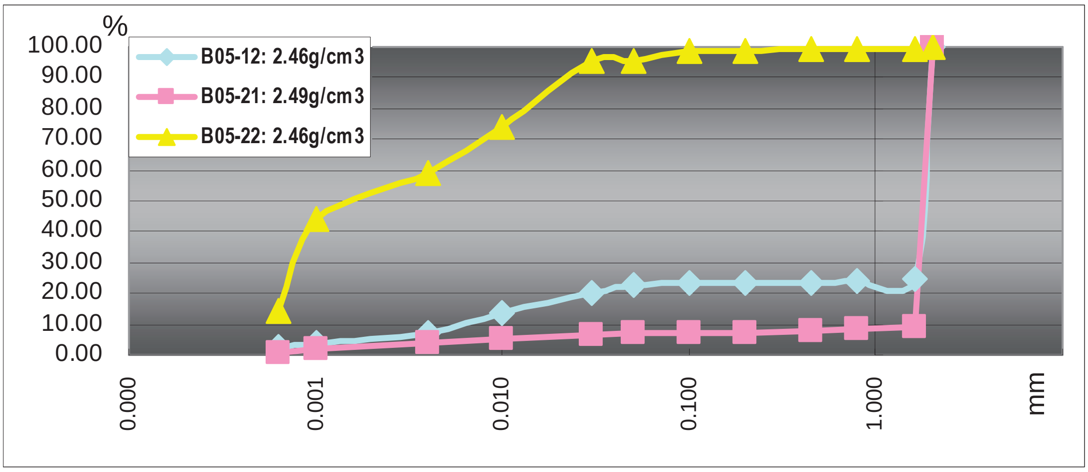


Figure 4.4.13 Cumulative distribution of grain size analysis

The limestone of B05-12 and B05-21 are well grained at around coarse sand to fine gravel, which means that the grain size is highly concentrated at 1.0-2.0mm. The limestone of B05-22 mainly consists of finely-divided particles less than 0.04mm

c. XRD

Table 4.4.2 The results of XRD

distinct	borehole number	sample number	depth(m)	geology	core photo	Pillar-shaped chart description	kind of mineral																notes
							Quartz	Quartz alpha	Muscovite	Dolomite	Calcite	Calcite magnesian	Albite	Albite high	Albite low	Microcline	Vermiculite	Kaolinite	Sepolite	Dickite	Cebalite	Tridymite	
L/S00	B00-14	a	27.6-27.8	tuffaceous mud/medium tuff		Cylinder shape core											○						Vermiculite or Dickite is rich
		b	28.9-29.0	tuffaceous mud/medium tuff			24.4													75.6			
		c	29.9-30.0	tuffaceous mud/medium tuff													○						
	B05-12		15.7-15.9	limestone		Cylinder shape core	52.9				10.1							37.1					Quartz,Calcite is rich partially contained Muscovite clay mineral is Kaolinite
	B05-13		30.9-31.0	limestone		crushed core	95.7				4.3												
	B05-21		34.15-34.25	limestone		crack	51.0				49.0												
	B05-22		28.15-28.3	limestone		rubble core contain clay		32.2	33.8		34.0												
	B05-23		31.7-31.85	limestone		weakly crushed core	49.6					50.4											
L/S27	B27-09	a	26.3-26.5	shale-silte alternation		crack	80.2						17.6						2.2				Quartz,Albite is rich partially contained Muscovite, Tridymite
	B27-10	a	15.6-15.8	shale-silte alternation		Crushed core(surroundings)	75.9			4.2	3.3		16.6										
	B27-23	a	10.1-10.25	siltstone&shale		crack	46.8								46.1						7.1		
									42.9						38.9							18.2	
		b	22.1-22.20	siltstone&shale		crack	8.3							17.3						2.4			
	B28-13	a	11.5-11.7	colluvial deposit		weathered	29.7		63.5							6.7							Quartz, Muscovite is rich
		b	25.7-25.9	colluvial deposit		weathered	71.8		25.1		3.1												

Figures in the table indicate percentage (%)

1) The tuffaceous mud and medium tuff layer in L/S00 area contains a lot of vermiculite or dickite.

2) The limestone layer in L/S05 area contains a lot of Quartz and Calcite, and it also contains some muscovite and clay mineral kaolinite.

3) The shale and the siltstone alternation of strata in L/S27 area contain a lot of quartz and albite, and also contain some muscovite and tridymite.

4) Colluvial deposit layer in L/S28 area contains a lot of quartz and muscovite.

4.4.5 Discussions on the slip surface

a. Methodology of landslide analysis

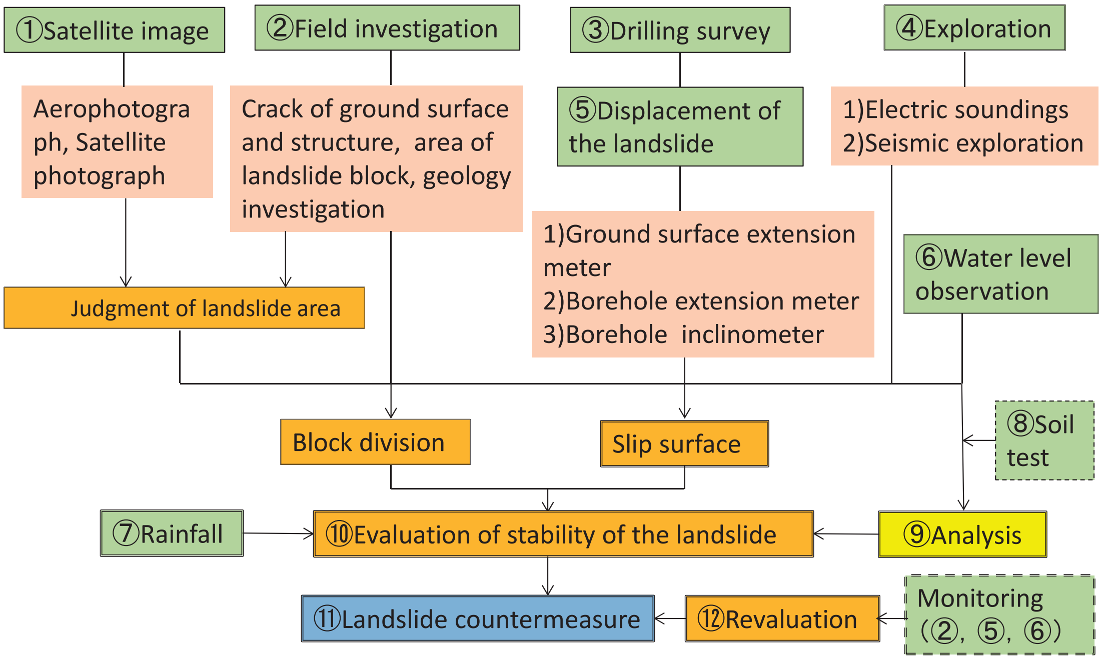


Figure 4.4.14 Flow of landslide survey and landslide analysis

Figure 4.4.14 shows the flow of the landslide item and the landslide analysis.

1) ① is acquisition of the satellite image, and ② is field investigation. Judgment of landslide area and rough block division are executed from these.

2) ③ is the drilling survey, and ④ is the exploration. The drilling survey is a survey of the point, and the exploration is a survey of the line.

3) Investigation of the displacement (⑤) of the landslide blocks and water level observation (⑥) are executed using boreholes.

4) Landslide block and the slip surface are identified by detailed field investigation, the drilling survey, geophysical exploration, monitoring of the displacement of the landslide, water level observation.

5) The stability analysis is executed by comprehensive investigation and the soil strength obtained from the soil test.

6) The landslide measures works ate planned based on this result of the survey, and a part of them is executed.

7) The stability of the landslide is revalued from the movement observation of the field investigation, investigation of the displacement of the landslide, and the observation of water level.

b. Slip surface on each site

b.1 L/S00

In view of the landslide situation, block 00-08 is assumed to be a "complex slide". The scarp zone is at the eastern end of the road, and the end zone is in the terrace located east-southeast of the road. Depression zone formed as a result of the horizontal movement of the soil mass in the middle slope. The block is assumed to have moved from the embankment of the road, due to the rising of the ground water level in the rainy season from 2009 to 2011. The extrusion is observed at the end zone. New cracks occurred in this extrusion, and landslide blocks 00-07, 00-10, and 00-11 are assumed to have been triggered by this extrusion. In view of the cracks on the ground surface, block 00-07 is divided into smaller blocks.

Multi-tuff layers existed at 27.8 to 28.4m depth and 31.5m depth for B00-12, and a multi-tuff layer or a clay layer existed in another borehole. A tuff layer existed on the line connected at 25m depth in the embankment and 15m depth in the middle to lower slope. It is assumed that the tuff layer forms the slip surface because the layer has low shear strength. It is possible that the tuff layer expands to the upper slope and develops into a potentially large landslide. Further investigation is needed.

Displacement of block 00-08 was detected at a depth of 17.0m depth by a borehole inclinometer in 2010. This displacement is assumed to have occurred at the inner embankment of the road; however, it could also extend to the entire block 00-08.

b.2 L/S05 area

Two roads exist in the landslide area. The cracks on the ground surface and retaining walls of the road due to the landslide suggest that the block is divided into an upper block (block 05-01) and a lower block (block 05-02). In the upper block, the scarp zone is just below the terrace of the upper slope, and the end zone is the slope shoulder of the upper road. In the lower block, the scarp zone is located on the lower road, and a new crack is observed on the road. The block 05-07 is treated as an independent block that is subdivided block 05-02.

The upper block (i.e., block 05-01) is a slide of colluvial deposit and pyroclastic material, located in the upper level of the limestone. However, no slip surface has been detected. Further investigation is needed.

Displacement is observed at depths of 6.6m depth for B05-21 and 11.6m depth for B05-22 using a borehole inclinometer; this result indicates that the lower block is an active landslide. Multi-tuffaceous siltstone layers are confirmed in the limestone layer. Currently actualized landslides may develop into a large landslide, including an upper block and a lower block. Further investigation is needed.

b.3 L/S22 area

The L/S22 belongs to the Landslide area III. Two active blocks exist in the L/S22 area. Block L/S22-1 is adjacent to the road, and its displacement is large. The crack of the scarp zone has expanded and extends close to the road shoulder.

Spring water is observed at the end of sliding mass from opposite side of the cliff in the rainy season. Ground water infiltrates into the landslide in the rainy season; as a result, the soil mass moves toward the valley. The bedrock is sandstone. As the weathering of the sandstone in this area progresses, the soil mass collapses at the end zone. Although no activity was observed in the moving layer during the Project period, cracks have developed on the surface.

b.4 L/S27 area

The L/S27 belongs to the Landslide area II. In this area, the landslide block continues from the upper slope to the lower slope. The road has a hairpin curve in this area. The landslide movement is remarkable along the cross section line. Landslide anomalies such as new cracks extending to extensometer EX-4, cracks in the right side wall of the road, continues cracks nearby the church, and cracks in the scarp zone in lower block containing the road shoulder can be found along the cross section line.

Two blocks damaged the road along the cross section line. In the upper block 28-01, the scarp zone of the landslide has cracks that continue to extensometer EX-4, and the end of the landslide is the lower road. In blocks 27-04, the scarp zone of the landslide is the lower road shoulder, which crosses over to the end zone of the upper block.

Block 28-01 is assumed to be a slide of colluvial deposit containing mainly basalt, and the matrix is siltstone and shale. The thin tuff layer is assumed to be the slip surface of the valley side wall of block 28-01 in the outcrop.

Borehole bending is at 7.5m depth for B27-21 and accumulated extension displacement using a borehole inclinometer at 15.0m depth for B27-22. Additional borehole surveys and further variation investigation are needed.

b.5 L/S28 area

The L/S28 belongs to the Landslide area II. The landslide block in this area continues from the upper slope to the lower slope. The large cracks of the scarp zone extend over the L/S27 area and the L/S28 area at an altitude of 1,810m. The depression zone, which is just below the scarp zone, is a source of water supply.

While the colluvial deposit in the L/S27 area is composed of siltstone and shale, the one in the L/S28 area is different for each borehole. The colluvial deposit in B28-11 is composed of siltstone and shale, which in B28-21 is gravel of basalt and tuff, and that in B28-31 is limestone.

In the past, a large landslide occurred in the L/S27 and L/S28 areas. That the colluvial deposit of L/S27 is silt stone and shale shows the possibility of a deep landslide exists. Because the colluvial deposit of B28-21, B28-31 and B28-32 are different from each other, geological differences between B28-31 and B28-32 may exist, and the landslide blocks in them may differ. Another borehole survey and further variance investigation are needed.

Blocks 28-03 and 27-02 exist under the landslide which length is 400m from middle to upper part of the slope. Block 27-02, which has a scarp located at altitude of 1,715m, damages the road in the end zone.

c. Summary of hydro-geological structure and landslide movement

The hydro-geological structure and landslide movement in Abay Gorge is summarized in Table 4.4.3.

Table 4.4.3 Summary of the hydro-geological structure and landslide movement in Abay Gorge

No.	Area	Hydro-geological structure and landslide mechanisms	Evidence behind the judgment		Note
1	L/S00	Surface anomalies of the landslide are a sliding of the rotation type inner colluvial deposit and the scarp zone is the buttress fill part of the road. It is judged that block 00-08 shows the movement that related to block 00-07 located in the lower side of block 00-08. Precipitation passes the water channel in the basalt layer where a lot of cracks exist. Groundwater gushes out as spring water along the limitation floor in the tuff layer etc. Though the landslide has been generated into the colluvial deposit, it is thought that the deep landslide along the tuff layer exists.	・The inclinometer monitoring result indicates that the accumulated displacement increases inner colluvial deposit. ・Series of consecutive cracks and slipping trace observed in the sidewall of block 00-07 in the field investigation. ・Spring lines area found at during the field reconnaissance. ・The slickensides are recognized in the weathering weak tuffaceous mud and medium tuff layer of the lower layer in the drilling survey.	◎ ◎ ○ ○	During the rainy season, the groundwater level in the borehole stayed nearly constant and there is no evidence showing groundwater level increasing. Besides, it is thought that there are smallest landslides along the embankment and potentially large landslides.
2	L/S05	This area is divided into the upper slope block 05-01and the lower slope block 05-02. Both these blocks are the major landslide block that directly damaged the road. From the observation of the spring water situation, it is estimated that the groundwater from an upper terrace at outside of the landslide block is supplied from the right side of the upper block, and water level is high in the terrace of the upper block. Precipitation passes the water channel in the limestone layer where cracks exist in the lower block. The groundwater is flown out as spring water along the bottom of the colluvial deposit or the limited surface in the limestone.	・The inclinometer monitoring result indicates that the accumulated displacement at the bottom of colluvial deposit in the upper block and at the bottom of colluvial deposit or inner limestone in the lower block. ・The cracks on the ground surface and retaining walls of the road due to the landslide exist. ・Spring water site in the right side of the upper block suggests the existence of the training source of the underground water.	◎ ◎ ○	During the rainy season, the groundwater level in the borehole stayed nearly constant and there is no evidence showing groundwater level increasing. Now the possibility of the deep sliding is low. But a slickenside is found at deeper formation within the lower block.
3	L/S22	The landslide is adjacent to the road, and its displacement is large. The landslide consists of colluvial deposit and the bedrock is sandstone. Cracks have developed at the surface and extend close to the road shoulder. As the weathering of the sandstone in this area progresses, the soil mass collapses at the toe. It is thought that the landslide is generated by rising of the water level of the shallow groundwater due to direct infiltration of rainfall to the groundwater.	・The range and the movement of the landslide block are confirmed by the field investigation.	○	As the landslide is active, the movement has observed.
4	L/S27	The toe zone of block 28-01 is located in the scrap zone of block 27-04, and the two blocks are closely related. The slip surface of the landslide is the thin tuff layer located in the bottom of the colluvial deposit containing mainly basalt, and the bedrock is siltstone and shale alternation. It is thought that the ground water in this area is abundant and the ground water level of ground water is high by antecedent rainfall. It is thought that water level rises rapidly to the vicinity of the ground level by heavy rainfall in the rainy season and the landslide is generated by rapid increases of pore water.	・The inclinometer monitoring result indicates that the accumulated displacement increases in the bottom of the colluvial deposit. ・The displacement of ground surface extension meter and borehole extension meter increase rapidly by rainfall 100mm at one time and continuous rainfall of 600mm or more. ・The rise of the groundwater level by the rainfall was observed at a position nearby the toe of the landslide.	◎ ◎ △	It is necessary to survey the depth of the slip surface at some distance from the road, and to investigate the groundwater level and the movement of the landslide.
5	L/S28	In this area, the landslide block continues from the upper slope to the lower slope. The fragments of colluvial deposit in this area is different for each borehole such as siltstone-shale, gravel of basalt-tuff, limestone and others. It is assumed that a large-scale landslide was generated in the past, and there are shallow and deep slip surfaces. It is thought that the groundwater channel that has pressure exists in the deep sliding for hydro-geological structure.	・The inclinometer monitoring result indicates shallow sliding. ・The sinking zone is formed in the scarp zone of block 28-05 and also several ponds are seen in the toe zone of block 28-05. ・The displacement in the scarp zone of the landslide indicates creeping movement. ・The rise of the groundwater level by the rainfall was observed at a position nearby the toe of the landslide.	◎ ○ △ ○	The stratum structure is roughly understood by the geological survey. Information of deep slip surface is not observed.

Annotation: ◎: The certainty is very high, ○: The certainty is high, △: Further verification is necessary though the possibility is high.

4.5 Stability Analysis of landslides

4.5.1 General

Generally, stability analysis for landslide is preceded as following procedure.

1) Geological reconnaissance at site
2) Setting up traverse line for the analysis
3) Designing drilling survey, monitoring and geophysical exploration
4) Estimation of slip surface by the survey result
5) Monitoring of the ground water level and movement of landslide
6) Setting up landslide model
7) **Stability analysis**

4.5.2 Safety factor in landslide analysis

Safety factor F_s is defined as the ratio of resistance force against landslide soil mass to force when landslide soil mass starts sliding along the slip surface. F_s =1 means when resistance force and sliding force are balanced. F_s >1 means the landslide is stable whilst F_s<1 is unstable or sliding.

$$F_s = \frac{\text{Resistance force against landslide soil mass}}{\text{Force when landslide soil mass starts sliding along the slip surface}}$$

If the slip surface and pore water pressure plane are decided, F_s is obtained from cohesion c' and shear resistance angle φ', which are constants for soil strength of slip surface, using the stability analysis formula.

Since F_s =1 when the land mass starts sliding, F_s is decided by considering the active state of the landslide for $0.95 < F_s < 1$ if a landslide occurs.

Table 4.5.1 Definition of safety factor for landslide

Safety factor	Landslide condition
F_s =0.95	Case in moving continuously anytime
F_s =0.98	Case in moving continuously for corresponding to rainfall etc.
F_s =1.00	Case in settling down of the landslide

Japan Construction Engineer's Association (2010)

4.5.3 Selecting parameters

The parameters for landslide stability analysis are as follows;

- γ_t : wet unit weight (wet density)
- u : pore water pressure
- c': cohesion (as a soil strength constant)
- φ': shear resistance angle (as a soil strength constant)

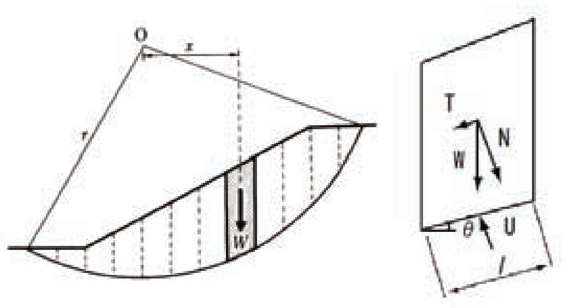
4.5.4 Stability analysis method

There are multiple landslide blocks in the four investigated areas (except L/S22). Previous investigations have suggested that there are shallow landslides appearing as ground surface phenomena and deep potential landslides. The possibility of a deep potential landslide will be discussed after the next investigation. In this report, the stability of shallow landslides occurring in the ground surface phenomena is analyzed.

The slip surfaces of four landslide areas are non-circular (complex) slide. The stability analysis is implemented by using “modified Fellenius method” and “simple Janbu method” generally employed in Japan. Two typical stability analysis methods are explained below.

a. Modified Fellenius method

The Fellenius method is also called a Sweden method or a simple method, and is based on the balance of the moment between soil weight and the shear resistance acting on the slip surface. In case of a large inclination angle at slice of slip surface, Wcosα-ul may become minus in this method. Therefore, Wcosα-ul is generally treated as 0.



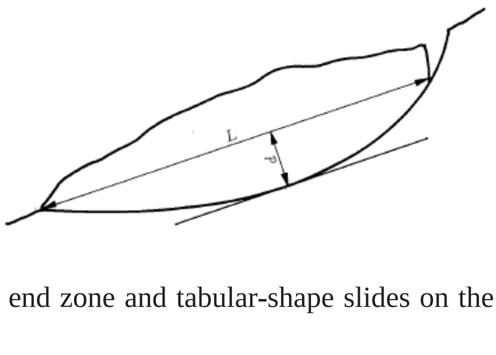
Actually shear stress occurs in the slip surface, so that safety factor is smaller than true value. This is corrected by the modified Fellenius method that employs the effective soil weight W’=W-ub instead of the soil weight W.

$$F_s = \frac{\sum\{c'l + (W - ub)\cos\alpha \cdot \tan\phi'\}}{\sum W \sin\alpha}$$

Here, F_s : safety factor, c' : cohesion, φ': shear resistance angle,
W: soil weight, u: pore water pressure, b: slice width,
$W=\gamma_t hb$, γ_t : soil unit weight, h : soil height,
l: slice length of slip surface, α: inclination angle of slip surface.

b. Simple Janbu method

The Janbu method is, from the point of view of the balance of the horizontal stress and vertical stress in each slice, based on that the total stress in the entire soil mass is balanced as zero. It is applied to tabular-shape slides controlled by the soil weight and the shear resistance on the bedrock, and to complex slides in which are mixed circular slides on the scarp zone and the end zone and tabular-shape slides on the middle zone in the slip surface.



$$F_s = f_0 \frac{1}{\sum W \tan\alpha + Q} \sum \frac{c'b + (W - ub)\tan\phi'}{n_\alpha}$$

Here, F_s : safety factor, c': cohesion, φ': shear resistance angle,
W: soil weight, u: pore water pressure, b: slice width,
α: inclination angle of slip surface,
Q: effective stress in tension crack of scarp zone,
n_α is defined as

$$n_\alpha = \cos^2\alpha(1 + \tan\alpha \cdot \tan\phi' / F_s)$$

f_0 : correction coefficient,

$$f_0 \cong \left(50\frac{d}{L}\right)^{1/33.6}$$

L : distance between the toe and crack at the scarp
d: distance between L and a line of parallel to L tangential line on the slip surface.

4.5.5 Result of stability analysis

The landslide stability analyzed using the modified Fellenius method and the simple Janbu method.

Wet unit weight of a moving soil mass is determined as 18kN/m3 in the stability analysis in the Project. However it is desirable to measure the unit weight in the site as possible.

The landslide block in each area is moving, and the landslide activates when ground water rises in the rainy season. Therefore it assigned $c' \fallingdotseq 0$. Although there are damages on the road due to cracks and subsidence, the landslide is not moving so much. Therefore, the safety factor F_s should be less than 1.0, it is reasonable to adopt 0.98 for the area.

The result of the stability analysis for each investigated areas is shown in Table 4.5.2. Almost the same results for both the modified Fellenius method and the simple Janbu method are obtained.

The slip surface is a tuff layer in both L/S00 and L/S27, here $\varphi' \fallingdotseq 10°$ is obtained. The landslide in L/S05 and L/S28 is a colluvial deposit slide, and φ' is 26° (L/S00) and 16° (L/S27), exceeding φ' of the tuff layer.

Table 4.5.2 Stability analysis results (shear resistance angle φ')

Area	Modified Fellenius method	Simple Janbu method	Geological information of slip surface
L/S00	10.8	10.7	Slip layer: embankment and tuff layer in colluvial deposit, complex slide
L/S05	26.3	26.6	Colluvial deposit slide, Bedrock: limestone
L/S27	10.2	10.0	Colluvial deposit slide contained basalt Bedrock: siltstone and shale
L/S28	16.3	16.1	Colluvial deposit slide, Bed rock: limestone contained basalt

4.6 Utilization of slope stability analysis

4.6.1 Principle of using the result of stability analysis

In a landslide countermeasure project, combinations of different countermeasure methods should be tested before determining the grand design of the countermeasure plan. Generally, multiple combinations of countermeasure works should be examined according to their cost effectiveness and feasibility. Figure 4.6.1 shows the changes in factor of safety when multiple countermeasure works are applied. Assuming there are two possible combinations to achieve a planned factor of safety (Fp), i.e., a combination of A and B, and a combination of C and D, the necessary number of each countermeasure and the resulting increments of the factor of safety can be estimated through the stability analysis. Based on the stability analysis, an appropriate combination can be decided according to the cost effectiveness and feasibility.

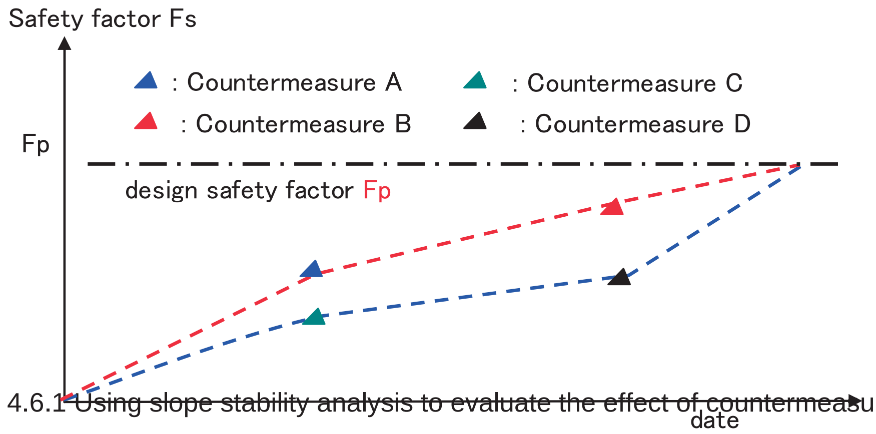


Figure 4.6.1 Using slope stability analysis to evaluate the effect of countermeasure works

4.6.2 Initial assessment of the effect of countermeasure works

a. Initial assessment of the effect of groundwater drainage work

It is necessary to predict how the groundwater level decreases when different types of drainage works with different configurations are implemented. In the initial assessment, the highest groundwater level recorded in a rainy season should be used as the initial condition. Then, the declined amount of groundwater level can be predicted through hydrological analysis and seepage flowing analysis. In this kind of analysis, Thiem's hydraulic equation is often employed to obtain the amount of inflow, and there is a finite difference method (FDM) software MOD-Flow for seepage flow analysis. The predicted groundwater level then can be used in the longitudinal section for stability analysis. The analysis verifies how much the factor of safety is improved. Generally, the prediction accuracy is relatively low. Hence, groundwater should be developed after groundwater drainage work is executed to further assess the effectiveness of the drainage works.

b. Initial assessment on the effect of surface water drainage

It is difficult to predict the fluctuations of groundwater level when different types and configurations of surface water drainage work are implemented. Surface water drainage work is easy and relatively inexpensive to implement compared to other counter structures. As a result, the initial assessment is not conducted. Only verification of measure's effect is conducted after the countermeasure construction work is executed.

c. Initial assessment on the effect of earth removal work, counterweight fill work

When topography is changed by implementing earth removal work and counterweight fill work, topographic geometry of the longitudinal cross-section should reflect the change so that the factor of safety after the implementation can be properly calculated.

d. Initial assessment of the effect of restraining works

The effect of restraining works can be evaluated with the following equation.

$$F = \frac{\sum S + P_s}{\sum T - P_m}$$

Here, ΣS, ΣT: The numerator and denominator of stability analysis equation; Ps: increment of shear strength resulted from the restraint work; and Pm: restraint force (in the opposite direction to the driving force).

In the formula, Ps is the increment of shear strength resulted from the restraint works, such as that can be obtained from anchor works. Pm is the restraining force, such as the detaining effect of the anchor works and the deterrent of the pile works and the shaft works.

4.6.3 Verification of the effect of the countermeasure works

a. Verification of the effect of surface water drainage and groundwater drainage

The effect of groundwater drainage is evaluated through the comparison of current groundwater level to the previous groundwater level before the drainage work is implemented. Generally, the highest groundwater levels before and after the execution of the drainage work are used in the comparison. However, the groundwater level changes frequently according to the amount of rainfall. Hence, groundwater response to precipitation pattern can be modeled using the monitoring data that was obtained before the execution of the drainage work. By using the model, groundwater level can be simulated in response to an intense rainfall after the drainage work, which then can be compared with the monitored groundwater level. Through applying this method for all of the groundwater monitoring points along the longitudinal section, and conducting the slope stability analysis, the effect of the drainage work can be verified.

b. Verification of the effect of earth removal work and buttress counterweight fill work

If an earth removal work and buttress counterweight fill work is conducted exactly as they were planned, the same effect should be achieved as expected. If the earth removal work and buttress counterweight work are not implemented as planned, another slope stability analysis should be conducted using the actual longitudinal topographic section after the execution of the countermeasure works.

c. Verification of the effect of restraint works

For the restraint works, if they are executed exactly according to the plan, the effect should be the same as expected.

4.6.4 Modification of the shear strength parameter of the soil

For a landslide during monitoring period, the factor of safety becomes exactly 1.0 (F=1.0) when the deformation starts to occur. If the groundwater is monitored in this period, the groundwater level at that deformation starting point is called the critical groundwater level (F=1.0). Using the critical groundwater level, the shear strength parameter of the soil in sliding surface can be obtained through back-analysis in the slope stability analysis. Using this approach, the calculated shear strength parameters can become closer to the true values. Using this modified shear strength parameter, relatively accurate estimation on the effect of countermeasure work can be obtained.

4.6.5 Trial calculation concerning the assessment on the effect of the countermeasure

A trial calculation was conducted to evaluate the effect of the countermeasure works along the L/S-00. The factor of safety was set as 0.98, and the shear strength parameters of soil were obtained through back-analysis. However, in this site, because normal groundwater level was not monitored, the groundwater level was set according to that observed during slope excavation.

Figure 4.6.2 shows the trial calculation result representing the effect of the groundwater drainage works. It indicates increase in the factor of safety in response to the decline of groundwater level. Two cases are plotted in the figure. Using two sets of specified shear strength parameter ϕ, where one is $\phi = 6^\circ$ and the other is $\phi = 4^\circ$, cohesion (c) was calculated through back-analysis. The results were plotted as blue and pink lines. According to the result indicated in blue when $\phi = 6^\circ$, by lowering the groundwater level (highest groundwater level) by 6 m, the planned factor of safety (Fp = 1.2) can be achieved. However, in the case when $\phi = 4^\circ$, the planned factor of safety cannot be achieved even by decreasing the groundwater level for 10 m. It is therefore clear that the effect of groundwater drainage may be overestimated when using a larger friction angle.

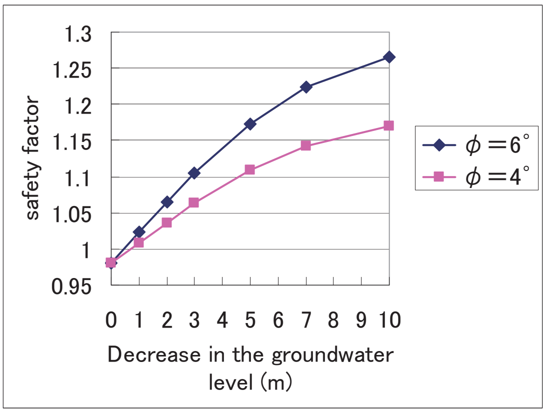


Figure 4.6.2 Changes in the factor of safety in response to decrease in groundwater level

Next is an example to show the trial calculation for a landslide with fill work in the middle of the slope. In the middle of the slope, when fill work with a depth of 1 to 3m was executed, the factor of safety increased from 0.98 to 1.02.

The trial calculation of stability analysis in which a fill work is implemented on a road at the head. When a fill work about 1 m thick is conducted at the landslide head, the factor of safety changed from 0.98 to 0.92.

When pile works (steel pipe pile) are implemented as a restraint work, a trial calculation helps to decide how many steel pipe piles should be used. The result shows that to improve the current factor of safety of 0.98 to 1.2, steel pipe piles of φ500mm×t40mm should be arranged at an interval of 1.9m. Another calculation also shows that, if a groundwater drainage work is executed at first to lower the average groundwater level by 3m, which means the factor of safety can be improved to F≒1.1, and then to improve the factor of safety from 1.1 to 1.2, it is necessary to arrange φ350mm×t25mm steel pipe piles at an interval of 1.9m.

4.7 Rockfall Analysis

4.7.1 Methodology

To accurately simulate or predict rockfall movement on a slope, various coefficients and parameters that may influence the motion behavior of rockfall are selected by referring to past test data.

Provided that these coefficients have a normal distribution random numbers are generated from the confidence limit (95% confidence interval), and various constants are determined and used for the simulation. Based on test results, an equivalent friction coefficients corresponding to the type of slope (Table 4.7.1) are used to obtain the kinetic energy (considering 10% rotational energy) of falling rocks in a simplified manner.

Dr. Spang’s rockfall simulation (Spang, 1987; Spang, 1998) specifies parameters by the state of slope: friction angles (dynamic, static), damping factors (normal, tangential), rolling resistance, and roughness of the slope (amplitude, frequency), as listed in Table 4.7.2. The parameters and their fluctuation ranges (%) are set as initial conditions for the simulation.

Table 4.7.1 Classification of Slopes and μ (equivalent friction coefficient) value

Classification	Characteristics of rockfall and slope	Range of μ	μ used for design
A	Hard rock, round rocks, low roughness, no wood	0.0 to 0.1	0.05
B	Soft rock, angular to round rocks, medium to high roughness, no wood	0.11 to 0.20	0.15
C	Sediment, talus cone, round to angular rocks, small to medium roughness, no wood	0.21to 0.30	0.25
D	Talus cone, (talus cone containing large rocks), angular rocks, medium to high roughness, no wood to some wood	0.31 to 0.60	0.31～0.40

Table 4.7.2 Dr. Spang’s Version – Parameter Selection Table for Rockfall Simulation

Surface Type	Friction Angle		Damping Factors		Rolling resistance Rw	Roughness	
	Dynamic Rg (deg)	Static Rh (deg)	Normal Dn	Tangential Dt		Amp. Oa (m)	Freq. Of (m)
(1) Rock with mainly smooth surface	29 to 32	38 to 42	0.05 to 0.07	0.86 to 1.00	0.02	0.10	1.00
(2) Rock with rough surface	29 to 32	38 to 42	0.05 to 0.07	0.86 to 1.00	0.04 to 0.06	1.00	2.00
(3) Rock debris covered with wood	25	33 to 37	0.04 to 0.06	0.81 to 0.99	0.07 to 0.09	0.50	1.00
(4) Rock covered with a thin soil layer	14 to 16	29 to 32	0.03 to 0.04	0.72 to 0.88	0.09 to 0.12	0.20	1.00
(5) Rock debris covered with a thin soil layer	14 to 16	33 to 37	0.03 to 0.05	0.77 to 0.94	0.13 to 0.17	1.00	1.00
(6)Residual soil covered with grass	14 to 16	29 to 32	0.03	0.68 to 0.82	0.10 to 0.14	0.05	1.00

4.7.2 Rockfall Interpretation

a. Forms of rockfall

Figure 4.7.1 depicts common relationships between the topography/geology and the movement type and landform of the rockfall source. Rockfall can be classified into "fall-off type" and "exfoliating type" in this Report, depending on the movement type at the source. In the Abay area, rockfall take the types of (1), (6), (7), and (8) in Figure 4.7.5.

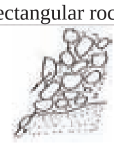
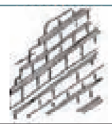
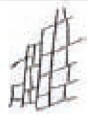
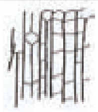
Fall-off type	(1) Floating and falling of rocks out of the talus deposit that composes a steep slope of talus and the cutout face of talus.	(2) Floating and falling of rocks out of the terrace layer that composes riverside and coast terrace cliffs and the cutout surface of terraces.	(3) Floating and falling of rocks out of the steep slopes and cutout faces slopes consisting of vulnerable conglomerate, or deposit of pyroclastic flow, and volcano mud flow.	(4) Floating and falling of non-weathered gravels in slopes due to weathering of granite and hard rock.
	Semi-rectangular rocks to rectangular rocks	Rounded rocks to semi-rounded rocks	Rounded rocks to rectangular rocks	Rounded rocks to semi-rectangular rocks
				
Exfoliating type	(5) Sliding down along the bedding plane or schistosity plane of bedrock with developed layers or schistosity that composes a dip slope.	(6) Exfoliating off from bedrock with developed three direction cracks and falling from the fracture plane.	(7) Slide down from steep bedrock with the developed columnar joints.	(8) Breaking and falling of the hard layers which overhung due to selective erosion.
	Massive to flat	Massive to flat	Massive	Massive
	Slate, shale, and schist and alternate layers of these and other rocks.	Plutonic rock such as granite, sandstone, schalstein, and sedimentary rock such as limestone, and fault fracture zones.	Basalt, lava such as andesite, and welded tuff, which have developed joints.	Alternative layers that are extremely different in harnesses.
				

Figure 4.7.1 Topography/Geology and Rockfall Type

b. Conditions for rockfall

The occurrence of rockfall has no premonitory phenomenon, and no correlation with events considered to be causes of rockfall has been clarified. Therefore, it is difficult to predict rockfall and to prevent rockfall disasters based on movement restrictions like a landslide. However, rockfall does exhibit characteristic types, depending on the topographical and geological conditions of where it occurs. Thus, risky rockfall locations can be specified by investigating basic factors and inducing factors of rockfall, state of the slope, and disaster records. It is therefore possible to roughly estimate the size, form, and movement of rockfall.

c. Basic factor and inducing factor of rockfall

c.1 Basic factor

Topographical and geological conditions have been cited as basic factors of rockfall.

A steep slope is a landform that easily causes rockfall. Also, rockfall commonly occurs when a slope is overhanging.

As for geology, a fall-off type rockfall easily occur where matrix around gravels is easily weathered and eroded in terrace conglomerate layer, pyroclastic sediment, and weathering rocks. An exfoliating type rockfall commonly occurs when the rocks surrounded by cracks developing in the bedrock are floating.

c.2 Inducing factor

Rainfall, wind, earthquake, and artificial matters are inducing factors of rockfall. However, it is difficult to determine the inducing factor of rockfall.

Rockfall occurs even when continuous precipitation and/ or rainfall intensity is small. Therefore, occurrence of rockfall correlates weakly with precipitation. However, there are data that rockfall increases when the rainfall intensity is 30 to 40mm/h.

4.7.3 Analysis result

a. Cross sections to be examined

Conditions for setting rockfall simulations are listed in Table 4.7.3. They include cross sections to analyze, the location of the rockfall source, and the size of the rockfall. The diameters of rocks observed near the cross section to be analyzed are used. The falling rocks are assumed to be spherical, and the density of rock is assumed to be 2.5 t /m^3.

Table 4.7.3 Cross Sections to be Examined and the Size of Rockfall in Rockfall Simulation

Section	Cross section to analyze	Location of the source of rockfall	Diameter of falling rocks ϕ (m)	Mass of rockfall m (kg)	Remarks
RF02-1	Section 6 (ST.2+400)	Source of rockfall (H = 25.0m)	0.3 ±0.1	35.3 ±3.5	Rockfall from the upper portion of the cut slope (Initial movement: Rolling)
RF05-1	Section 15 (ST.5+480)	Source of rockfall (H = 18.8m)	1.3 ±0.1	2874.4 ±67.0	Rockfall from the hillside of the slope (Initial movement: Free fall)
RF16-1	Section 28 (ST.17+630)	Source of rockfall (H = 80.4m)	1.4 ±0.2	3590.1 ±155.0	Rockfall from the top of the slope (Initial movement: Free fall)
RF20-3	Section 46 (ST.21+000)	Source of rockfall (H = 45.5m)	1.5 ±0.2	4415.6 ±175.0	Rockfall from the upper portion of the slope (Initial movement: Rolling)
RF34-1	Section 50 (ST.34+380)	Source of rockfall (H = 18.9m)	0.7 ±0.1	448.8 ±19.5	Rockfall from the upper portion of the slope (Initial movement: Rolling)

b. Parameters selected for rockfall simulation

Parameters such as the friction angle, rolling resistance, and roughness of the slope for each slope are set. In case the analysis results do not match the actual state of rockfall at the site, the parameters should be reviewed.

c. Results of rockfall simulation

The results of the rockfall simulation are presented in the Appendix. In the simulation, the kinetic energy and bounce height of the falling rocks at an arbitrary point can be obtained. The results presented below indicate the kinetic energy and bounce height of falling rocks on the boundary between the road and the end of the slope.

Table 4.7.4 Maximum Energy and Maximum Bounce Height on the Roadside in the Rockfall Simulation

Cross section to analyze	Location of the rockfall source	Diameter of falling rocks ϕ (m)	Mass of rockfall m(kg)	Rockfall Movement		Remarks
				Max. energy (kJ)	Max. bounce height (m)	
Section 6 (ST.2+400)	Source of rockfall (H = 25.0m)	0.3±0.1	35.3 ±3.5	12	3.54	Kinetic energy is small, but bounce height is great.
Section 15 (ST.5+480)	Source of rockfall (H = 18.8m)	1.3±0.1	2874.4 ±67.0	352	2.23	Bounce height is somewhat high.
Section 28 (ST.17+630)	Source of rockfall (H = 80.4m)	1.4±0.2	3590.1 ±155.0	1754	0.11	Kinetic energy is the greatest.
Section 46 (ST.21+000)	Source of rockfall (H = 45.5m)	1.5±0.2	4415.6 ±175.0	492	2.46	Bounce height is somewhat high.
Section 50 (ST.34+380)	Source of rockfall (H = 18.9m)	0.7±0.1	448.8 ±19.5	64	0.03	Bounce height is low.

4.8 Debris Flow Analysis

4.8.1 Methodology

Parameters of debris flow (e.g., flow velocity, flow rate, and sediment concentration) depend on (1) the longitudinal and cross-sectional forms of the river bed in the upper river basin, (2) longitudinal distribution of the thickness and distribution of particle sizes of deposit on the river bed, and (3) rainfall conditions. When a large volume of deposit exists on a steep slope, the slope can be eroded and incorporated into debris fluid, and debris flow can develop rapidly. On a gentle slope, materials in debris flow begin to sediment, and debris flow attenuates.

Table 4.8.1 Parameters Required for Debris Flow Simulation

Simulator model variable	Value	Simulator model variable	Value
Simulation continuance time (sec)	Set from time rainfall continues	Volumetric ratio of finer material in the bed	Set from rock size in the bed
Time interval of calculation (sec)	Do.	Gravity acceleration (m/s^2)	9.8
Number of particle grades	Default 2	Coefficient of erosion rate	Default 0.0007
Diameter of each grade particle (m)	Coarser material, finer material	Coefficient of deposit rate	Default 0.05
Mass density of bed materials (finer material)	Default 2650kg/m^3	Minimum depth at the front of debris flow (m)	Default 0.05
Mass density of fluid phase	Default 1100kg/m^3	Minimum flow depth (m)	Set from the state of the river bed
Concentration of movable bed	Default 0.65	Minimum concentration of material in the bed	Default 0
Internal friction angle	0.7 to 0.8	Manning's roughness coefficient	Set from the state of the river bed
Volumetric ratio of coarser materials in the bed	Set from gravel size in the bed	—	—

4.8.2 Debris flow Interpretation

a. Types and triggers of debris flow

Types of debris flow include (1) flow-in of sediment due to hillside failure and (2) liquefaction of sediment on the stream bed. With the former, hillside failure occurs, and collapsed soil changes into debris flow (some debris flows are caused by landslides). The amount of rainfall and the sediment materials on the stream bed are also related to the occurrence of debris flow. With the latter, the slope of the stream bed, the drainage area, and the state of the stream bed are largely involved. Triggers of debris flows include heavy rain, snow melting, earthquake, and volcano eruption. Debris flows in the Abay area are caused by heavy rain.

b. Mechanism of the occurrence of debris flow

Based on general debris flow disasters, debris flow occurs frequently at sites where the slope of the stream bed is 20° or greater. In contrast, when the slope of the stream bed is 10° or less, sediment carried by debris flow begins to deposit. Debris flow occurs frequently in basins like small valley where a drainage area of 1 km² or less. The sediment yield produced by debris flow is usually 10,000m³ or less.

When debris flow occurs, most of the sediment deposited on the stream bed erodes and flows out with the water supplied after the debris flow. The erosion depth (thickness of sediment on the stream bed) is 1 to 2m, regardless of geology.

In the Abay area, unstable sediment on the stream bed, colluvial soil on the foothill, and colluvial sediment in the landslide area flowed out due to rainfall.

4.8.3 Analysis result

a. Cross sections to be examined

Conditions of the cross sections to be examined in the debris flow simulation (characteristics of the basin, particle diameter, volumetric ratio of particle diameters, and sediment concentration) are listed in Table 4.8.2. Sediment concentration is assumed to be constant.

Table 4.8.2 Cross Section to be Examined in Debris Flow Simulation

Cross section	Characteristics of the basin				Particle diameter (m)		Sediment concentration (Max., Min.)
	Basin area (km^2)	Length of stream (m)	River width (m)	Slope of stream bed (°)	Max. (Volumetric ratio)	Min. (Volumetric ratio)	
S30-2 (ST.30+420)	0.059	600	1.5～6.0	15.3	0.5 (50%)	0.1 (50%)	0.3,0.15
S31-2 (ST.31+580)	0.018	500	2.0～20.0	16.0	0.7 (70%)	0.1 (30%)	0.3,0.15

b. Model variables for debris flow simulation

Table 4.8.3 Parameters Selected for Debris Flow Simulation

Simulator model variable	Adopted value	Simulator model variable	Adopted value
Simulation continuance time	10800sec	Gravity acceleration	9.8
Time interval of calculation	0.01sec	Coefficient of erosion rate	0.0007
Mass density of bed material (finer material)	2650kg/m^3	Coefficient of deposit rate	0.05
Mass density of fluid phase	1100kg/m^3	Minimum depth at the front of debris flow (m)	0.05
Concentration of movable bed	0.65	Minimum concentration of material in the bed	0kg/m^3
Internal friction angle	0.7 (35°)	Manning's roughness coefficient	0.03

c. Results of debris flow simulation

The results of the debris flow simulation are presented in Table 4.8.4. Using this simulation, the flow discharge and/or volume of sediment movement at an arbitrary point can be obtained.

The results indicate the thickness of deposit and volume of sediment that flows into cross-drainage work under the road.

The thickness of deposit is obtained by that the volume of sediment divided by the river width and length for the calculation. Sometimes it actually flows out in flood.

Table 4.8.4 Examination Results in Debris Flow Simulation

Cross section	Parameters of the basin				Cross-drainage work		Calculation result	
	Basin area (km^2)	Length of stream (m)	River width (m)	Slope of stream bed (°)	Width (m)	Height (m)	Volume of sediment (m^3)	Thickness of deposit (m)
S30-2	0.059	600	1.5～6.0	15.3	2.0	1.0	90.6	2.26
S31-2	0.018	500	2.0～20.0	16.0	3.0	1.5	104.5	1.74

Chapter 5

Landslide Countermeasure

5 Landslide Countermeasure

5.1 General countermeasure for landslide

Landslide countermeasure is divided into control works and restraint works. The control work indirectly affects landslide risk by removing factors contributing to the slide; restraint work directly affects the landslide risk by countering against the driving forces.

The types of landslide countermeasure are shown in Figure 5.1.1 and Figure 5.1.2.

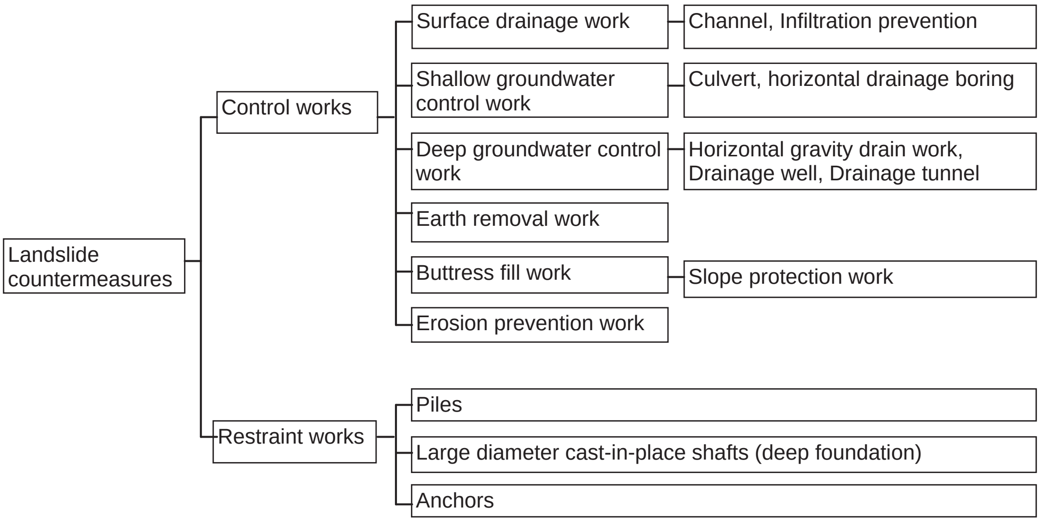


Figure 5.1.1 Landslide countermeasures

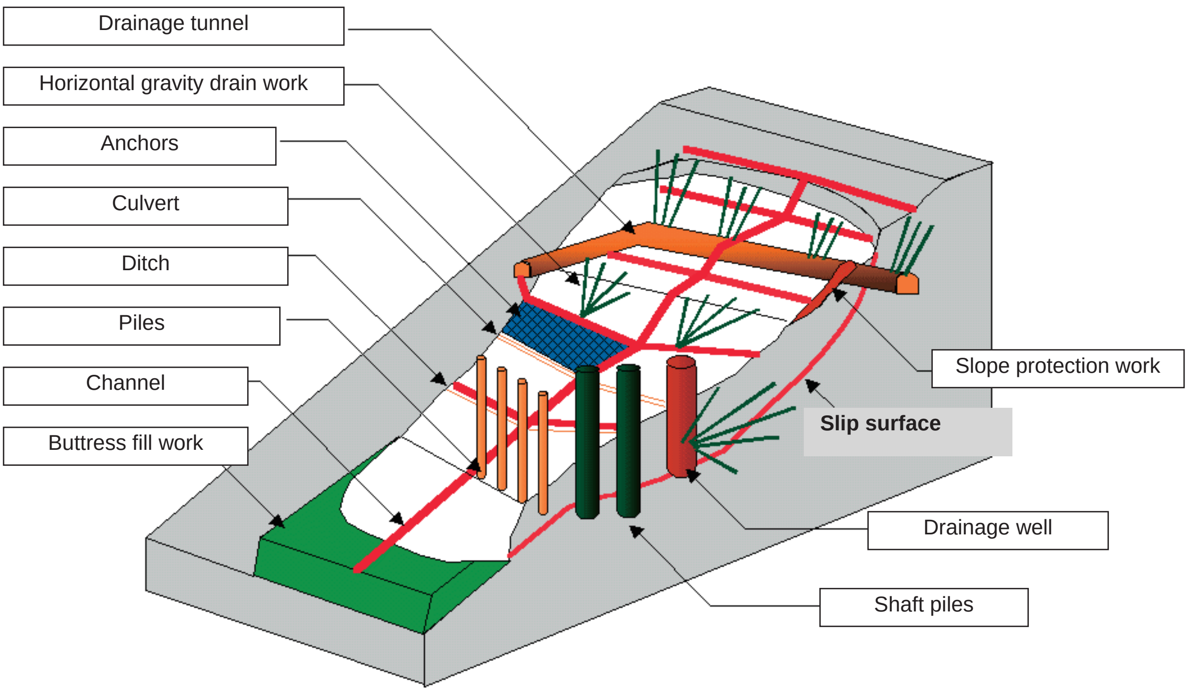


Figure 5.1.2 Schematic figure of landslide countermeasures

5.2 Landslide countermeasures in Abay Gorge

5.2.1 Interpretation of stability analysis

The safety factor selected for the current study is 0.98 since the landslide damaged the road even when the land did not move so much. Although the variation of the groundwater level is currently unclear, landslide displacement increases when groundwater rises in the rainy season. Therefore *c'* (cohesion) is selected to be very close to zero. Table 4.6.1 presents *φ'* (internal friction angle) obtained by inverse analysis. Even though *c'* is assumed to be very close to zero, it is slightly different from zero, and it is considered that *c'* has a certain value due to asymmetric characteristics of the three-dimensional configuration of the landslide.

5.2.2 Expected countermeasures in each landslide block

Table 5.2.1 lists expected landslide countermeasures in the Abay Gorge area. Table 5.2.1 is separated into two stages. The first stage includes relatively cheap landslide control works including horizontal drainage borings and buttress fill work. In the second stage, drainage wells in order to further reduce the ground water level should be installed; otherwise piles should be constructed to ensure a proper safety factor.

Table 5.2.1 Design of countermeasures

area	plan #	Stage 1		Stage 2	
		countermeasures	remarks	countermeasures	remarks
L/S00	(1)	Horizontal drainage borings (embankment and upper part of the road)	Examination of effects horizontal drainage borings by monitoring of movement and water level.	Improvement of safety factor in the landslide by piles or drainage wells (depression zone and toe zone)	a) Examination of construction technology, cost b) Monitoring of movement and water level for drainage wells
	(2)	Buttress fill works (depression zone)	Examination about the influence for lower blocks in advance	Buttress fill works (light embankment + anchors)	a) Examination of construction technology, cost
L/S05	(1)	Horizontal drainage borings+surface drainage works (flat land in upper zone of the slope, block 05-02, 05-03, 05-04)+retaining wooden structures (block 05-02, 05-03)	a) Examination of effects horizontal drainage borings by monitoring of movement and water level. b) Retaining structures in block 05-02, 05-03 for unstable sediment	Piles or drainage wells (depression zone and toe zone)	a) Examination of construction technology, cost b) Monitoring of movement and water level for drainage wells
L/S22	(1)	Surface drainage works		Improvement of safety factor in the landslide by piles	Examination of construction technology, cost
	(2)	Road repair work for shelving	Examination of construction feasibility	Protect of road shoulder by H-shape steel sheet pile	Examination of construction technology, cost
L/S27	(1)	Horizontal drainage borings (upper part and lower part of the road)		Piles (upper block of the road) or drainage wells (depression zone)	Examination of construction technology, cost Consideration of water supply for residents
L/S28	(1)	Horizontal drainage borings (upper part and lower part of the road)+channels	a) Examination of effects horizontal drainage borings by monitoring of movement and water level. b) Bigger channels	Improvement of safety factor in the landslide by piles (depression zone) or drainage wells (middle slope)	a) Examination of construction technology, cost b) Monitoring of movement and water level for drainage wells

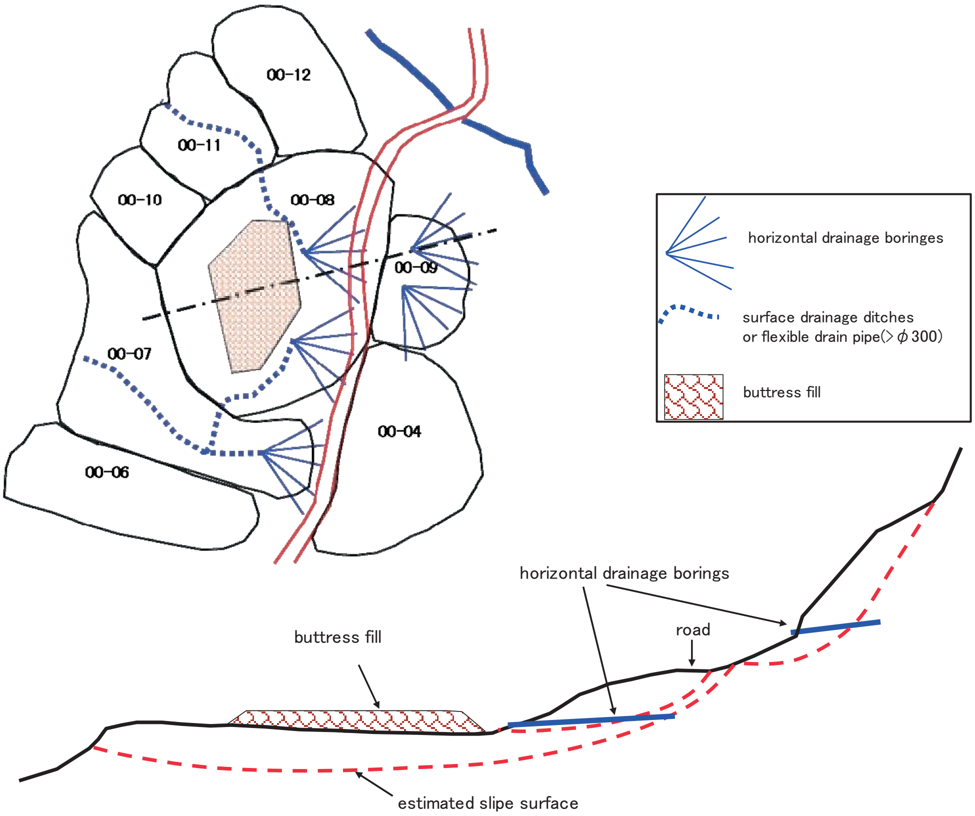


Figure 5.2.1 Schematic figures of expected countermeasure for landslide on L/S00

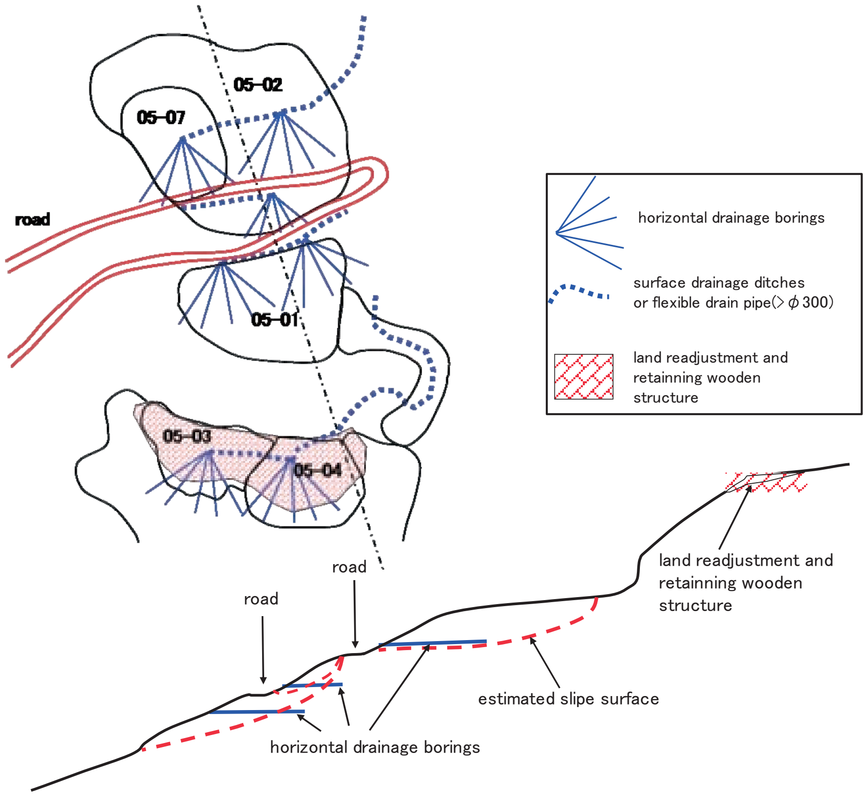


Figure 5.2.2 Schematic figures of expected countermeasure for landslide on L/S05

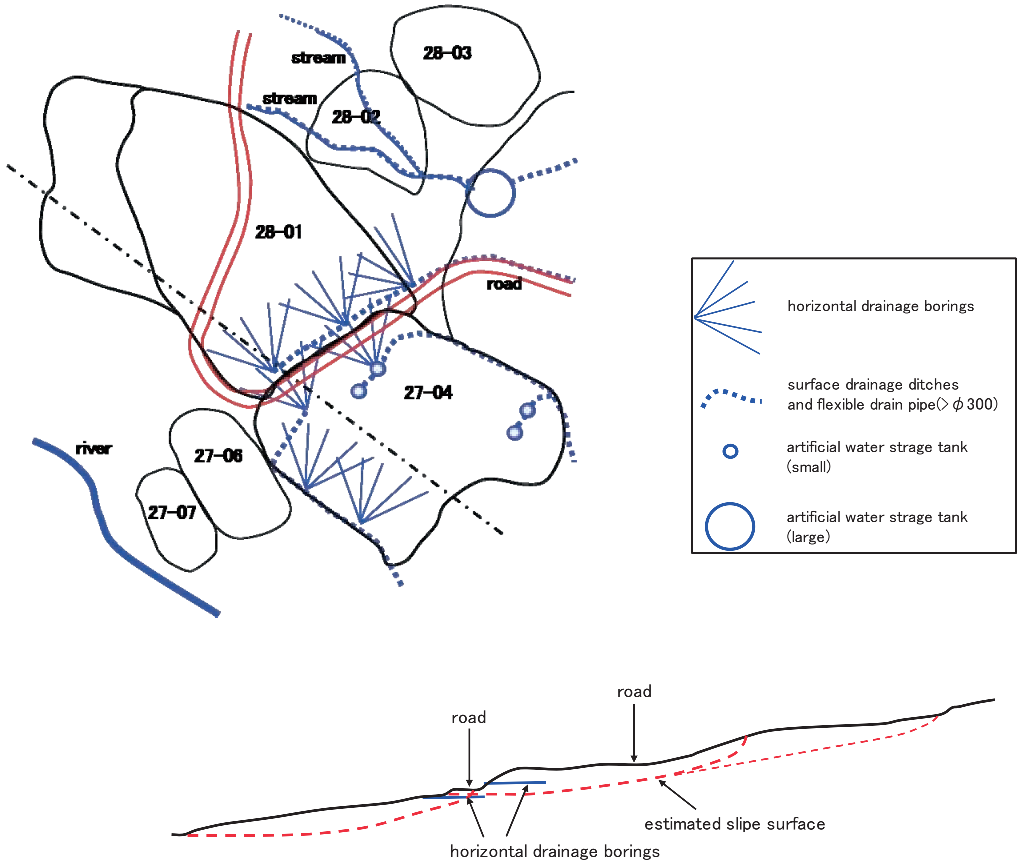


Figure 5.2.3 Schematic figures of expected countermeasure for landslide on L/S27

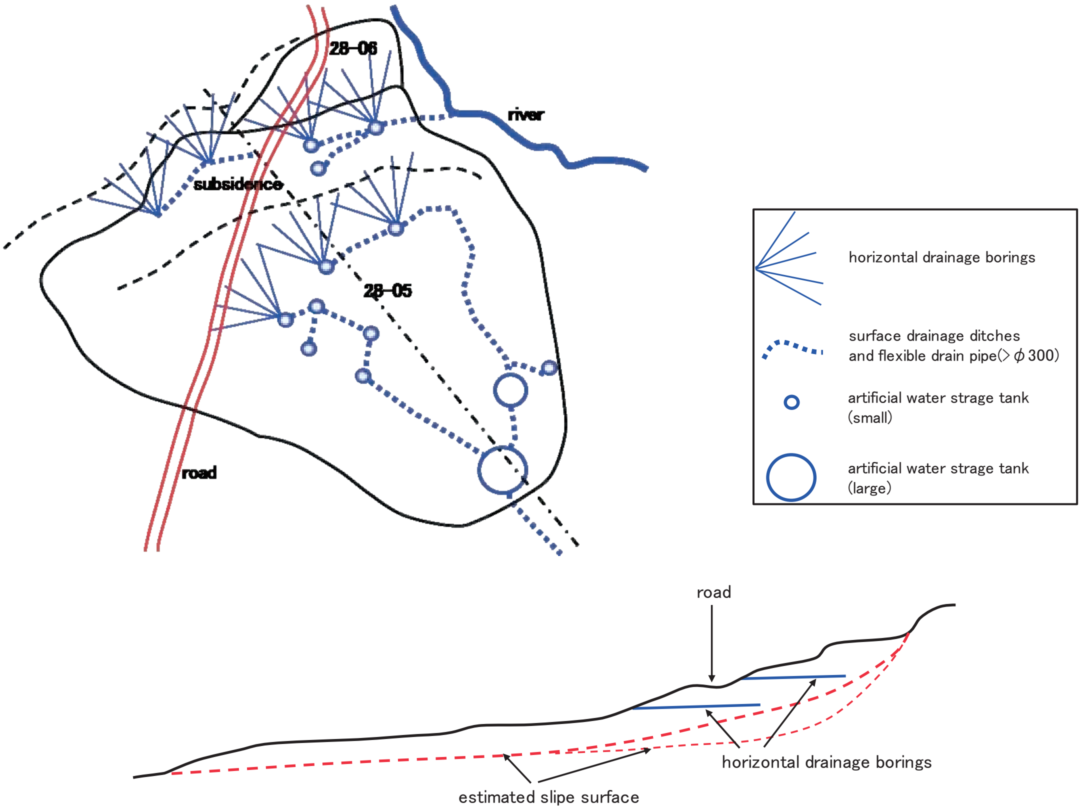


Figure 5.2.4 Schematic figures of expected countermeasure for landslide on L/S28

5.2.3 Remarks in practice

Landslides can be triggered in the rainy season by rising ground water levels. Therefore, it is rational that groundwater control work such as horizontal drainage borings would be constructed to reduce the landslide activity. However horizontal drainage borings might not be effective in some cases. Therefore the effect of the groundwater control work should be examined by monitoring movement and water level. Buttress fill work is also relatively cheap but could trigger another landslide block depending on the construction site. The influence of buttress fill work for other blocks should also be examined in advance.

Many types of erosion of the ground surface and collapses are confirmed due to rain intensity. Surface drainage work on the slope is effective to prevent rainfall water from infiltrating into moving mass of landslide and controlling rising water levels. Additionally, although drainage well effectively reduces the ground water level, residents may consume the ground water for domestic use.

5.2.4 Requirements for setting appropriate countermeasure

a. Investigation and monitoring

A drilling survey of the necessary volume is planed for deciding the configuration of the slip surface after selecting an appropriate site where the landslide block will need landslide countermeasures. Three to four drilling surveys will be necessary in one landslide block. At least one borehole should be deep deeply enough to cross the unstable bedrock.

The drilling survey should be done while recording the water level a day before and after completing drilling. Borehole inclinometer and water level meter should be installed in the boreholes for monitoring purpose. Water level monitoring is especially important for obtaining a reliable *φ’* in stability analysis.

The rain duration is short in the Abay area, so the sampling time should not exceed about 10 minutes. If it is difficult to install a borehole inclinometer due to cost, it is possible to replace it with borehole extensometer.

b. Examination of practical effects of countermeasures

If groundwater control work such as horizontal drainage borings and drainage wells are to be conducted, the effect of the groundwater control work should be examined by monitoring the ground movement and water level. The accuracy of the safety factor could be improved by reviewing soil constants *c’* and *φ’* in the stability analysis. Selecting an appropriate *φ’* makes a big difference for the effectiveness of the groundwater control work.

c. Establishment of objective safety factors

Even in Japan, it is difficult to establish an objective safety factor for landslides. For landslide countermeasures, it has been progressing from just setting existing safety factor and the construction works to comprehensive countermeasures including both landslide preventing works like constructions and management works after occurrence of landslides such as making hazard maps.

Considering Ethiopia's economic situation, this program involves feasibility in construction technology and economic efficiency. In the near future, the landslide administration in Ethiopia should develop a policy for achieving a certain safety factor at any level and start practicing hard countermeasure works. Nevertheless, a certain level of safety factor should be established to prevent landslides for specified levels of rainfall because landslides usually occur in the rainy season every year. The Project is hence important for establishing the guidelines. If a certain level of safety factor has not been set against landslides, precautionary evacuation measures including installation of a slope monitoring system should be in place.

d. Feasibility of construction technology and economic efficiency

It is necessary to investigate the feasibility of construction technology, the construction period, the economic efficiency, and the environment and social consideration in Ethiopia. Generally speaking, are more preferable rather than low feasibility countermeasures.

Those countermeasures which are relatively cheap and cost effective are proposed in the first stage of Table 5.2.1. However, it is necessary to re-examine the effectiveness and determine the safety factor that should be establish at certain level. In case a safety factor is proposed at the 1.05 to 1.10 level, countermeasure plans in the second stage in Table 5.2.1 are required. Because the safety factor changes with the landslide size and elements at risk, the study team must pay attention to these points as well.

5.3 Early warning and evacuation

5.3.1 General relationship between rainfall, groundwater level and landslide deformation

Figure 5.3.1 shows the relationship between rainfall, groundwater level and landslide deformation. Rainfall can result in the rising of groundwater level. At that time, the pore water pressure acting on the slip surface will increase, and a landslide deformation will be initiated.

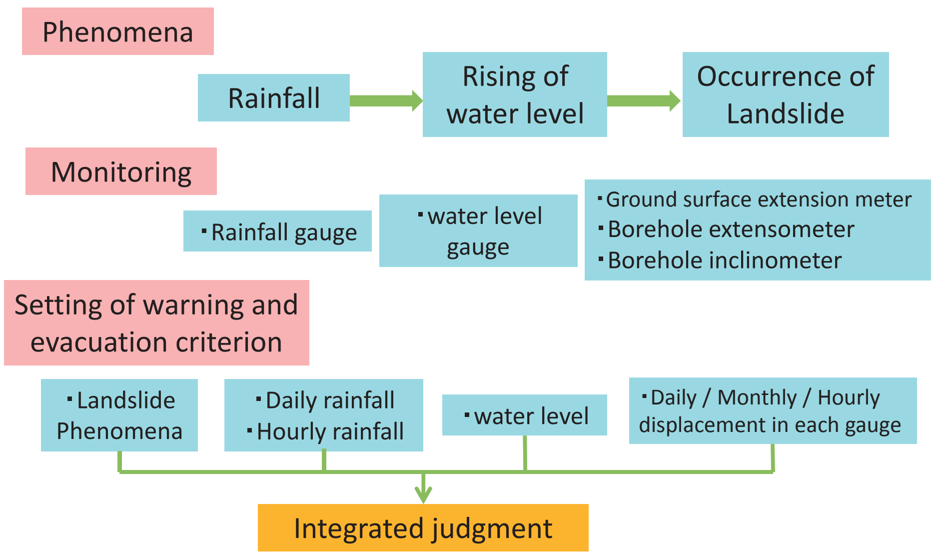


Figure 5.3.1 The relationship between rainfall, groundwater level and landslide deformation

5.3.2 Response of landslide deformation to groundwater level variation

Figure 5.3.2 shows the response of landslide deformation to the pore water pressure in different types of landslide.

The figure shows that type-a landslide is a year-round active rockslide. In this type, the landslide deformation sensitively responds to the variation of pore water pressure, regardless of the inducing factor, snowmelt or intense rainfall.

Type-b landslide shows a hysteresis between increasing and decreasing periods of pore water pressure. Type-b is often found in cases in which rate of increase in deformation velocity exceeds rate of increase in pore water pressure when pore water pressure increases, and rate of decrease in pore water pressure is almost the same as rate of decrease in deformation velocity when the pressure decreases. Landslides in this type are such kind of rockslide that their deformation becomes active in the intense rainfall period and snowmelt period, and attenuates to silent in dry period.

While type-c landslide shows a quite different behavior. The deformation velocity in the period of pore water pressure descending is higher than that in the period of pore water pressure rising. Such case is often found when the peak of deformation velocity comes later than the peak of pore water pressure. Actually, the difference of pore water pressure between the deformation initiating period and deformation stopping period generally occurs in colluvial deposit landslides which consist of muddy schist but the strata formed in Neogene period.

In type-b and type-c, the hysteresis exists between the two periods of pore water pressure rising and descending. In Abay River Gorge area, there are many landslides belonging to the type-b and type-c.

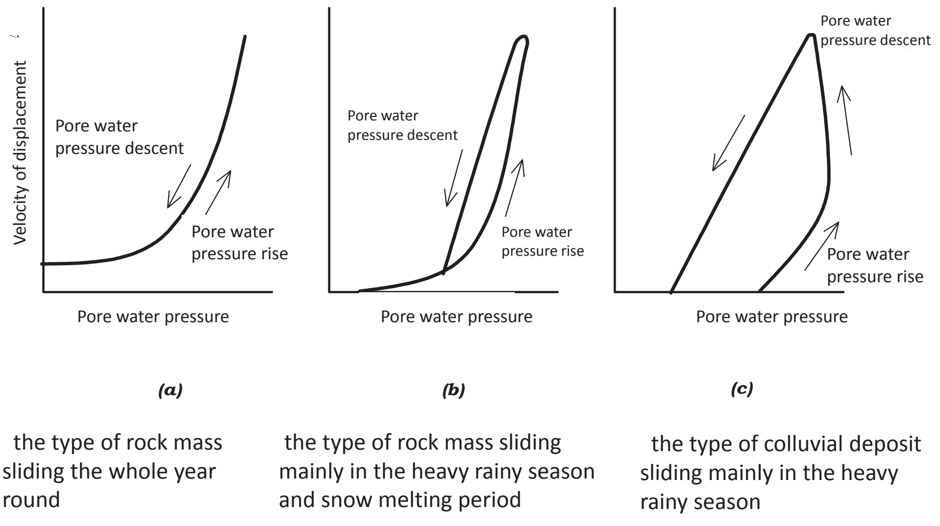


Figure 5.3.2 Time series change of pore water pressure and landslide deformation velocity

5.3.3 Case study of hydrological analysis in Abay River Gorge landslide areas

a. Analysis targets

The targets for hydrological analysis are L/S27 and L/S28 areas. In the analysis, the monitoring data of extensometer EX-5 are used for landslide deformation analysis, and monitoring data in B28-23 are used for groundwater level variation analysis.

b. Deformation situation of the landslide

Case 1 and case 2 show rapid increase in the extensometer whereas case 3 shows rapid increase in the groundwater level. Hydrological analyses are conducted for the three cases.

c. Rainfall data

The rainfall data used for the analysis are obtained from the nearby meteorological observation stations.

Daily rainfall for a location without meteorological observation station is calculated by weighted average method shown in Equation (1), in which using inverse distance as the weight. For the location near Gabrielle Church, three meteorological observation stations are employed, i.e., Gohatsiyon observation point or Filiklik observation point, Abay Gorge observation point, and Dejen observation point.

$$R_c = (R_1/d_1+R_2/d_2+R_3/d_3)/(1/d_1+1/d_2+1/d_3) \cdots\cdots\cdots\cdots \text{Eq.(1)}$$

R_c : daily rainfall expected in nearby location;
R_i : daily rainfall monitored at a meteorological observation station.

The distances from different meteorological observation stations to the Gabrielle Church are as follows.

Gohatsiyon (d_1 = 14.9km), Filiklik (d_1 = 13.4km), Abay Gorge (d_2 = 5.2km), Dejen (d_3 = 6.6km)

Then using Equation (2), the practical effective rainfall affecting the landslide deformation can be obtained. The practical effective rainfall is an accumulation of the rainfall from several days before the current day considering the attenuation effect of the rainfall. The attenuation effect is represented by the attenuation factor α.

$R_{ce} = R_{c0} + \Sigma \alpha_i R_{ci}$ • Eq.(2)

R_{ce} : Practical effective rainfall;
R_{c0} : Rainfall at the current day;
α_i : Attenuation factor at previous *i* days
R_{ci} : Rainfall at previous *i* day.

Generally, the attenuation factor α should be obtained through trial and error. Here for simplicity, it can be set as, α_1 = 0.5, α_2 = 0.25, α_3 = 0.0625.

d. Summary

The following are the summaries for the relationship between rainfall, groundwater level and landslide deformation.

- A continuous rainfall for at least four days is necessary to cause the groundwater level rising and landslide deformation. The critical practical effective rainfall is 24 mm for this landslide.

- The time lag for water level rising after the practical effective rainfall is one day, and the time lag between water level rising and landslide deformation is two days. A schematic model is shown in Figure 5.3.3.

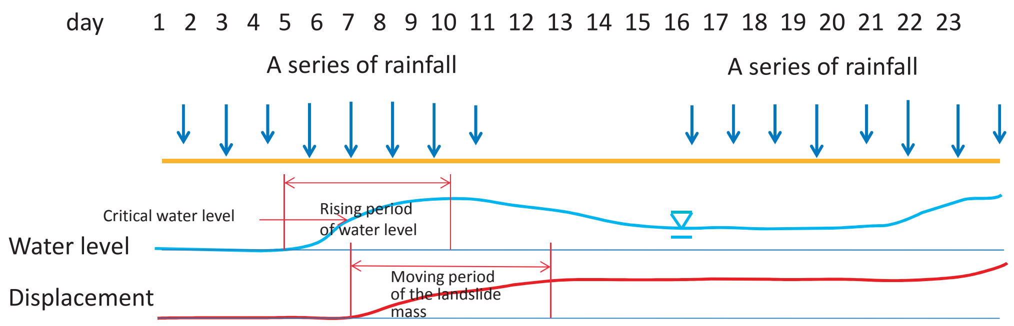


Figure 5.3.3 Schematic model between rainfall, groundwater level and landslide deformation

5.3.4 An example to set the criterion for early warning and evacuation

Table 5.3.1 An example to set criterion for landslide warning, alerting and evacuation

	Rainfall	Pore water level	Extensometer	Bohehole extensometer	Bohehole inclinometer	Behavior for early warning and evacuation
Level I (precaution)	>20mm/day	–	3mm/day-1mm/day	1mm/day -0.3mm/day	0.5mm/day-0.1mm/day	Patrol
Level II (warning)	>50mm/day	critical water level	10mm/day-3mm/day	3mm/day-1mm/day	1mm/day-0.5mm/day	Patrol
Level III (evacuation)	>100mm/day and/or >50mm/hour	–	> 5mm/h	>2mm/h	>0.5mm/h	・Patrol ・Distributing information to resident ・Preparation for evacuation ・Evacuation instructions
notes		Pore water level is difficult to use for evacuation standard because it fluctuates a lot.	The evacuation standard should be established in combination with surface extensometer, bohehole extensometer and borehole inclinometer.			[Points to check] ・Generation of cracks and bumps ・Collapse of the toe of the landslide ・Damage of structure ・Murky situation of surface water and river ・Generation and dryness of spring water

5.4 Rockfall/Debris Flow Countermeasures

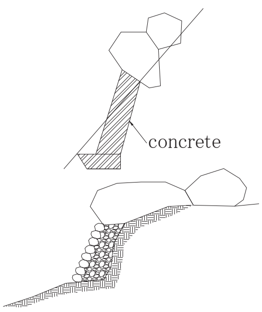
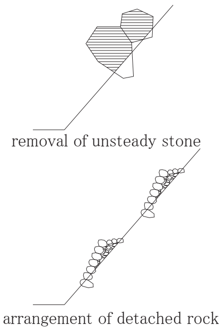
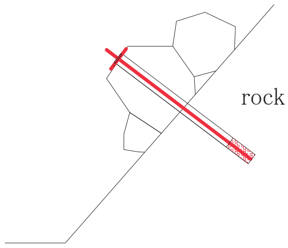
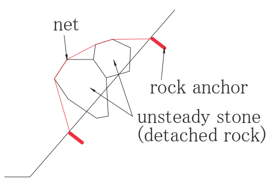
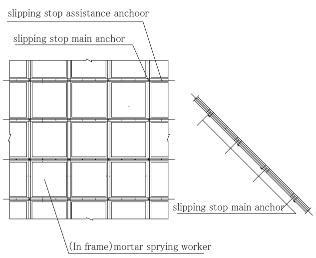
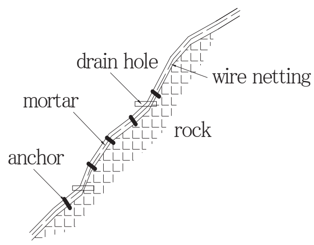
5.4.1 General Countermeasures

a. Common measures against rockfall

The two types of countermeasures against rockfall are “rockfall prevention work”, which keeps rockfall from occurring (countermeasure at the source), and “rockfall protection work”, which defends the downward object to be protected before fallen rocks reach it when rockfall does occur (preservation countermeasure).

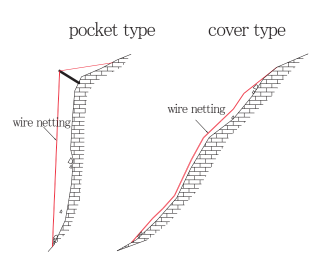
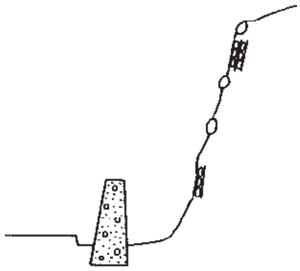
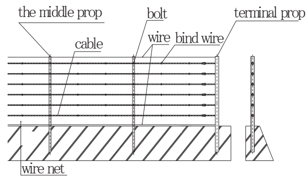
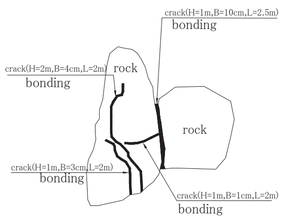
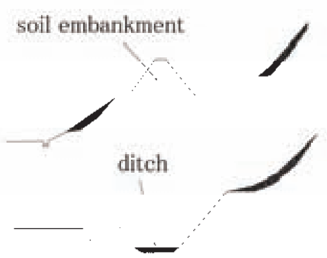
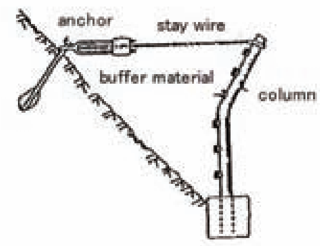
Rockfall prevention work includes root protection work, unsteady rock removal, rock-bolt work, wire-rope sling work, and grating crib work. Rockfall protection work includes rockfall protection nets, rockfall protection wall, rockfall protection fence, soil embankments, and high-energy absorbing fences.

Table 5.4.1 Examples of Rockfall Prevention works

Method	Concrete root protection work	Removal of unsteady rocks/ detached rocks	Rock-bolt work
Conceptual scheme			
Feature	Use concrete to protect the base and surrounding area from unsteady rocks and/or detached rocks to stabilize them so that they do not move.	Manually gather and pile rolling rocks in safe places on the slope	Bore a hole through a large unsteady rock or detached rock, and stabilize it by inserting a bolt into the base rock
Method	Wire-rope sling work	Grating crib work	Concrete spraying
Conceptual scheme			

Feature	Weave wire ropes to form grids and fasten them with cross clips over unsteady and detached rocks so that they do not move.	Cut unstable soil and soft portions of bedrock exposed to the cliff surface, and then stabilize the slope with grating cribs	Spray concrete or mortar on the slope to prevent weathering and slipping.

Table 5.4.2 Examples of Rockfall Protection Works

Method	Rockfall protection net	Rockfall protection wall	Rockfall protection fence
Conceptual scheme			
Feature	Cover the slope that has a risk of rockfall with wire netting and wire ropes.	Disperse or decrease the energy of rockfall by building a wall of concrete or cushion material to catch fallen rocks from the slope.	Prevent rockfall by installing a fence in the lower or middle portion of the slope where rockfall is likely to occur.
Method	Bedrock bonding	Soil embankment	High-energy absorbing fence
Conceptual scheme			
Feature	Bond desquamative bedrock and/or open joints of rock lumps at the rockfall source by glue.	Construct a soil embankment and ditch in a relatively flat landform and has an allowance to absorb and disperse the energy of fallen rocks	Install a fence with excellent energy-absorbing capacity, composed of nets and stays.

b. Common countermeasures against debris flow

Suitable countermeasures against debris flow should be selected with a full understanding of the type of debris flow (stony or mud flow), amount of falling debris flow, and characteristics of the catchment basin.

The two types of countermeasures against debris flow are hardware countermeasures, which use structures such as sabo dams, training dikes and channel work, and software countermeasures, which do not use structures such as proper land use, evacuation, and reinforcement of buildings.

Examples of hardware countermeasures are listed in Table 5.4.3.

Table 5.4.3 Types of Debris Flow Countermeasure Facilities

Type of countermeasure facility	Example of work	Main effects
Debris flow capturing work	Dams ・Non-permeable ・Permeable	Reducing the amount of debris that flows down as debris flow
Debris flow training dike	Channel work	Preventing debris flow from reaching the area to be preserved
Debris flow deposition structure	Depositing ・Sediment-retarding basins ・Desilting basin	Reducing the amount of debris that flows down as debris flow
Buffer forest zone against debris flow		
Debris flow direction controlling works	Guide bank	Preventing debris flow from reaching the area to be preserved
Works for controlling occurrence of debris	Low dams ・Non-permeable ・Bed protection works ・Channel work ・Hillside protection work	Preventing debris flow (including expansion of erosion)

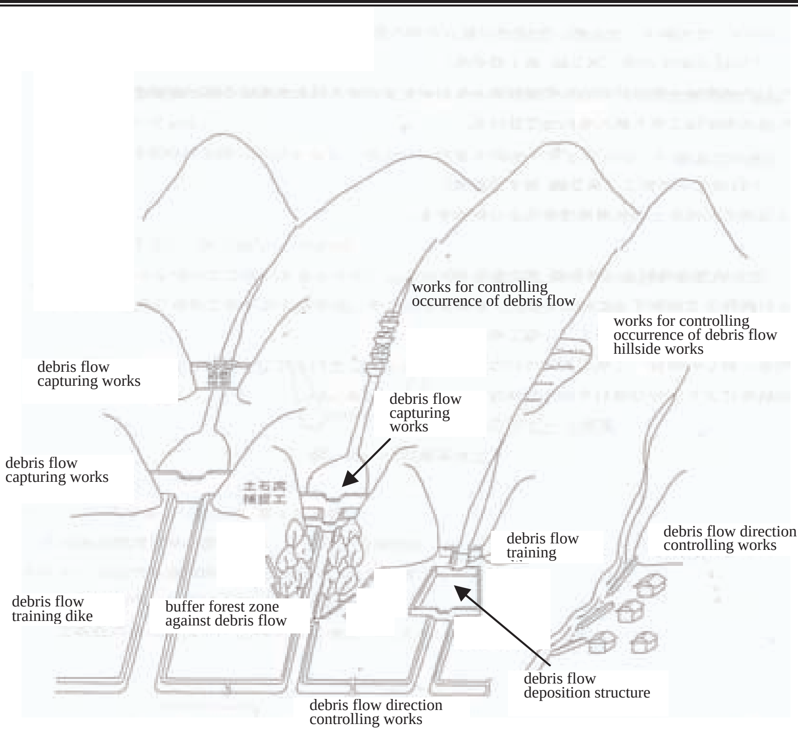


Figure 5.4.1 Representative Debris Flow Countermeasure Facilities

5.4.2 Application of countermeasure on rockfall/debris flow

a. Applicability of countermeasures against rockfall

Both fall-off-type rockfall and exfoliating-type rockfall can be observed in the Abay area. The sources include rockfalls from the natural slopes, rockfall from the cut slopes, and combinations of these.

The energy of a rockfall from the natural slope is usually great because the slope is high and there are rocks with diameters exceeding 1m. In such cases, high-energy-absorbing rockfall countermeasures are suitable. When there are few fallen rocks or the source of rockfall can be identified, however, such rockfall prevention countermeasures as root protection works and removal of unsteady and detached rocks are also appropriate.

For rockfalls from the cut slope, cracks develop or weathering advances over the slope; thus, rockfall from the whole surface of the slope can be observed. Most fallen rocks have 0.3m diameter or less with less rockfall energy. Therefore, various countermeasures may be appropriate. Many cut slopes are near roads, so construction of a grating crib work or a rockfall protection net may be considered.

Selection of the most suitable rockfall countermeasure or combination of countermeasures for the state of the road and the state of the slope at the site should involve consideration of functions, durability, workability, economic efficiency, and potential maintenance and management problems for countermeasures. Selection of the most suitable rockfall protection work should involve consideration of rockfall energy.

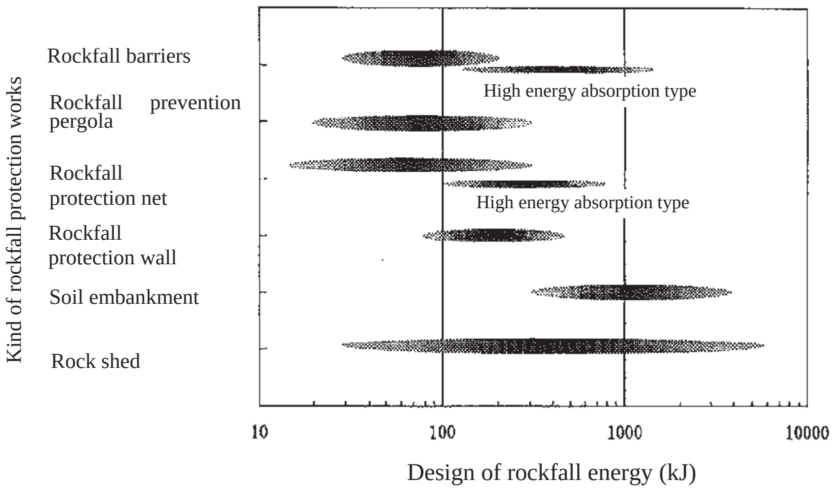


Figure 5.4.2 Guideline for Applicable Range of Rockfall Countermeasures

b. Applicability of countermeasures against debris flow

Many of the streams in the Abay area are short length, and steep slopes. The type of debris flow is stony debris flow, and the amount of sediment to flow out is estimated to be $100m^3$ or less in most cases.

The danger of flow-out of a large volume of sediment is low, in light of the amount of continual rainfall, current deposit on the stream bed, and the state of hillside collapse upstream; therefore, debris flow capturing works (e.g., sabo dams) are suitable. However, construction of large dams is difficult on narrow streams that have shallow river beds. The installation of low dams as bed protection works to suppress the occurrence of debris flow is appropriate.

For streams in Filiklik Village, where debris flow disasters have occurred in the past, unstable sediment deposits are relatively thicker; thus, it is necessary to consider combination of direction controlling works, and occurrence controlling works to prevent debris flow.

In this area, there are many streams where drainage processing is insufficient or cross-drainage facilities are blocked with pebbles. For these streams, it is desirable to extend channel work or remove deposited sediment.

Many sabo dams are filled with sediment and their sleeves are damaged, so they are not fully functional. Moreover, some of the dams are of insufficient height or have insufficient strength. For a high risk debris flow channel where discharge of sediment is repeated, it is necessary to predict the discharge volume of sediment and to install sabo dams of appropriate sizes. Existing dams with decreased functions require repair and/or reinforcement.

It is difficult to install sabo dams on small streams. For the small streams, debris flow training dike or debris flow deposition structure is appropriate if procuring of the land is possible.

5.4.3 Requirement for setting appropriate countermeasure

a. Requirement for setting countermeasure against rockfall

To implement appropriate rockfall countermeasures, it is important to determine and record the locations, the diameters of fallen rocks, and the conditions at the time of rockfall disasters (season and amount of rainfall). When the rockfall source and the rockfall path can be identified, it is possible to select the type of works that is suitable for the size of rockfall and to plan effective countermeasures.

Rockfall countermeasures use many concrete structures and flexible structures, and soil embankment work involves civil engineering. However, the removal of unsteady rock/detached rocks is performed manually. These rockfall countermeasures do not require any special construction machinery.

Some rockfall prevention works (e.g., grating crib work and concrete spraying) and rockfall protection works (rockfall protection walls and fences) use concrete and reinforcing steel bars as the main materials. Construction of these structures requires measuring equipment, kneading machines, spray machines, and their accessory devices. While some materials (e.g., cement and reinforcing steel bars) can be procured at the site, it is important to secure stable, high-quality supplies.

For structures that are made up mostly of reinforcing bars and metallic products (e.g., flexible structures), procurement of materials that have the prescribed strength and processing techniques are required.

When implementing each countermeasure, it is important to prepare manuals to ensure that construction technique, quality control, work progress control, and construction management standards suitable for each type of works are properly implemented.

b. Requirement for setting countermeasure against debris flow

To implement appropriate countermeasures against debris flows, it is important to understand and record the state of debris flows in the past, volume of sediment deposited in streams, the state of hillside collapses, and the season and the amount of rainfall during debris flow.

In planning the size of a sabo dam, the amount of rainfall for 100 years probability or the largest amount of rainfall in the past (whichever is greater) should be adopted. Therefore, it is important to analyze the records of rainfall amounts at each observation station. Observation data must include the amount of rainfall per hour.

The structure and size (e.g., height, thickness at the top end, and gradient of slope) of the sabo dam to be constructed should be determined by performing stability calculations considering the effect of the countermeasures, workability, and economic efficiency. Existing dams are thin at the top (50cm or less) with insufficient foundation of sleeves, and they are weak. Designing stable sabo dams requires design standards that are suitable for the district.

Construction of sabo dams requires a large volume of specialized heavy machines (e.g., truck cranes, concrete mixer cars, mobile concrete pumps, backhoes, and rough terrain transportation vehicles). It is important to procure construction machines and a supply of stable, high-quality materials.

Furthermore, it is necessary to prepare manuals to ensure that construction methods, quality control, work progress control, and construction management standards for properly implementation.

Chapter 6

Technical Transfer

6 Technical Transfer

6.1 Methodology

6.1.1 Improvement of the capacity of C/P regarding landslides

a. Confirm GSE's capacity

b. Propose gradual technical transfer

Table 6.1.1 Method of capacity development in each stage of development

Development stage	Phase	Method of capacity development
- Field reconnaissance and various monitoring skills	Phase 1	The Study Team will transfer basic skills such as how to select equipment necessary for landslide surveys/analysis and sites to install it, and monitoring methods. Also, transfer perspectives on prioritizing areas of risk using aerial photographs and field surveys. Further, transfer methods of surveying and analyzing slope disasters besides landslides.
- Various data analysis skills	Phase 2	The Study Team will transfer skills to figure out contributing factors and mechanisms that trigger landslides based on the data gained in phase 1.
- Application of analysis skills	Phase 3	Transfer practical analysis skills after gaining monitoring data from the target area; while making the most of the knowledge gained in phase 2. Also, give instruction to ERA—the organization in charge of countermeasures—on methods of technical response.

c. Confirm Project Design Matrix (PDM) content

6.1.2 Effective technical transfer on landslide

a. Share landslide classification methods and selection of landslide sites suitable for monitoring

b. Introduce methods of evaluating risk

6.1.3 Support investigation into effective landslide countermeasures

a. Consideration of measures appropriate to socioeconomic conditions in Ethiopia

b. Joint Coordination Committee (JCC)

c. Regular Meetings

d. C/P Training in Japan

e. Promote understanding among road users and local residents

6.2 Structure of technical transfer

For the effective and smooth technical transfer, the initial idea was to form groups based on the respective expertise of both the Study Team and C/P. The groups are basically comprised as follows in Table 6.2.1. However, the concept of the technical transfer was to transfer a basic understanding and know-how of landslide surveys and analysis to all the members of the C/P.

Table 6.2.1 The Study Team Members by Group of Expertise

	Group/Expertise	JICA Expert	Counterpart	Remarks
1	Team Leader	Kensuke ICHIKAWA	Getnet MEWA	
2	Geomorphological Analysis	Satoru TSUKAMOTO Mitsuya ENOKIDA	Leta ALEMAYEHU Melukamu TEGEGNE	
3	Hydrological Analysis	Shigekazu FUJISAWA	Demis ALAMIREW	
4	Geological Analysis Landslide Monitoring	Takeshi KUWANO Makito NODA Shoji TSUCHIYAMA	Solomon GERA Zulfa ABDURHAMAN	
5	Landslide/Rockfall/ Debris Flow Analysis	Masao YAMADA Shigekazu FUJISAWA Yoichi KASAHARA	Zulfa ABDURHAMAN Yewubnesh BEKELE	
6	GIS Database	Yoshimizu GONAI	Yewubnesh BEKELE	
7	Geophysical Survey, Analysis	Naohiro ISOGAI	Tadesse LEMA Sisay ALEMAYEHU	
8	Drilling Survey	Takashi SUZUKI	Bayu WEDAJ	
9	Topographic Survey	Shozo SHIMODA	Haile G/SELASSIE	

The schematic image of the technical transfer is shown in the Figure 6.2.1. The transfer was made from group of Experts to the C/P group so that the transfer will benefit most of the C/P regardless of the C/P's expertise.

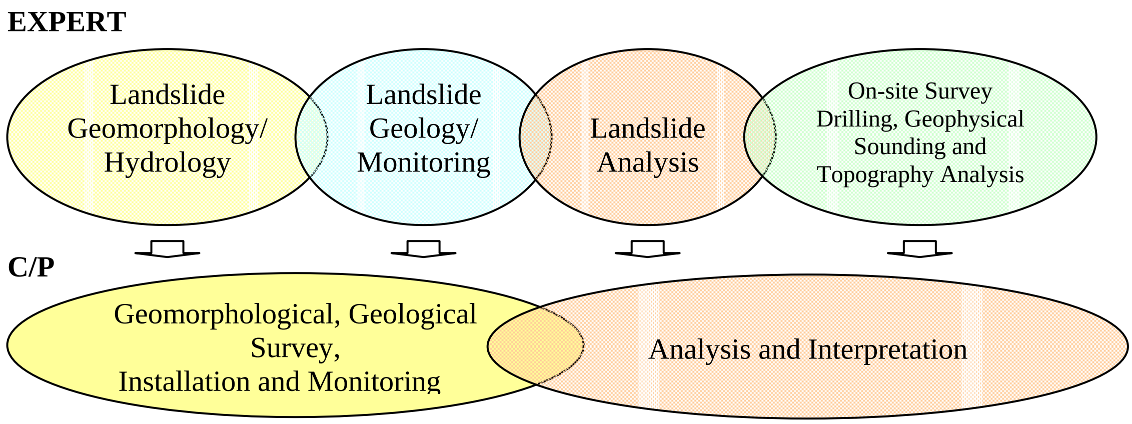


Figure 6.2.1 Structure of Technical Transfer

6.3 Main contents of technical transfer

6.3.1 Technical Transfer Seminar

a. 1st technical transfer seminar

b. 2nd technical transfer seminar

c. Final technical transfer seminar

6.3.2 Work shop

Several work shops for certain themes have been conducted by the Study Team to accelerate C/P's understanding for landslide survey, analysis and evaluation in the Project as follows.

Table 6.3.1 Summary of landslide work shop

Contents	Date/Time	Place	C/P	JICA expert
GIS fundamental	10 Jun. 2010, 11:00-12:00	GSE	Yewubnesh Bekele, Tesfaye Shewa	Y. Gonai
Monitoring data organization (1)	13, 14 Oct. 2010, 10:00-12:00	GSE	Getnet Mewa, Solomon Gerra, Demis Alamrem, Leta Alemayehu, Tekalegne Tesfaye, Melkamu Tegegne, Beruku Abel , Habtamu Eshetu, Yewubnesh Eshetu Bekele	S.Tsuchiyama, Y. Yamamoto
Landslide, debris flow and rock fall survey/analysis (1)	25 Feb. 2011, 9:00-17:00	GSE	Getnet Mewa, Leta Alemayehu, Hailesalassie G/lselassie, Tekalegne Tesfaye, Sisay Alemayehu, Debebe Kifle, Melkamu Tegegne, Brook Abel, Habtamu Eshetu	S. Fujisawa, M. Yamada, M. Enokida, Y. Kasahara, Y. Gonai
GIS utilization in landslide project	18 Mar. 2011, 9:00-17:00	GSE	Getnet Mewa, Habtamu Eshetu, Ezera Tadesse, Debebe Kifle ,Yewubinesh Bekele, Brook Abel, Sisay Alemayehu, Haileslassie G/selassie, Melakamu Tegegne, Tadesse Lemma, Tekaligne Tesfaye	Y.Gonai
Landslide, debris flow and rock fall survey/analysis (2)	7 Oct. 2011, 10:00-12:00	GSE	Tekaligne Tesfaye, Beruku Abel, Yewubnesh Bekele, Debebe Kifle, Zulfa Abdurahman	Y. Kasahara, M. Noda, Y. Gonai
Monitoring analysis	11 Oct. 2011, 14:00-17:00	GSE	Demis Alamrem, Samiel Molla, Tekalegne Tesfaye, Habtam Eshete, Beruku Abel, Yewubnesh Bekele, Zulfa Abdurahman	S.Tsuchiyama, M. Enokida, Y. Gonai
Early-warning system	13 Oct. 2011, 14:00-17:00	GSE	Demis Alamrem, Samiel Molla, Tekalegne Tesfaye, Habtam Eshete	S. Tsuchiyama, Y. Gonai
Monitoring data organization (2)	14,16 Oct. 2011, 10:00-12:00	GSE	Demis Alamrem, Habtam Eshete, Samiel Molla, Beruku Abel, Tekalegne Tesfaye, Zulfa Abdurahman	S. Tsuchiyama
GIS, hydrological observation, soil parameter of stability analysis	25 Oct. 2011, 14:30-17:00	GSE	Tekaligne Tesfaye, Samuel Molla, Yewubnesh Bekele, Demis Alamirew, Habtamu Eshete, Biruk Abel, Debebe Kifle, Zulfa Abdurahman, Tewodros Alene(ERA)	S. Fujisawa, Y. Gonai, M. Enokida
Exercise of stability analysis	1 Nov. 2011, 14:30-15:00	GSE	Tekaligne Tesfaye, Samuel Molla, Yewubnesh Bekele, Demis Alamirew, Habtamu Eshete	M. Enokida
Integrated analysis	7 Nov. 2011, 4:00-16:00	GSE	Demis Alamirew, Samuel Molla, Tekalegne Tesfaye, Habtam Eshete, Sisay Alemayehu, Erza Tadesse, Yewubnesh Bekele, Debebu Tekle	M. Yamada, S. Tsukamoto, K. Ichikawa

6.3.3 On site training

Table 6.3.2 Summary of on-site-type technical trainings

Contents	Date	Place	C/P	JICA expert
Rockfall survey training Debris flow survey training	22,23 Jun., 2010	ST.30 -33	Leta Alemayehu, Tekaligne Tesfaye, Yewubnesh Bekele,	M. Enokida M. Noda Y. Kasahara
Monitoring data collection	7,8 Oct. 2010	Whole Abay Gorge	Solomon Gerra, Demis Alamrem, Leta Alemayehu, Tekalegne Tesfaye , Melkamu Tegegne, Beruku Abel, other ERA Member 5 persons	S. Tsuchiyama, M. Noda, Y. Yamamoto
Exchange knowledge and question/answer regarding to the drilling	9 Jun., 2011	L27	Leta Alemayehu, Bayu Wedajo, other drilling team members	T. Suzuki Y. Kasahara
Measurement method of monitoring devices using personal computer Estimation of monitoring data	14 Jun., 2011	L28	Ezra Tadesse, Habtam Eshete	M. Noda Y. Kasahara
Exchange knowledge and question/answer regarding to the monitoring	15 Jun., 2011	Kajima camp	Ezra Tadesse, Habtam Eshete	M. Noda Y. Kasahara
Installation method of water level meter	15 Jun., 2011	L27	Ezra Tadesse, Habtam Eshete	M. Noda Y. Kasahara
Landslide risk evaluation using sheet Check the deformation points, and mapping of the locations and conditions Monitoring method with devices	24 Jan., 2011	L/S 22	Tekaligne Tesfaye, Yewubnesh Bekele, Ezra Tadesse, Debebe Tekle	S. Tukamoto, M. Yamada, Y. Kasahara
Measurement method of cracks using pole and inclinometer Estimation of the landslide's movement direction and shape by crack direction	25 Jan., 2011	L/S00	Tekaligne Tesfaye, Yewubnesh Bekele, Ezra Tadesse, Debebe Tekle	S. Tukamoto, M. Yamada, Y. Kasahara
Cross-check of the movement and topographical map Mapping of the location of cracks	27 Jan., 2011	L/S 27,28	Tekaligne Tesfaye, Yewubnesh Bekele, Ezra Tadesse, Debebe Tekle	S. Tukamoto, M. Yamada, Y. Kasahara
Exchange knowledge and question/answer regarding to the landslide	28 Jan., 2011	Kajima camp	Tekaligne Tesfaye, Yewubnesh Bekele, Ezra Tadesse, Debebe Tekle	S. Tukamoto, M. Yamada, Y. Kasahara
Monitoring devices Data collection of the rain gauge and borehole extensometer	18 Feb., 2011	L/S 00	Getnet Mewa, Leta Alemayehu	S. Fujisawa, Y. Kasahara
Measurement method of monitoring devices preparation by personal computer Estimation of core logging	7 Jul, 2011	Kajima camp	Biruk Abel, Ezra Tadesse, Habtam Eshete	M. Noda
Field survey and integrated analysis	28,29,30 October 2011	Whole Abay Gorge	Samuel Molla, Demis Alamrew, Tekalegne Tesfaye, Habtamu Eshete	M. Yamada, S. Tsukamoto

6.3.4 Training in Japan

a. Summary of Training Course

Title of the course: Training on Landslide investigation and monitoring
Training period: 18/June/2011 – 8/July/2011
Trainee: 4

b. Outline of the Training

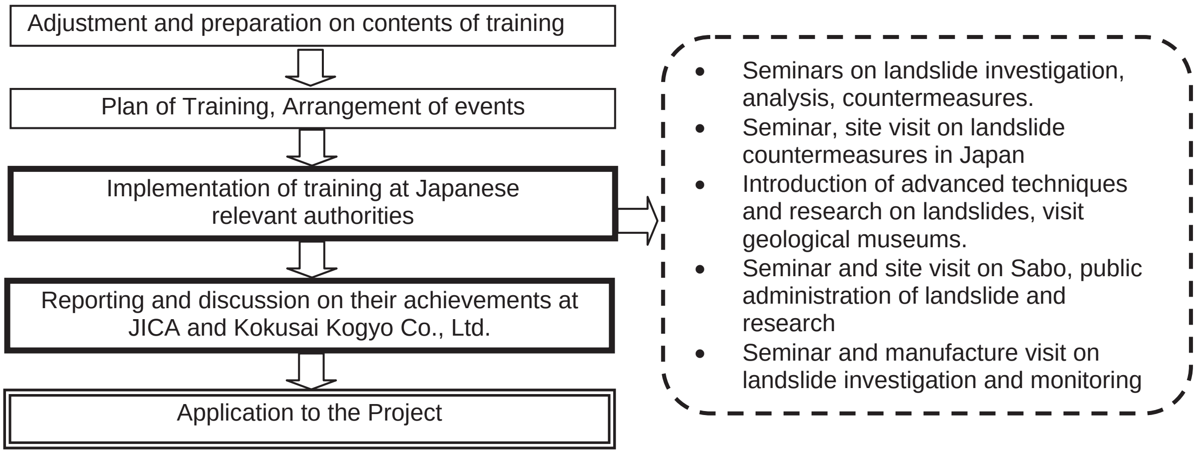


Figure 6.3.1 Outline of the training in Japan

c. Contents and Purpose of Training

Table 6.3.3 Contents and purpose of training

No.	Major Title	Training Method	Purpose	Hrs	Major organizations as
1	• Seminar on landslide investigation, analysis and countermeasure • Geohazards in Japan	Seminar	Considering application to the Project through the seminar on geohazards	6	• Japan Conservation Engineers Co. Ltd • Kokusai Kogyo Co. Ltd.
2	• Seminar on landslide countermeasure • Site visit on landslide countermeasure	Seminar Site visit	Understand the basics, theory and actual implementation as LGU and national project in Japan. Consideration of its application in Ethiopia	26	• Tonegawa River/Sobo Office, MILT • Takasaki River/Road Office, MILT • Raito Kogyo Co. Ltd. • Fuji Sabo Office, MILT • Asago Agriculture & Forestry Promotion Office, Hyogo Prefecture
3	• Introduction of advanced research on landslide • Visit Geological Museum	Seminar Site visit	Understand the case study and analysis method of landslide in Japan and world. Gain knowledge and consideration of utilization of analysis equipment and soil testing machinery on landslide.	6	• Research Center on Landslides, Disaster Prevention Research Institute, Kyoto University
4	• Administration of landslide and Sabo, landslide research	Seminar	Gain the knowledge and consideration of application to the home country on administration on Sabo and landslide.	3	• Landslide Team/ Geology Team, Public Works Research Institute
5	• Site visit of the manufacturer of landslide monitoring devices and equipment	Seminar Site visit	Understand the mechanism and consider its application on monitoring devices and equipment.	3	• OYO Chishitsu Co. Ltd.

d. Summary of the training result

Throughout the training, either side respect each others intention and obligation. This made the training effective and smooth implementation. The satisfaction level of the trainee was high.

6.4 Capacity assessment

6.4.1 Contents of Questionnaire

To understand the capacity of C/P for the landslide technology in the Project, capacity assessments (hereinafter referred to as CA) were conducted in April 2010, November 2010 and November 2011; which were assumed to be the technical level of the C/P at the beginning, after phase 1 and after phase 3 respectively. The CA was in the form of a questionnaire, and it was divided into two forms: one multiple-choice questions and the other comment/proposal format. This questionnaire is prepared to grasp the level of counterparts' understanding of investigation and analysis, significance of monitoring, application of analysis, and proceeding of the landslide project. The Question Form and its results are attached in the Appendix.

6.4.2 The Result of CA

It is clear that the level of knowledge of the C/P have all advanced, however, this is not the case for engineers in every category. The technical transfer structure was targeted to make all the C/P the same level, but this attempt seems to have failed. It is difficult to update all engineers' skills evenly within the limited time frame, and moreover, the C/P teams' capacity was strengthened by the end. This fact will surely contribute to the future operation of the C/P team.

6.5 PDM

In accordance with the PDM, the review of effectiveness of technical transfer will be described. Through out the project period, the technical transfer was smoothly implemented and the C/P was cooperative. Their major achievement on the output in PDM is shown in Table 6.5.1 and the results of activities are compiled in the Table 6.5.2.

Table 6.5.1 Achievements of Technical Transfer

No	Items of Technical Transfer	Score	Achievement
1	Establishment of the project implementing system	A	The project was started the counterpart members without knowledge of landslide monitoring and analysis. Therefore, the establishment of mechanism to conduct the monitoring and analysis was considered. The activity was conducted on OJT bases which the C/P joins each expert's investigations and other activities during the project period. The step by step approach was applied. Phase I: OJT, Phase II: Analysis, Phase III: C/P's responsible activities. Therefore, C/P could systematically earn the basic knowledge to handle all activities at Phase III.
2	Landslide identification	A	The areal photograph was not taken due to the bad weather during the Phase I. The landslide identification was mostly done by using satellite imaginary. C/P earn the necessary skills to identify the landslide.
3	Identification of features of geomorphologic and geological on landslide	A	Not only geomorphologic and geological survey on landslide, geophysical sounding, and installation of monitoring device has been also conducted with C/P. They are able to conduct installation and monitoring of the landslide movement as well as surface/subsurface survey.
4	The seasonal change on landslide characteristic will be recognized	A	By using the monitoring devices such as extensometer, inclinometer, bore hole inclinometer, water level gauge and rain gauge, C/P are able to recognize the not only seasonal change but also day by day difference of the landslide.
5	The landslide mechanism has been identified	B	In relation with the monitoring result of rainfall and the movement of landslide, the preliminary idea of the mechanism was understood. However, it requires longer time period to recognize mechanism of landslide.
6	The survey and analysis of disasters other than landslides are conducted	B	Rock fall and debris flow survey and analysis were also conducted during this period. But the measures and analysis was mainly focused on the landslide.
7	The counterpart agencies become familiar with landslide survey and analysis work	A	During the project period, C/P earned the skills of landslide survey, monitoring and analysis. Moreover, joint effort with Ethiopia Road Authorities (ERA) was fully supported the drilling activities and shared the experience of the project.

(A: Successfully transferred, B: Fully transferred but need some additional effort in the future, C: Technical transfer was failed and their understanding is poor)

Table 6.5.2 Results of activities

PROJECT OUTLINE	INDICATORS	RESULT
<Overall Goal> • To figure out the mechanisms triggering landslides in the Abay Gorge along national road 3; and to mitigate human suffering and economic losses by implementing appropriate countermeasures.	• Work together with ERA to propose countermeasures • Hazard map of Ethiopia is made, sites are selected according to surveyed demand, budget application is approved, and other landslide sites are surveyed.	The appropriate countermeasure will be implemented in the near future and mitigate human suffering and economic losses can be achieved
<Project Purpose> • To clarify landslide mechanisms in the Abay Gorge • To assist GSE to acquire skills to analyze and investigate landslides	Grasp the current situation and risk, investigate basic and inducing factors, and after developing the implementing organization's capacity, make a report on landslide mechanisms	• The landslide mechanisms were identified • Landslide investigation skills of GSE has been transferred
<Outputs> 1 The Project implementing system is established	1 Project implementing system is established so that it can be continued after the Project is completed	1 Project implementing system is established
2 The situation of landslides is identified	2 Detailed topographical map is made, and the distribution of large scale landslide geomorphology and the size of disasters is grasped through aerial photo interpretation	2 Detailed topographical map is made, and aerial photo interpretation was transferred
3 The geomorphological and geological condition of landslides is identified	3 Survey plans for landslide blocks are established, and the geomorphology and geology of the surrounding area is grasped from the results of survey implementation	3 Survey plans for landslide blocks are established, and the survey was implemented for technical transfer to C/P
4 The landslide characteristics due to seasonal changes are identified	4 Observation is implemented and ground/underground movement and groundwater level secular change is grasped. Further, standards—based on these observation results—are established on activation of the early-warning system in the event of a landslide.	4 Installation and monitoring of landslide monitoring devices are properly transferred to C/P. Basic Idea of establishment on activation of the early-warning system has been introduced.
5 The landslide mechanisms are figured out	5 Landslide mechanisms/factors are figured out through survey and observation results, and risk is evaluated	5 Landslide mechanisms/factors are figured out through survey and observation results, and risk were evaluated
6 The survey and analysis of disasters other than landslides are conducted	6 Risk of slope disasters besides landslides is grasped, various simulations undertaken, and danger zones mapped	6 Landslide risk map and danger zones were identified. Various simulations on landslide, rock fall and debris flow are undertaken.
7 The counterpart agencies become familiar with landslide survey and analysis work	7 OJT and training on landslide survey/analysis is held, and after basic survey/analysis capacity has been developed, an overall survey/analysis manual is put together systematically	7 OJT and training on landslide survey/analysis is held, and an overall survey/analysis manual is put together
<Activities> As same as PDM above.	**＜Inputs＞** **Japanese Side** Experts, Equipment, Training in Japan **Ethiopia Side** 1 Counterpart assignment 2 Administrative work 3 Facilities for the implementation of the Project 4 Local costs 5 Other local costs necessary to implement Project activities 6 Data and information necessary for project implementation 7 Coordination with other relevant organizations on aerial photography by GSE	Activities are performed properly to achieve the goal **But the budget for drilling was not prepared by GSE as indicated in Important Assumption.** Finally it was agreed that GSE will secure the budget for fiscal year 2010/2012 so that the monitoring activities are conducted through rainy season which was necessary for the assumption of landslide measure

6.6 JCC

The JCC was held 5 times in the Project, twice during the phase 1, once during the phase 2 and twice during phase 3. The initial JCC was held to explain the role of the JCC followed by the explanation of outline of the Project to the concerned organizations and agencies. The second JCC was to further the understanding of GSE and JICA regarding budgetary issues rose in the Project. The third JCC was to discuss the budget of drilling operation in 2011 and its burden sharing, and the drilling plan for phase 2. The fourth JCC was to report the contents of ITR and to discuss the activities. The fifth JCC was to wrap up the entire Project. For more detailed results, see attached Appendix.

6.7 Biweekly Meeting

Biweekly meeting was initially planned so that each party gains an understanding of the other's activities for convenience, as well as to hold discussions on technical issues during the site and in-house activities. To date, the meeting has been held four times until June, and since that time, the major activities became on-site technical transfer.

This meeting is valuable for both the Study Team and C/P to exchange technical issues and to improve communication with each other..

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