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

a. Monitoring in borehole

Outline of the devices installed in the Project and other methods are described as follows. Details and way of installation of those devices are described in chapter 3.5.2.

a.1 Borehole inclinometer measuring

Method of borehole inclinometer is to measure the inclination of the guide pipe that is installed in the borehole.

When the guide pipe is installed in an active landslide, the guide pipe is bent by movement of the landslide. So the guide pipe is not straight at the initial state, initial value of inclination should be measured at the time of installation.

If there is a great deal of landslide movement the inclinometer can not be inserted at the point of the slip surface.

a.2 Borehole extensometer

Method of borehole extensometer is to measure the distance between the main part of the extensometer and the end of the wire that is installed in the borehole. When the wire is installed in an active landslide, the wire expands the length by movement of the landslide. The record of extensometer can be obtained in real time to compare with inducing factors, but it is difficult to identify the depth of the slip surface.

a.3 Groundwater monitoring

The groundwater level in boreholes will be measured continuously, the correlation between groundwater level and precipitation is investigated, and also the relationship between groundwater level and landslide activity will be considered. Frequency of data measurements will be from once to several times a month, while the frequency will be increased in the rainy season when there are more landslides.

b. Monitoring on ground surface

b.1 Ground surface extensometer survey

Method of ground surface extensometer is to measure the distance between main part of extensometer and the end of the wire that is installed over the pressure mounds, cracks and steps. When the wire is installed on an active landslide, the wire expands the length by movement of the landslide. The record of extensometer can be obtained in real time to compare with inducing factors, such as precipitation and groundwater level. With this device we can not obtain the macro movement of the landslide, but it measures the movement of a specific part of the landslide.

b.2 Ground surface inclinometer measuring

Method of this inclinometer, which was not installed in the Project, is to measure the inclination of the ground surface of the landslide. This type of inclinometer should be installed a lot on the landslide to measure the movement over a wide area. From the results of ground surface inclinometers, the landslide area and mechanism of the landslide can be estimated.

Photo 3.5.1 Ground surface inclinometer measuring (not installed in the Project)

b.3 Ground survey (total station)

This method is to measure movement on the ground surface using a total station. The stations of the survey are not fixed and can be shifted depending on the direction of landslide movement. However, once measuring has started, the stations shall be fixed and continue observation for some period.

Photo 3.5.2 Ground survey by total station (not installed in the Project)

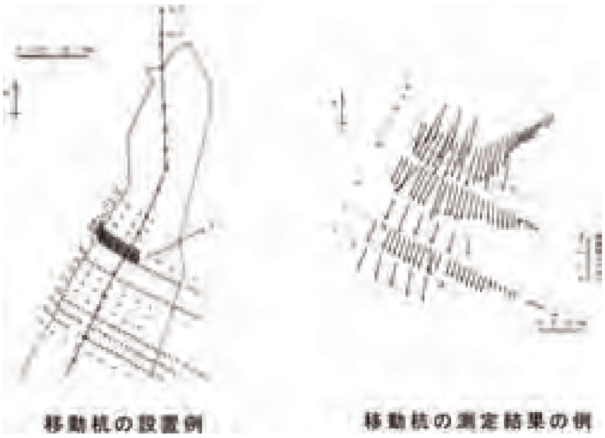


Figure 3.5.2 The result of ground survey
（Left: Location of movable posts, Right: Movement of movable posts）

b.4 GPS survey

This method is to measure movement on the ground surface using GPS, and has become popular in Japan. The stations of the survey are not fixed, and can be shifted depending on the landslide movement. However, once measuring has started, the stations shall be fixed and continue the observation for some period. Monitoring data is transmitted from the site to the operation center simultaneously, even at night or during bad weather and can be connected to an early warning system.

Photo 3.5.3 GPS survey (not installed in the Project)

c. Inducing factors survey

Inducing factors survey is necessary for determination of landslide mechanism and relation between landslide factors. In the Project, only precipitation observation has been conducted.

Two precipitation observation stations (rain gauges) are installed in the Project site.

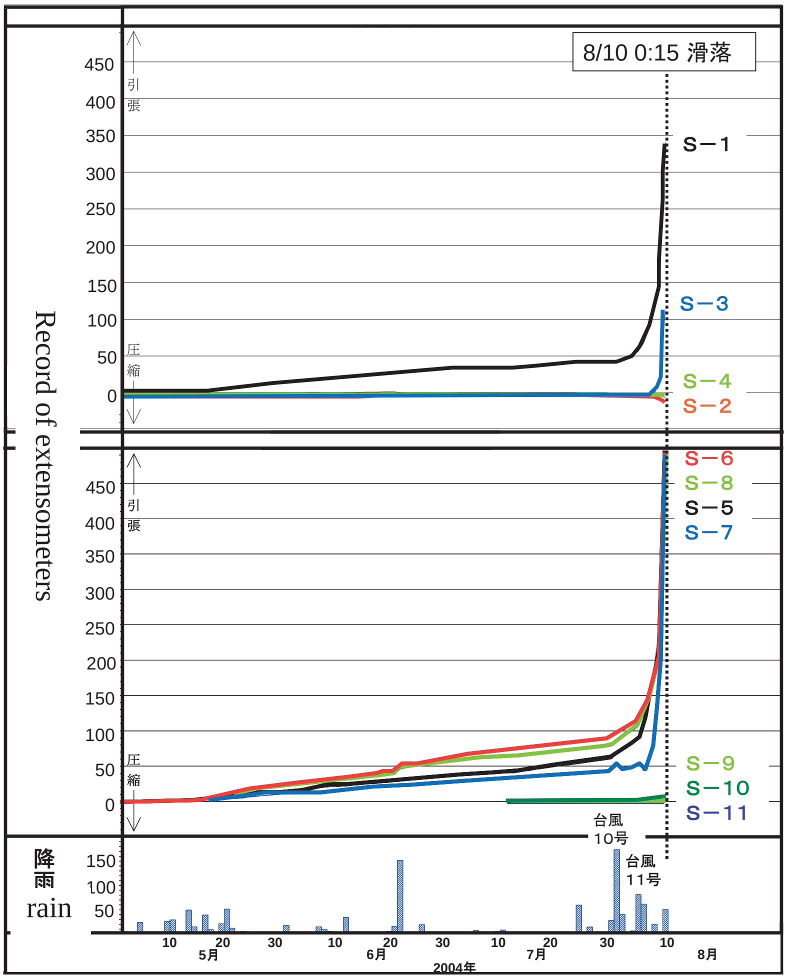


Figure 3.5.3 Graph of the results of extensometers and rain gauge (example from Japan)

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.

The number of the monitoring device installed at the selected priority sites is shown below. The monitoring locations and results are indicated in Chapter 4.4.3.

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

The purposes and specifications of the monitoring devices and the procedures of the monitoring are described in detail in following section.

3.5.3 Landslide monitoring in Abay Gorge

a. Extensometer

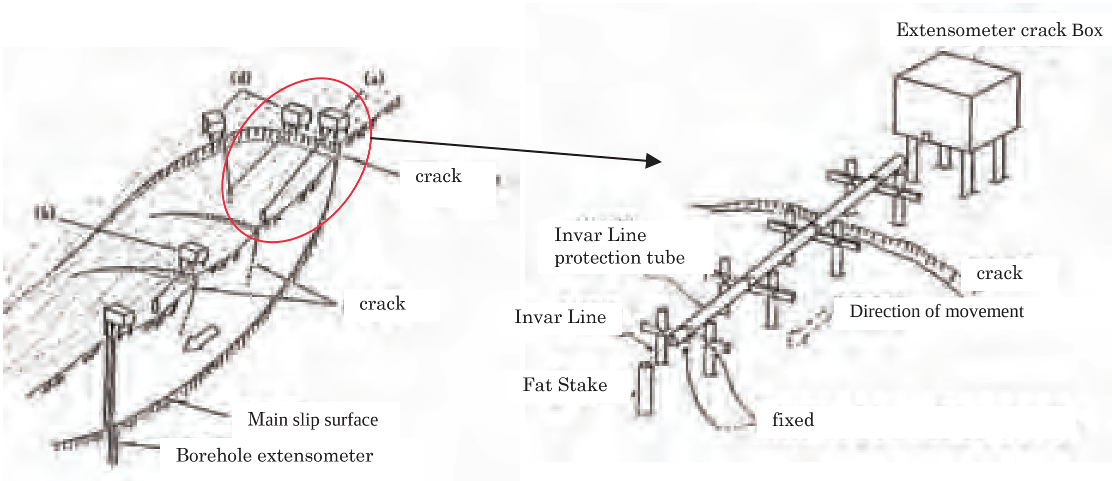


Figure 3.5.4 Conceptual diagram of Extensometer

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. The procedure of the installation of the extensometer is described as follows.

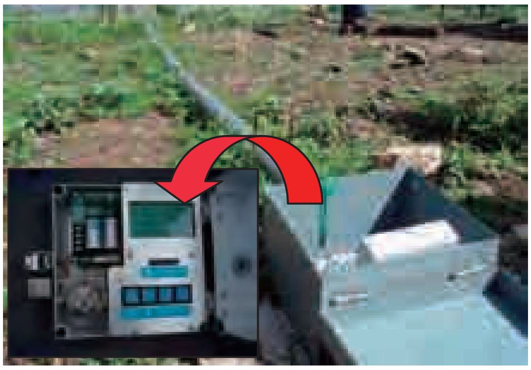


Photo 3.5.4 View of Extensometer

1) Before setting the device, two batteries, CR123A, were procured and set for the power source, and unique ID numbers were set by rotary switch for “ID number setting”. The range of the number is between 00 and 98.

2) The body of the device was set on the stabilized floor which was fixed by cement and gravel, and a peg connected to wire was driven into separate stable ground. The body was protected by a steel box.

3) After the data and time of the internal clock and starting time of the measurement were set, the measurement would be started. Data is saved to the data logger automatically every minute and every hour. The resolution of the measuring displacement is 0.1 mm.

b. Borehole Extensometer

To measure movement of a slip surface in the ground, borehole extensometers were installed at drilled borehole points. The procedure of the installation of the borehole extensometer is described as follows.

1) An anchor connected with wire was put down to the bottom of the borehole and was

suspended, and it was fixed by grouting the borehole. The detailed procedure of the installation of the anchor is described in Chapter 3.7.

2) A platform of the device was fixed on the stabilized floor using cement and gravel on top of the borehole. The detection wire from the anchor was wound and fixed to detection pulley. Then weight was connected to back tension pulley. The body on the surface was protected by a steel pipe.

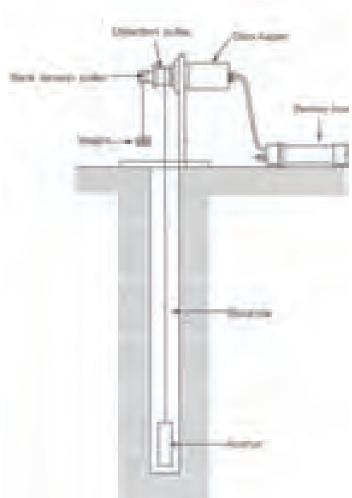


Figure 3.5.5 Conceptual diagram of Borehole Extensometer

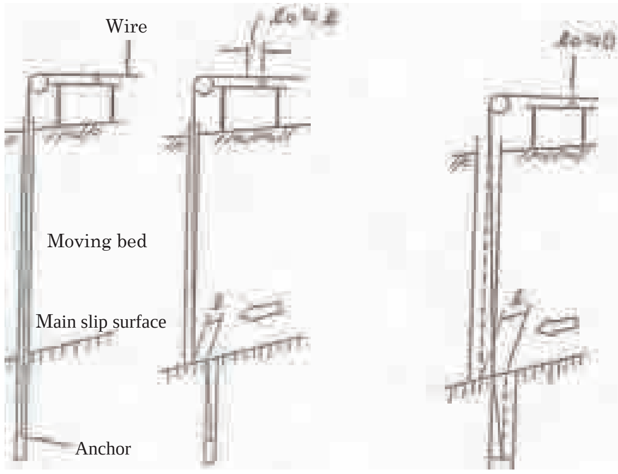


Figure 3.5.6 A principle of Borehole Extensometer

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. The procedure of the installation of the borehole inclinometer is described as follows.

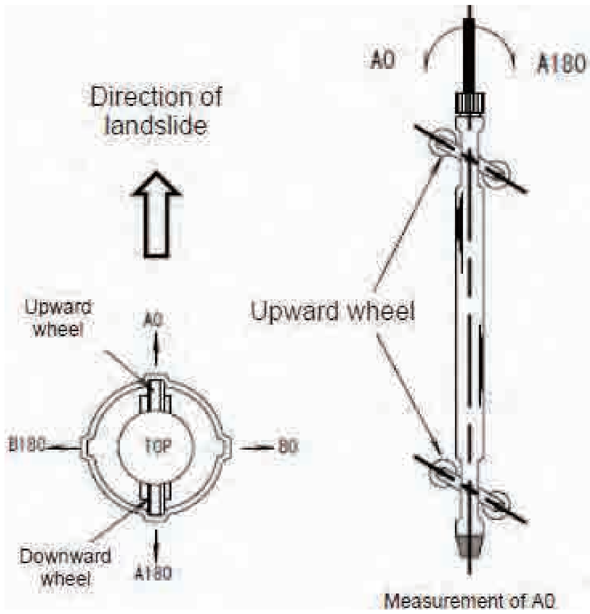


Figure 3.5.7 Borehole Inclinometer

1) For the measurement by the borehole inclinometer, special aluminum casing pipes which were hermetically sealed were installed into a drilled borehole. The casing pipes were put down to the bottom of the borehole and were suspended and they were fixed by grouting of sand/cement in the borehole. The top of the casing pipes stands up from the surface, and the part on the surface is protected by a steel pipe. The detailed procedure of setting and installation of the special casing pipes is described in Chapter 3.7.

2) Around 1 week should be kept for stabilization after the installation of the casing pipes. Measurement by the inclinometer is done to grasp initial values of the pipes in the ground

at the landslide area. The procedure of the measurement is as follows;

A) After connection of the inclinometer, a cable, and a data logger, it is installed at the bottom of the casing pipe in the borehole. An upward wheel is set on A0 rail on A-axis, which shows the direction of landslide movement at the area, when the inclinometer is installed at the pipe.

B) More than 30 minutes should be kept at the bottom of the pipes for stabilization of temperature and electrical circuit on the inclinometer. After confirmation of stabilizing the value at the bottom, the data at every 50 centimeters is collected during pulling up of the inclinometer.

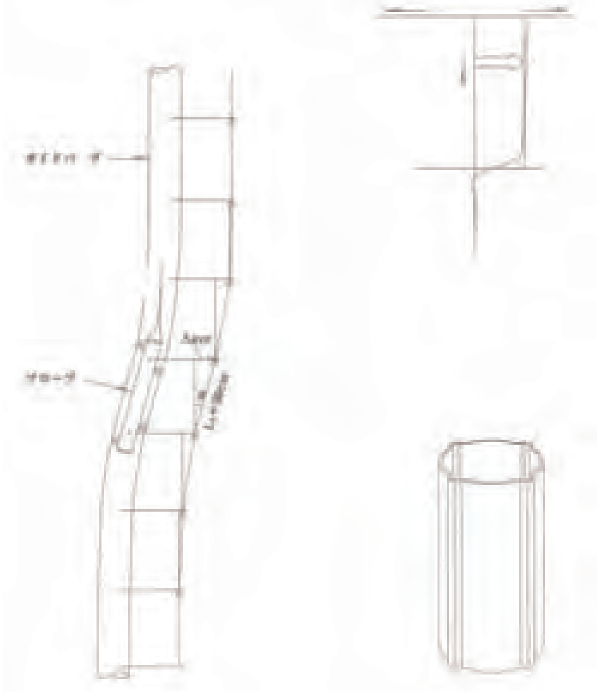


Figure 3.5.8 Measurement of Borehole Inclinometer

C) After the collecting data at all depths, the inclinometer should be rotated 180 degrees, which means that the upward wheel is set on A180 rail on A-axis, and is installed at the bottom of the casing pipe in the borehole. The stabilization at the bottom is around 5 minutes.

D) The data at every 50 centimeters is collected at the opposite side in the same way.

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. The procedure of the installation of the groundwater level meter is described as follows.

1) For the measurement by the groundwater level meter, polyvinyl chloride (hereinafter PCV) pipes which were fabricated were installed into drilled borehole. The PVC pipes were put down to the bottom of the borehole and were suspended, and they were fixed by gravel grouting in the borehole. The top of the PVC pipes stands up from the surface, and the part on the surface is protected by a steel pipe. The detailed procedure of setting and installation of the PVC pipes is described in Chapter 3.7.

2) Before setting of the device, three D-size batteries were procured and set for the power source. The measuring condition such as date/time setting and measurement starting time was set by a laptop PC through RS232C cross cable.

3) The groundwater level meter was installed at lower part in the groundwater in the PVC pipe. Calibrations should be implemented at three different depths in the borehole. The data is automatically collected after the calibration.

Photo 3.5.5 Device of Groundwater Level Measurement

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. Quantity and Specifications

Table 3.6.1 shows the specifications of the seismic exploration method and Table 3.6.2 outlines the technical requirements for the survey. We conducted seismic exploration at 18 traverse lines in five areas.

Table 3.6.1 Specification of seismic exploration

Survey method	Seismic exploration according to seismic refraction method (P wave)
Vibration-receiving point interval	5 m
Vibration source point interval	About 30 m
Shaking method	Hammering

Table 3.6.2 Outline of technical requirement (Phase1)

Classification	Area / Traverse line	Traverse line length (m)	Measuring pitch (m)	Specification	Remarks
Longitudinal	L/S 00 3 Traverse line	BO-01:170.0 BO-02:170.0 BO-03: 55.0	5.0 m	Stacking method	
Longitudinal	L/S 5 3 Traverse line	BO-04:100.0 BO-05:310.0 BO-06:115.0	5.0 m	Stacking method	BO4:100.0m BO5:115.0m+50.0m+145.0m BO6:115.0
Longitudinal	L/S 22 1 Traverse line	BO-07:230.0	5.0 m	Stacking method	
Longitudinal	L/S 27 2 Traverse line	BO-08:230.0 BO-09:275.0	5.0 m	Stacking method	BO8:115.0m+115.0m BO9:115.0m+95.0m+65.0m
Longitudinal	L/S 28 2 Traverse line	BO-10:655.0 BO-11:379.14	5.0 m	Stacking method	BO10:550.0m+105.0m BO11:270.0m+109.14m
Total	5 area 11 Traverse line	2689.14			

Table 3.6.3 Outline of technical requirement (Phase3)

Classification	Area / Traverse line	Traverse line length (m)	Measuring pitch (m)	Specification	Remarks
Longitudinal	L/S 00 1Traverse line	BO-12:240.0m	5.0 m	Stacking method	Lower220.0m+Upper20.0m
Longitudinal	L/S 27 3Traverse line	BO-081:195.0m BO-091:245.0m BO-092:620.0m	5.0 m	Stacking method	BO-081 Lower115.0m+Upper80.0m BO-092 Lower140.0m+Upper480.0m
Longitudinal	L/S 28 3Traverse line	BO-13: 815.0m BO-14:540.0m BO-15:460.0m	5.0 m	Stacking method	BO-13 Lower185.0m+Middle435.0m Upper195.0m BO-14 Lower460.0m+Upper80.0m
Total	3 area 7Traverse line	3115.0m			

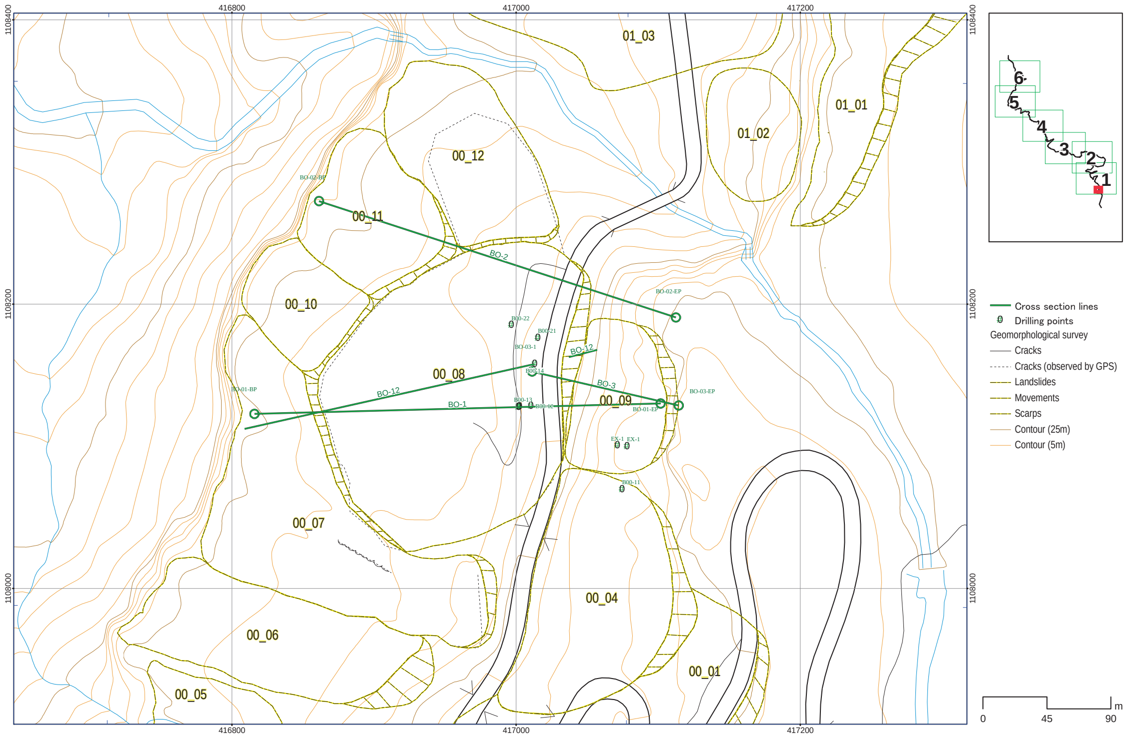


Figure 3.6.1 Location of Seismic Exploration in L/S00

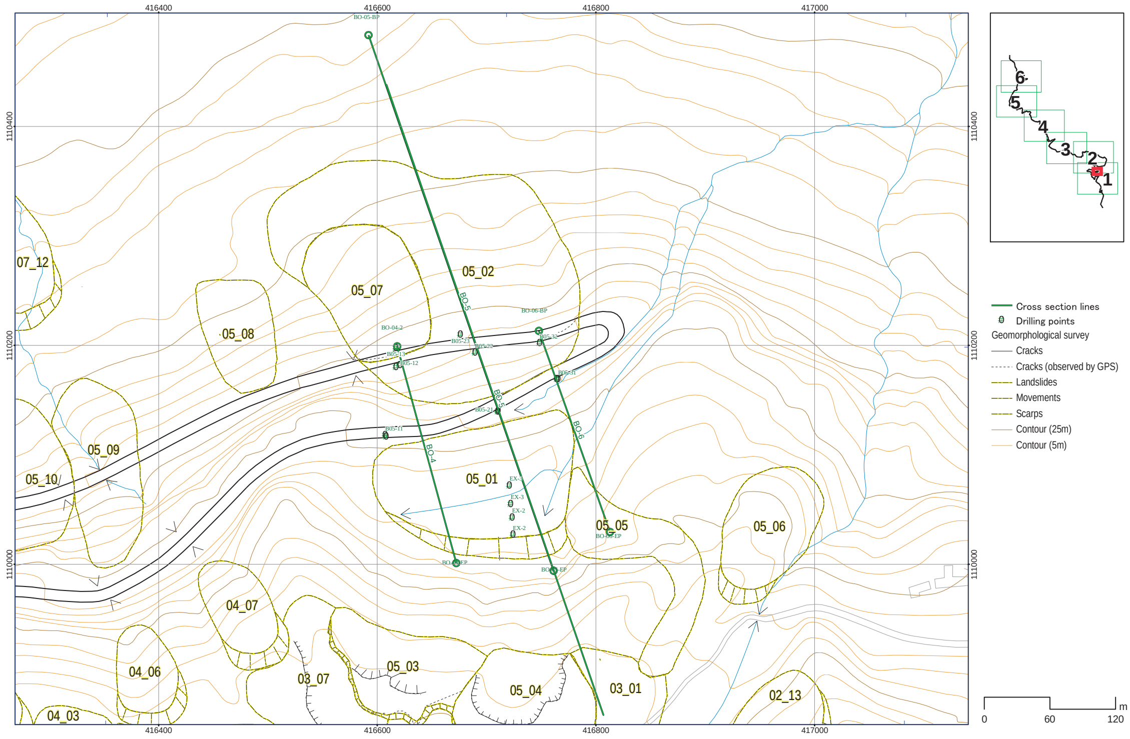


Figure 3.6.2 Location of Seismic Exploration in L/S05

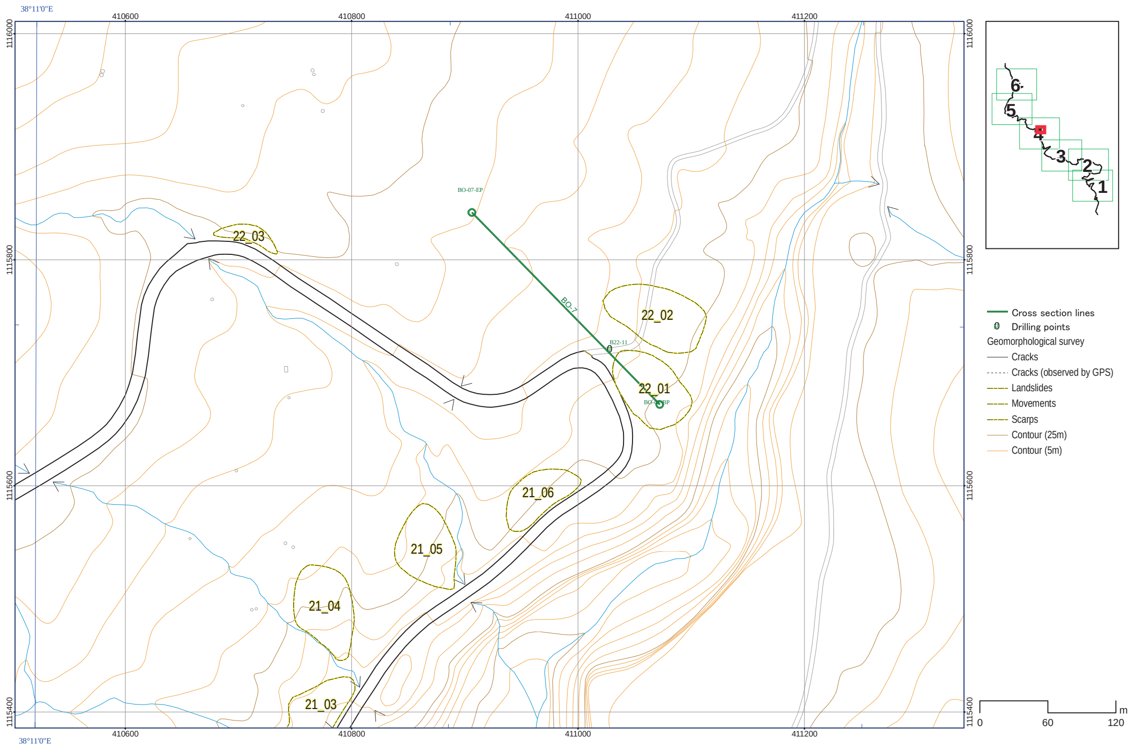


Figure 3.6.3 Location of Seismic Exploration in L/S22

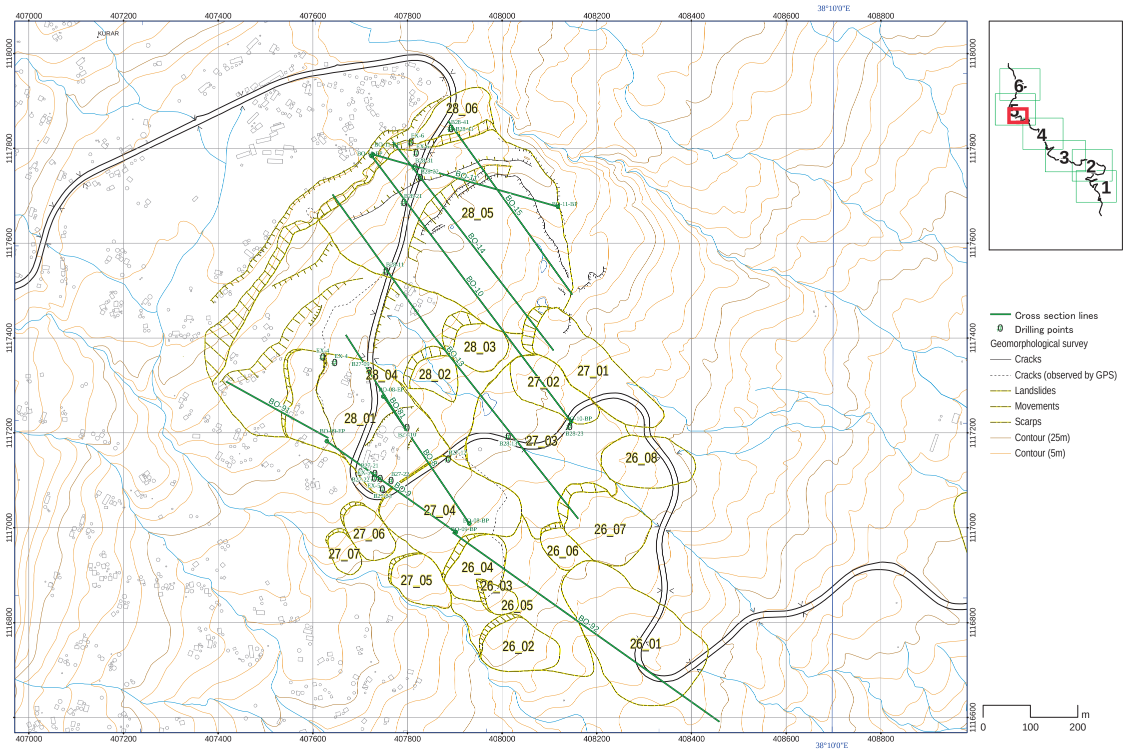


Figure 3.6.4 Location of Seismic Exploration in L/S27 and L/S28

c. Exploration method

c.1 Principles

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.

Based on the principle of the seismic refraction method, a method of elastic wave exploration, observations were made above the ground of how primary wave (P wave) and secondary wave (S wave) of “elastic undulation” travels through the geological stratum either directly or refracted at different boundaries. By understanding the behavior of the waves, it allows us to determine the subsurface structures. Here, elastic undulation or earthquake motions are generated artificially through hammering, crushing powder, etc. In the Project, we used the P wave output.

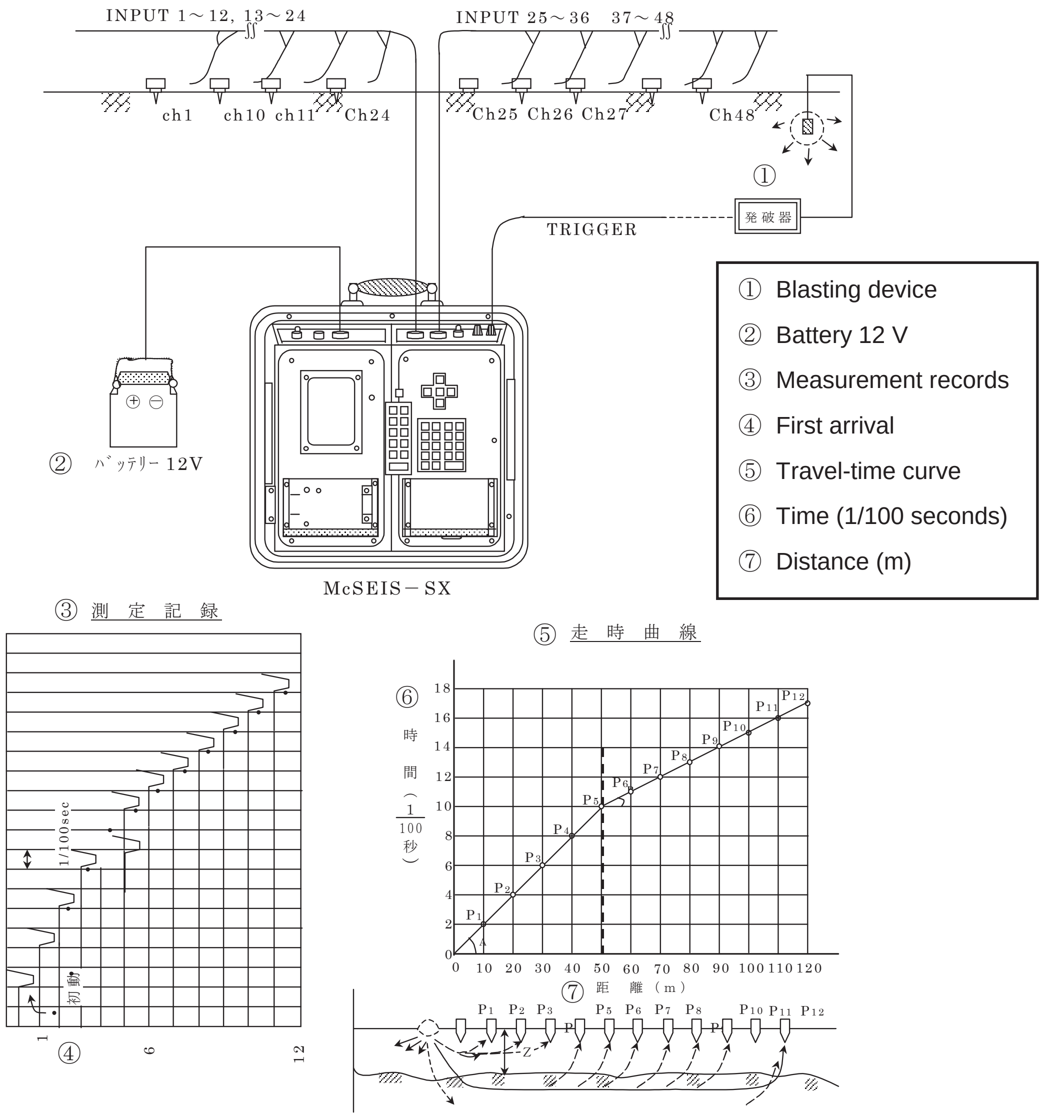


Figure 3.6.5 Conceptual diagram of elastic wave exploration

c.2 Equipment and analysis software

Table 3.6.4 shows the equipment and analysis software used in elastic wave exploration.

Table 3.6.4 List of equipment

Name	Type	Specification	Qty.	Manufacturer
Digital data recorder	McSEIS SX type Model 1125T	24 elements Frequency characteristic 10 to 4600 Hz	1 unit	OYO Corporation
Geophone	Land type	Natural frequency 28 type	24 pieces	OYO GEO SPACE Corporation
Takeout cable	Main line cable	12 elements	2 rolls	OYO Corporation
Analysis software	High density seismic refraction method (Seis Imager/2D)			OYO Corporation
Others	Big hammer, iron plate			

c.3 Observation procedure

Observation procedure is as follows:

Selecting the traverse line	Choose position and bearing of traverse line on which exploration is carried out based on the results of reconnaissance on landslide area
↓ Spread work (install the geophones)	Install the geophones on each survey point while wiring the “takeout cable” from the end of traverse line to connect them with “takeout cable”.
↓ Installing the shot points	Install 6 to 7 shot points for each traverse line at predefined points. In the case of hammering, produce vibration by hitting the iron plate placed on the ground with a hammer and the time will be transmitted to the body of recorder from the hammer switch attached to the hammer.
↓ Measuring	Adjust the noise with amplifier so as to minimize the noise due to the traffic vibration, wind and the like by means of elastic wave survey instrument. Instructions will be given from the measurement headquarter on a timely basis to produce vibration in each shot point to record its vibration-receiving waveform.

Repeat these tasks (Spread→Producing vibration→Measurement) in sequence as described above to complete the measurement of one spread. Perform the same series of tasks on other traverse lines as well to complete the measuring of all traverse lines.

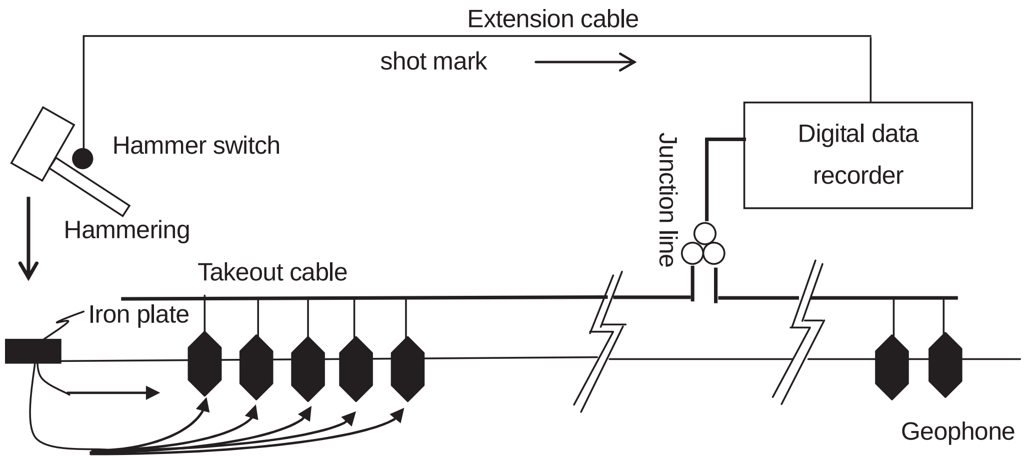


Figure 3.6.6 Observation procedure and diagram of observation

d. 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.

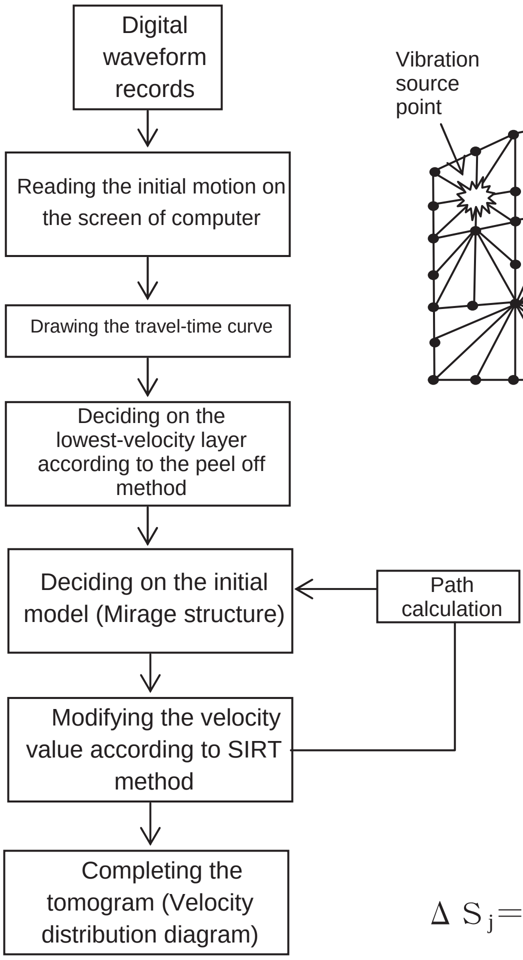
Shape of travel-time curve reflects the velocity structures, equivalent of velocity distributions of the underground. Gradient of travel-time curve represents the amplitude of apparent elastic wave velocity (the smaller the gradient of curve is, the bigger the velocity value is). The range of same layers 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.

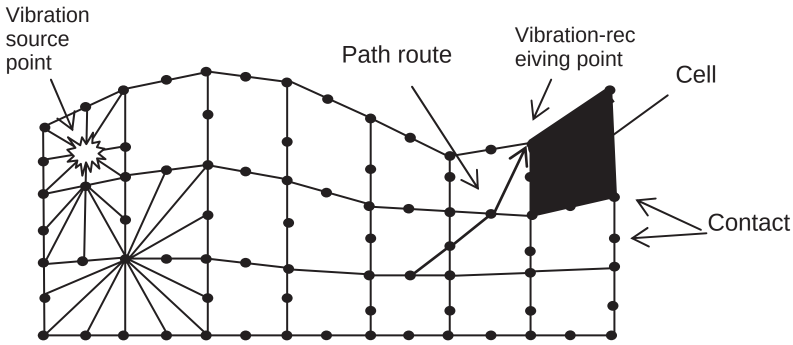
Major analysis methods of travel-time curve include two methods: Hagiwara’s peel off method (Peel off method) most-commonly used in a conventional civil engineering geological survey and a tomographic analysis method (hereinafter referred to as “tomographic method”) developed in recent years. While the peel off method reflects layered subsurface structures well, the tomographic method is suitable for block-like structures (matrix structure) and structures where the velocity varies gradually and the like. Table 3.6.5 shows major differences and characteristics of two analysis methods.

During the Project, we took advantage of the two by obtaining the initial model with the peel off method and optimizing it through the means of the tomographic method. Figure 3.6.7 shows its analytical flow.

Table 3.6.5 Comparison between peel off and tomographic methods

Item		Peel off method (Hagiwara’s method)	Tomographic method
Class of elastic wave		Direct wave + Refracted wave	Direct wave + Refracted wave + Transparent wave
Constraints of velocity structure	Structure	Supposing that the greater the depth is, the bigger the velocity value gets.	Essentially, same as the “peel off method”. Stereological measurement enables the detection of velocity-inversion layer as well.
	Velocity value	Same velocity in one layer	Same velocity in one lattice.
How the elastic wave propagates		Elastic wave propagates at the velocity of lower layer along layer boundary (critical refracted wave)	Elastic wave propagates while transmitting in each lattice at the unique velocity in each lattice.
Effects attributable to the terrain and irregularity at velocity boundary surface		Great Apparent high velocity at convex portion Apparent low velocity at concave portion	Small
Features		• Suitable for the layer structure including sedimentary layers • Suitable for the zoning (large classification) of weathering zone	• Suitable for the block-like and nervation structures including eruptive rock and fault in addition to hard-and-soft alternate layer as well. • Since it is easy to capture the slight change in velocity, detailed interpretation is available.





SIRT method is the one in which velocity structure models are approximated in two or more quadrangles (cell), on the assumption that the velocity in each cell is constant, and then the optimum velocity model which goes hand-in-hand with observed value (travel-time) is estimated while modifying the correction amount of j^{th} cell (ΔSj) by means of following formula repeatedly.

$$\Delta S_j = \sum_i \left(T_i^{0-c} \cdot l_{ij} \cdot S_j / T_i^c \right) / \sum_i l_{ij}$$

Sj : Slowness of J^{th} cell

l_{ij} : Length that i^{th} P wave passes through j^{th} cell

T_{0-c} : All residual errors of i^{th} P wave

T_i^c : Theoretical travel-time of i^{th} P wave

Figure 3.6.7 Analytical flow of tomographic method

e. 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.

As an example of the results of the exploration, Illustrated below is a travel-time curve generated based on the values recorded along the traverse line BO-12 in L/S 00 (Figure 3.6.8). Figure 3.6.9 is an analytical diagram of velocity profile for the same line.

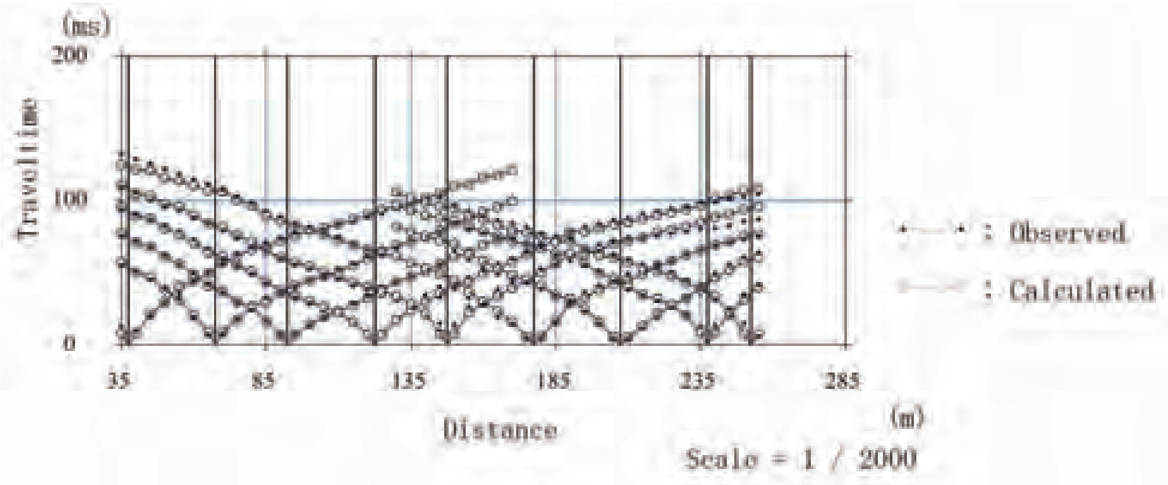


Figure 3.6.8 Travel-time curve of L/S 00: Traverse line BO-12

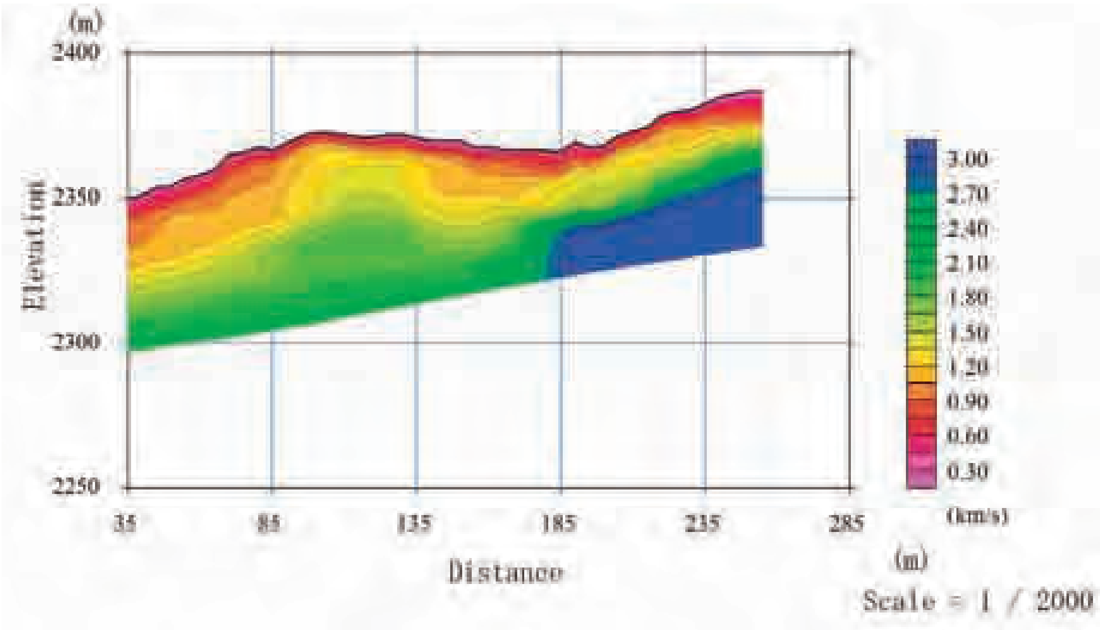


Figure 3.6.9 Analytical diagram of velocity profile of L/S 00: Traverse line BO-12

f. Summary and analysis of exploration results

f.1 Location L/S 00

In this landslide site, elastic wave exploration was conducted for four measuring lines. The following shows the explanation results for each measuring line.

f.1.1 Cross Section BO-01

This measuring line is from the road shoulder to the toe of the landslide. It is located at the south of the landslide. The layer with velocity lower than 1.0km/s is about 10 m thick, and it is relatively thicker at both ends (road shoulder and landslide toe). Since the refill layer at the road shoulder is thick, this may be reflected in the measuring result. At the toe of landslide, thick layer of low velocity may be due to the slope failure occurred at the toe part, where the layer is loose as indicated by relatively lower velocity. Generally, the characteristic of this measuring line is that the layer with velocity around 1.2 km/s is thicker than the other parts near 50m post. The lowermost layer with velocity higher than 2.0km/s corresponds to mudstone.

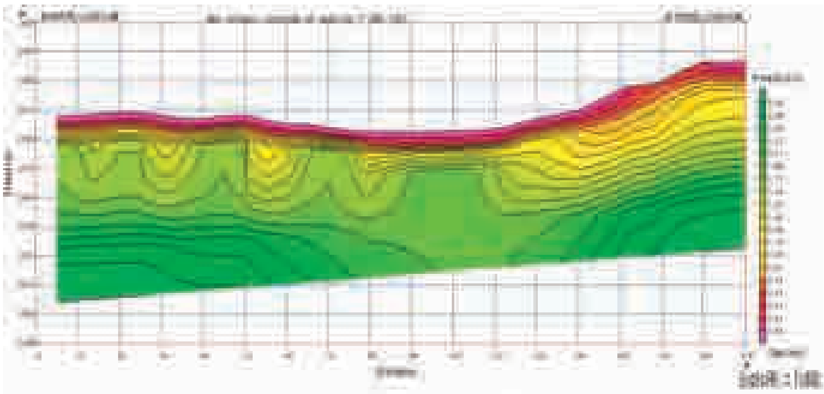


Figure 3.6.10 Analytical diagram of velocity profile: Traverse line BO-01

f.1.2 Cross Section BO-02

This measuring line is also from the road shoulder to the toe of the landslide, and it is located at the north side of the landslide. It is the same as BO-01 measuring line in ways which the thickness of the layer with velocity lower than 1.0km/s is about 10 m. However, it is about 20 m at the road shoulder side. It is estimated that thick refill layer is distributed here gently. The layer with velocity near 1.20km/s showed a convex shape between 50 m to 100 m posts, showing the same tendency as that of BO-01measuring line.

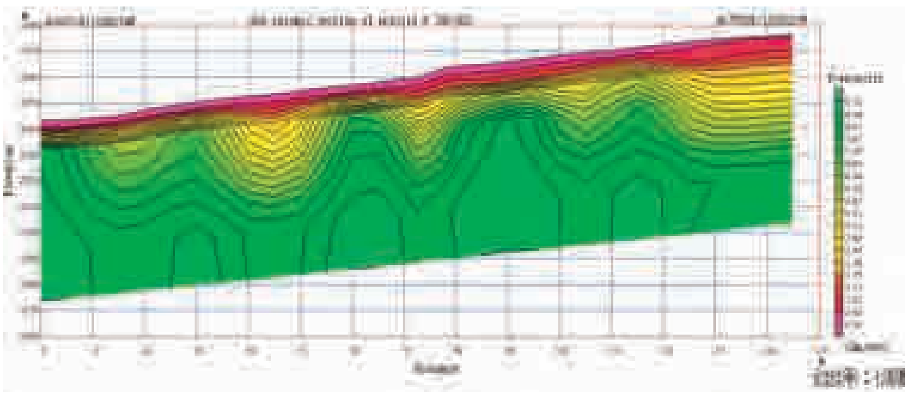


Figure 3.6.11 Analytical diagram of velocity profile: Traverse line BO-02

f.1.3 Cross Section BO-03

This measuring line is from the cutting slope of the road, and past the natural slope. It is a short line with a length of only 50 m. The velocity becomes higher than 1.5km/s below 10 m. The boundary of velocity layer is almost parallel to the ground surface. The elastic wave velocity may be controlled by tuff and basalt.

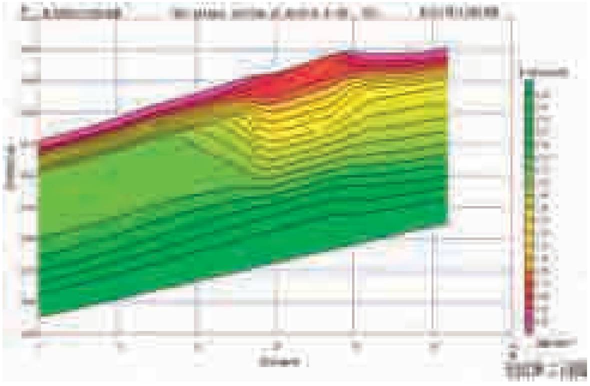


Figure 3.6.12 Analytical diagram of velocity profile: Traverse line BO-03

f.1.4 Cross Section BO-12

This measuring line is along the central longitudinal line of the landslide. It starts from the cutting slope of the road, and finishes at the toe of the landslide. Between the distance ranges from 150 to 250 m, the isograph lines are dense and the velocity is higher than 3.0 km/s. In addition, between the distance range of 50 m and 110 m, the velocity layer around 1.20km/s shows a convex shape. As in the other measuring lines, the differences in geology, consolidation degree, hardness of the layer is measured. At the distance range from 0 to 50 m, the layer with a velocity lower than 1.0km/s is about 20 m thick, indicating a possibility of loosening of materials at the landslide toe. Analytical diagram is shown in Figure 3.6.9.

f.2 Location L/S 05

In this landslide site, elastic wave exploration was conducted in 3 measuring lines. The following are the explanation for each measuring line in details.

f.2.1 Cross Section BO-04

The landslide is in a hairpin curve shape. This measuring line crosses the landslide longitudinally and is located at the west side of the landslide. This slope has thick talus deposit. From the slope shoulder to the gentle part at the back of the slope, the layer with velocity lower than 1.0km/s is about 20 m thick. However, the layer is thin at the slope part, and the isographic lines are dense. It is confirmed that limestone outcropped near the road side, and it is estimated that the velocity higher than 1.0 - 1.5km/s may be influenced by the existence of limestone.

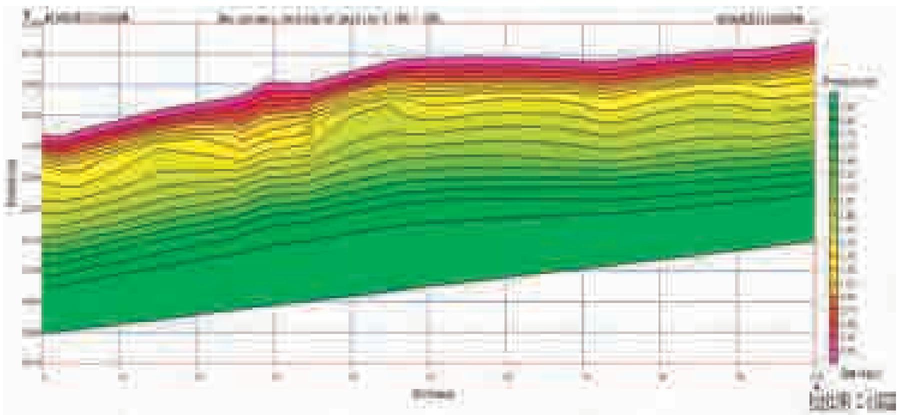


Figure 3.6.13 Analytical diagram of velocity profile: Traverse line BO-04

f.2.2 Cross Section BO-05

This measuring line crosses the landslide longitudinally along the central line. There is an obvious difference in the velocity distribution between the upper part and the lower part of the road. At the upper part of the road, the velocity layer of 1.0km/s - 2.5km/s is thick, and the isographic lines show disturbances. While in the lower part of the road, the velocity layer higher than 3.0 km/s has been recorded. It is estimated that the velocity layer corresponds to limestone; and the situation of the limestone, such as fission distribution, weathering condition, and hardness may affect the velocity. On the other hand, the velocity lower than 1.0km/s may correspond to the talus deposit.

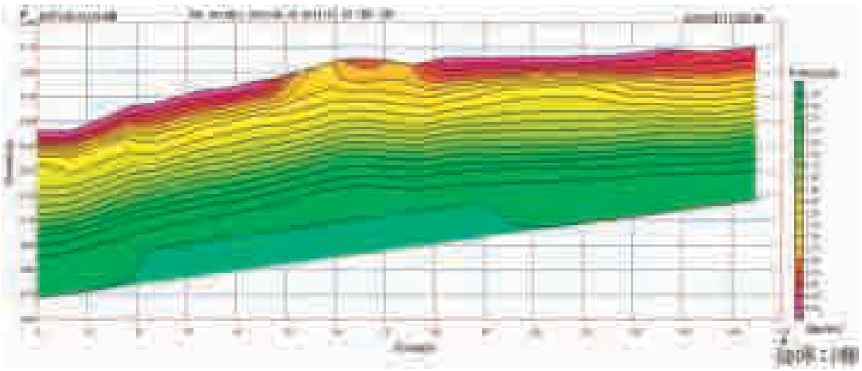


Figure 3.6.14 Analytical diagram of velocity profile: Traverse line BO-05

f.2.3 Cross Section BO-06

This measuring line is parallel to the central longitudinal section of the landslide and located at the east side of the landslide. As in the other measuring lines, the velocity layer of 1.0km/s - 2.5km/s is thick and the isographic lines show disturbances. Moreover, from the cutting slope to the road, the velocity layer around 3.0km/s has been confirmed near GL-15.0m. At the road, fresh limestone with little fission is confirmed from the ground surface. The entire line shows a different velocity distribution compared to the other measuring lines.

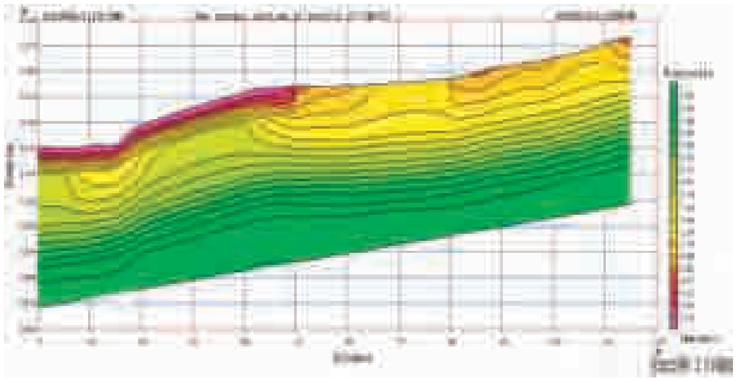


Figure 3.6.15 Analytical diagram of velocity profile: Traverse line BO-06

f.3 Location L/S 22

In this landslide site, elastic wave exploration was carried out along 1 measuring line. The following is the results.

f.3.1 Cross Section BO-07

This measuring line is along the central longitudinal section of the landslide block near the road side. At the toe part of the landslide block, sandstone outcrops. Refills and talus deposited on the sandstone layer, with a depth of 18 m which is confirmed through borehole data. The velocity for the talus deposit is smaller than 1.5km/s, and the velocity layer smaller than 1.5km/s shows the thickest distribution at the shoulder of the cutting slope. The velocity layer larger than 3.0km/s is distributed below 35.0 - 40.0m. It is estimated to correspond to fresh sandstone layer.

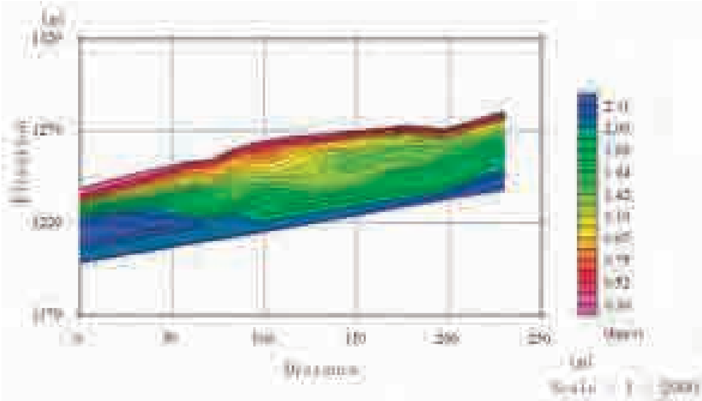


Figure 3.6.16 Analytical diagram of velocity profile: Traverse line BO-07

f.4 Location L/S 27

In this landslide site, elastic wave exploration was conducted along 2 measuring lines. The following is the result for each line.

f.4.1 Cross Section BO-08

This measuring line crosses the church. The road also intersects in the middle of the line, so the line is divided into three parts. The velocity layer smaller than 1.0km/s has a thickness of 10 – 20m and from the slope on the lower side of church to the lower slope, the layer becomes thicker. On the road near the church, the landslide shows the most active deformation, and subsidence is still ongoing. From the church to upper slope, the velocity layers are almost parallel to the slope surface topography, and the velocity layer of 1.2km/s is thick. The velocity layer larger than 1.5km/s is distributed continuously below the depth of 20 – 30m, and there is no velocity layer larger than 3.0km/s.

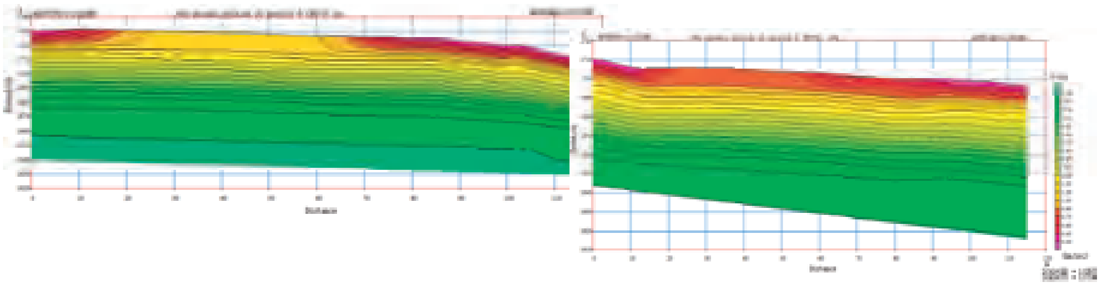


Figure 3.6.17 Analytical diagram of velocity profile: Traverse line BO-08

f.4.2 Cross Section BO-091・BO-09・BO-092

The measuring lines are located on the south side of the landslide site, and the total length reaches 1400m. As in the BO-08 measuring line, the velocity layer smaller than 1.0km/s is distributed with a thickness of 20 – 30m from the road which is located on the lower side of the church to the lower slope. In addition the thickness of the low velocity layer is about 30m from the road above the church to the gentle slope on the north side. In the lower slope of the southeast side, the low velocity layer gradually becomes thicker, and the velocity layer larger than 1.5km/s is shallowly distributed. Velocity layer larger than 3.0km/s was not detected within the exploration range. In these lines, it is estimated that only talus deposit and sliding mass are loosely distributed.

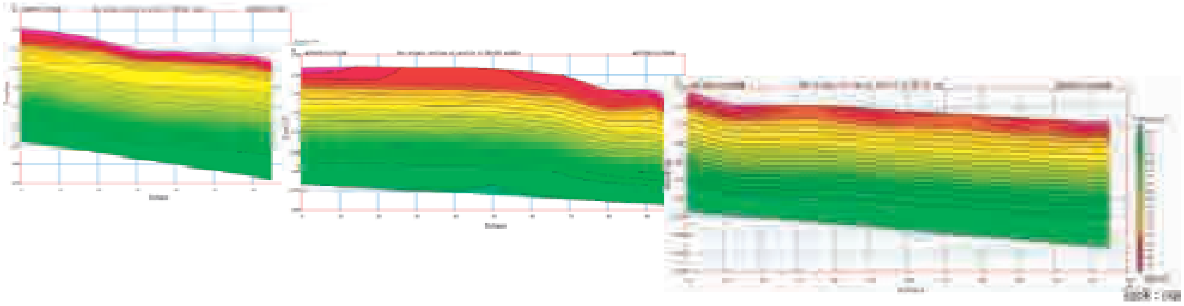


Figure 3.6.18 Analytical diagram of velocity profile: Traverse line BO-09

f.5 Location L/S 28

In this landslide site, elastic wave exploration was conducted along 5 measuring lines. The followings are the results.

f.5.1 Cross Section BO-10

This measuring line is located near the center of the landslide. It is a long line with length of 650m. At the road side, boreholes B28-21 and B28-23 are located. Low velocity layer smaller than 1.0km/s is distributed around the road with a thickness of 25 - 30m. In addition, the same layer is widely distributed in the lower slope (distance range: 30 – 250m) with a thickness of about 30m. It is estimated that this area is the domain area for the talus deposit and sliding mass. On the other hand, velocity layer larger than 1.5m/s is distributed shallowly in a convex shape near the road on the lower slope (distance range: 0 - 25m), and near the mid-slope (distance range: 330 – 450m). It is estimated that the degree of compaction may be higher, or stiff rock mass such as basalt may be included in this

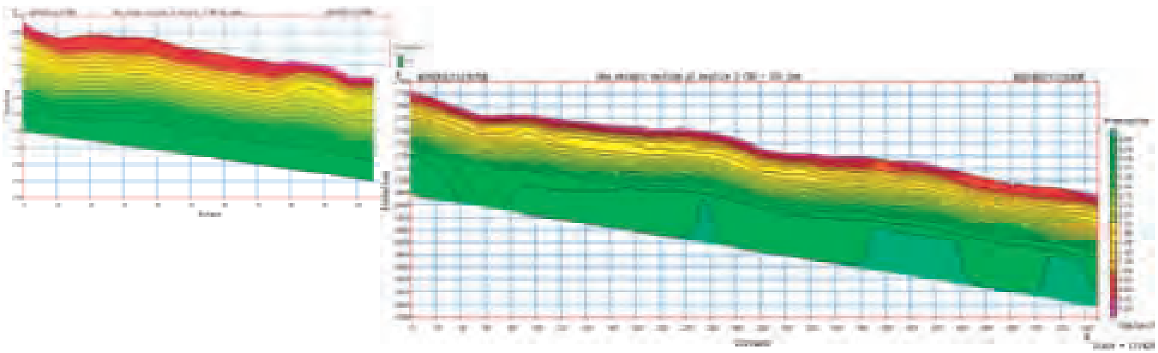


Figure 3.6.19 Analytical diagram of velocity profile: Traverse line BO-10

f.5.2 Cross Section BO-11

This measuring line is located on the north side of the landslide site. Borehole B28-31 is located along this line. Near the road, velocity layer smaller than 1.0km/s is distributed thickly in a circular shape. The low velocity layer becomes thin toward the lower slope (distance range: 50 - 170m), and the high velocity layer larger than 1.5km/s is distributed shallowly. It is estimated that the measuring line passes through the main scarp and flank of the landslide and the results reflects the thick talus deposit.

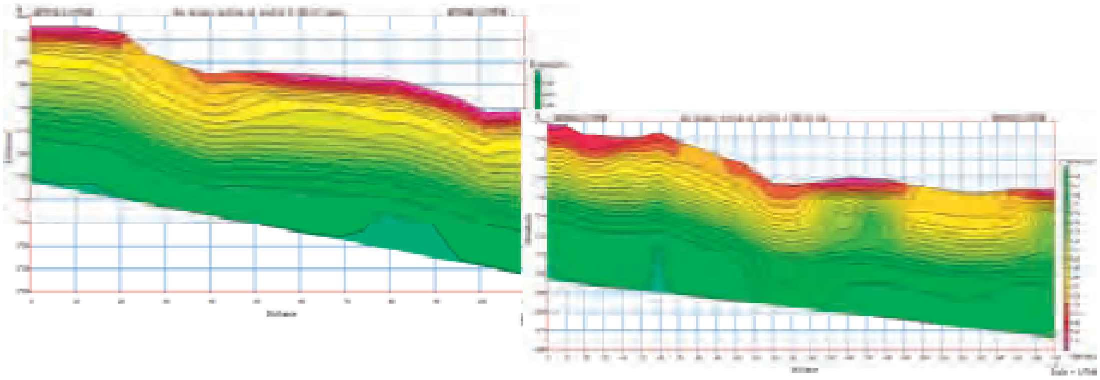


Figure 3.6.20 Analytical diagram of velocity profile: Traverse line BO-11

f.5.3 Cross Section BO-13

This measuring line is located on the south side of the landslide site. The road crosses the middle of the line, and the line is divided into three parts. Boreholes B28-11 and B28-13 are located along the road side. Thin layer of low velocity smaller than 1.0km/s is distributed throughout the line and it is estimated approximately 10 – 15 meters thick. On the other hand, the layer with 1.2km/s in velocity is distributed thickly in some parts. It is about 15m thick in the lower slope (distance range: 50- 100m), middle slope (distance range: 320 – 550m), and near the road (distance range: 600 – 750m). Layer with high velocity greater than 1.5km/s is distributed in a convex shape, and the shallowest point is near the road in the lower slope (distance range: 100 – 300m).

f.5.4 Cross Section BO-14

The BO-10 measuring line passes the north side of the landslide, and is located near the landslide center. On the road side, bore holes B28-31 and B28-32 are located. As in the BO-10 measuring line, layer with low velocity which is smaller than 1.0km/s is distributed from the road to the upper slope with a thickness of 15 - 30m. In addition, the same layer is distributed in the middle slope (distance range: 200 -250m) with a thickness about 35m. Similar to that of BO-13 measuring line, distribution of the high velocity layer larger than 1.5km/s showed a convex shape in places with fluctuation.

f.5.5 Cross Section BO-15

This line is located at the north side of the landslide, crossing with BO-11 measuring line. The bore hole B28-41 is also located along the line. The low velocity layer smaller than 1.0km/s is relatively thick below the borehole B28-41. In addition, similar trend was observed in the lower slope (distance range: 0 -50m). The high velocity layer larger than 1.5km/s is distributed shallowly in the middle slope, at the depth near 10m. It is estimated that this measuring line is near the flank of the landslide where the talus deposit is thin.

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. Quantity and Specifications

Table 3.6.6 shows outlines the technical requirements for the survey. We conducted two-dimensional resistivity exploration at 8 traverse lines in three areas.

Table 3.6.6 Technical settings of resistivity exploration

Area name/ # of traverse line	Traverse line	Electrode interval (m)	Max. depth measured (m)	Traverse line length (m)	Remarks
L/S 00 3lines	BO-01 BO-02 BO-03	5.0	40	170 170 52	Not conducted Not conducted Not conducted
L/S 05 5 lines	BO-04 BO-05(Upper part) BO-05(Central part) BO-05(Lower part) BO-06	5.0	40	100 145 50 115 115	Conducted Conducted Not conducted Conducted Conducted
L/S 22 1 line	BO-07	5.0	40	230	Conducted
L/S 27 5 lines	BO-08(Upper part) BO-08(Lower part) BO-09(Upper part) BO-09(Central part) BO-09(Lower part)	5.0	40	115 115 65 95 115	Not conducted Not conducted Not conducted Not conducted Not conducted
L/S 28 4 lines	BO-10(Upper part) BO-10(Lower part) BO-11(Upper part) BO-11(Lower part)	5.0	50	105 550 110 270	Conducted Not conducted Conducted Conducted
5 area 18 lines				2687	Not conducted 10 lines 1497m Conducted 8lines 1190m

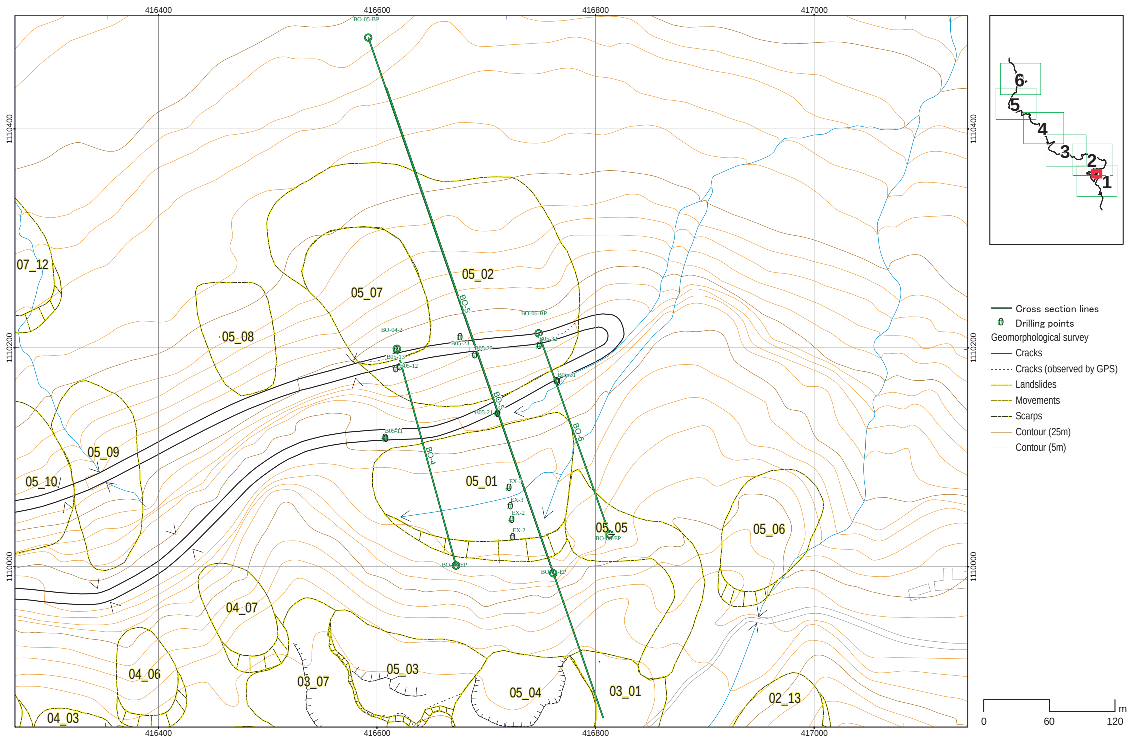


Figure 3.6.21 Location of Resistivity Exploration in L/S05

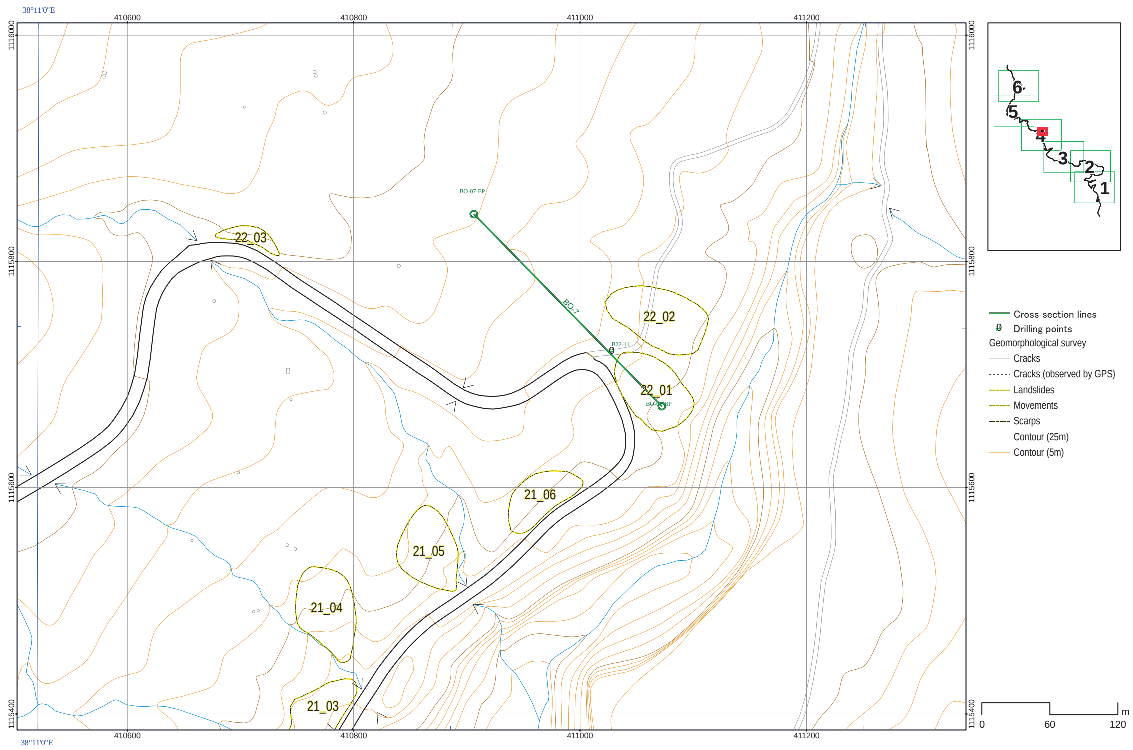


Figure 3.6.22 Location of Resistivity Exploration in L/S22

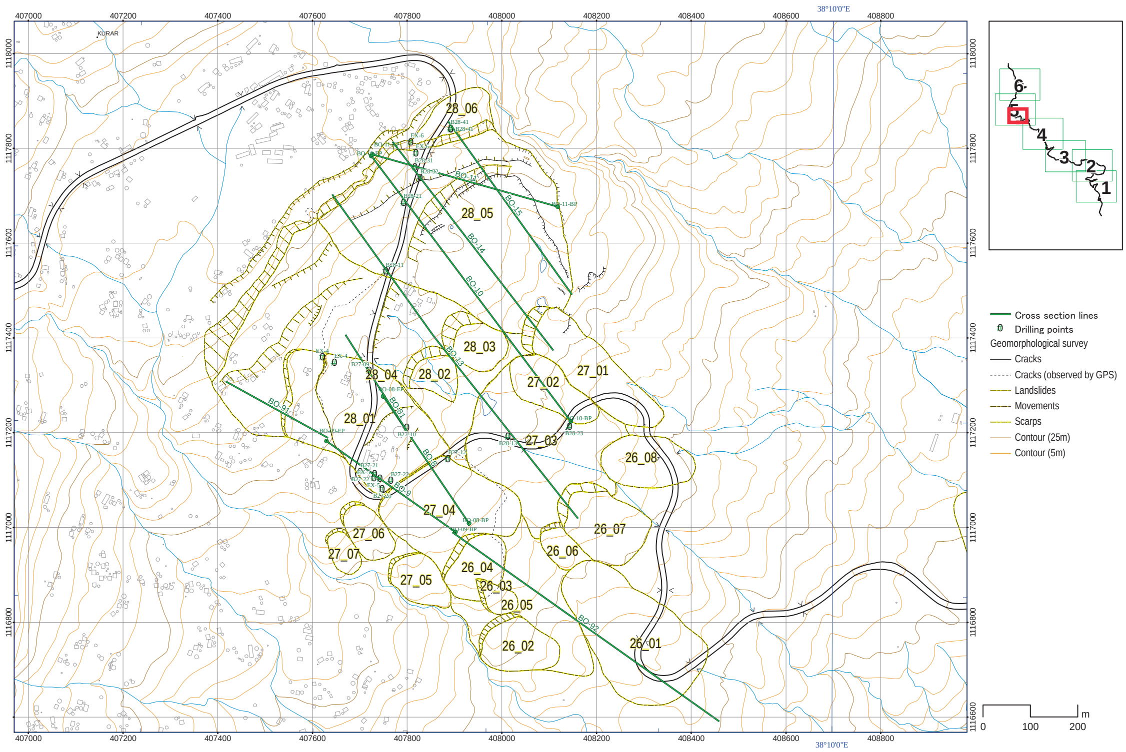


Figure 3.6.23 Location of Resistivity Exploration in L/S27 and L/S28

c. Exploration method

c.1 Principles

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.2 Equipment

- Super Sting R1/IP manufactured by Advanced Geosciences, Inc.
- Resolution: 30nV, input impedance: 20 MΩ

- Electrode bars made of stainless steel
- Electrode cable, battery

c.3 Measurement method

The method is manual measurement by 2-pole method. Table 3.6.6 shows a circuit where current I is passed through current electrodes C and C∞ to measure the voltage difference V between P and P∞. The apparent resistivity ρ can be obtained from the following equation using the potential theory of semi-infinite medium.

$\rho = 2\pi a \times V / I\ (\Omega m)$

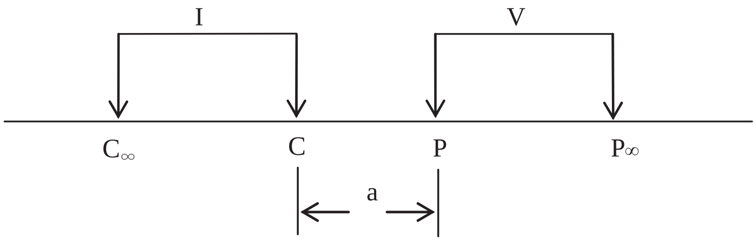


Figure 3.6.24 Electrode Arrays for 2-Pole Method

As shown in Figure 3.6.25, the apparent resistivity is measured with an earth resistivity meter from electrodes installed at predetermined intervals of measurement points through non-inductive cables and an electrode scanner.

However, we manually measured by moving and applying a pair of electrodes C1 and P1 along the survey lines instead of using an electrode scanner

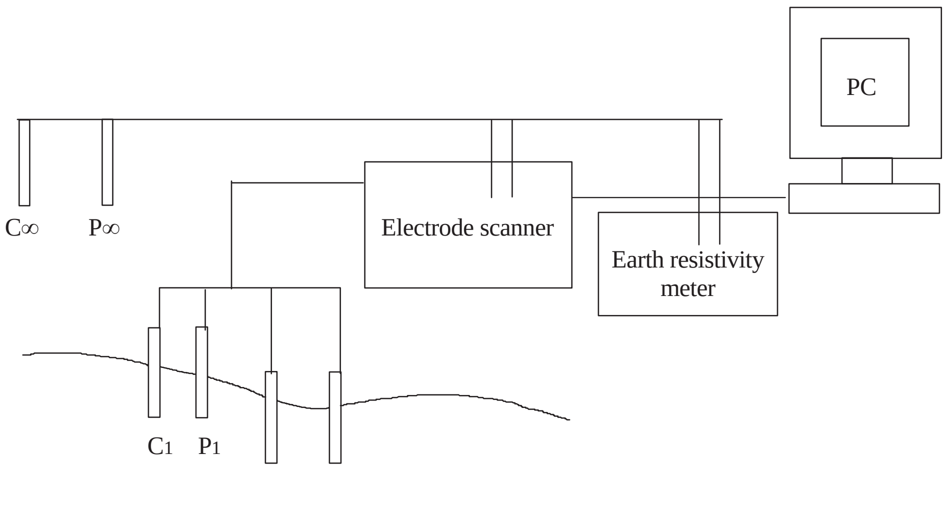


Figure 3.6.25 High-Density Electrical Resistivity Exploration Measuring Method

d. 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.

Figure 3.6.26 shows a resistivity inversion analysis flow. Procedures for analysis and calculation are as follows.

1) Create an initial model of resistivity distribution using the measured data.
2) Obtain a logical potential based on the resistivity distribution using the finite element method.
3) Calculate the difference (residual) between the measured potential and the logical potential.
4) Calculate the logical potential while modifying the initial model so that the residual becomes minimal.
5) Repeat steps 2) to 4) until the residual converges to gain a final resistivity model.

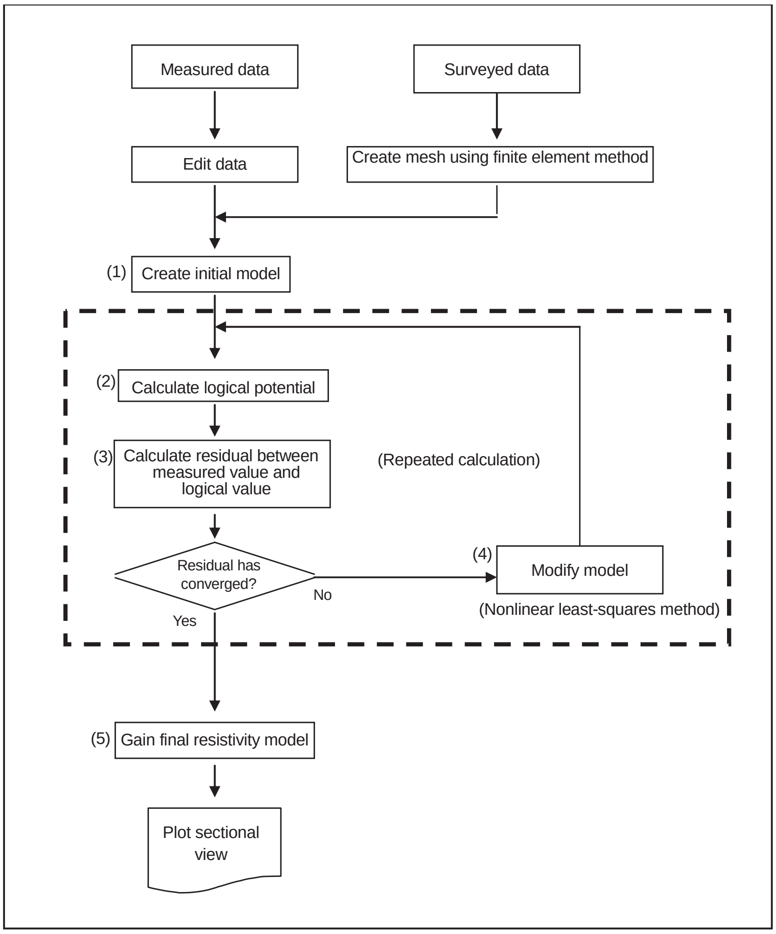


Figure 3.6.26 Resistivity Inversion Analysis Flow

e. Results of exploration

As an example of the results of the exploration, Illustrated below is a resistivity sectional view generated based on the values recorded along the traverse line BO-07 in L/S 22 in Figure 3.6.27

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

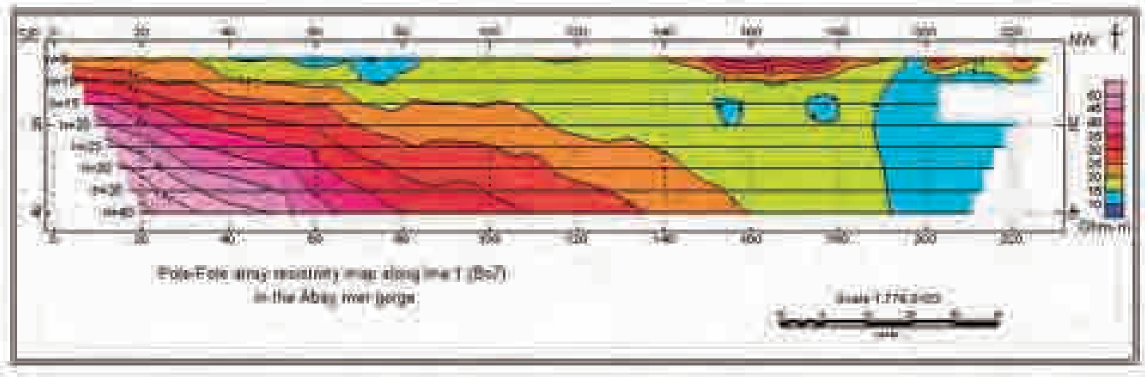


Figure 3.6.27 Resistivity Sectional View of BO-07

f. Summary and analysis of exploration results

f.1 Location L/S 05

f.1.1 Cross Section BO-04

The resistivity increases with the depth. The difference caused by strata and rock type, weathering degree, water-retaining condition may be reflected. In the slope by the road, (distance range: 15 – 35m) shows a domain of high resistivity, while in the slope behind the road where slope is more gradual shows a domain of low resistivity. It is estimated that low resistivity of the layer may be a result of large void ratio and water content in the talus deposit. On the other hand, in the domain of high resistivity, limestone and blocky basalt may exist.

Figure 3.6.28 shows the relationship between the rock types and resistivity. Compared to the limestone, basalt presents higher resistivity. However, limestone shares the same resistivity value with surface water. This makes it difficult to distinguish the limestone from surface water.

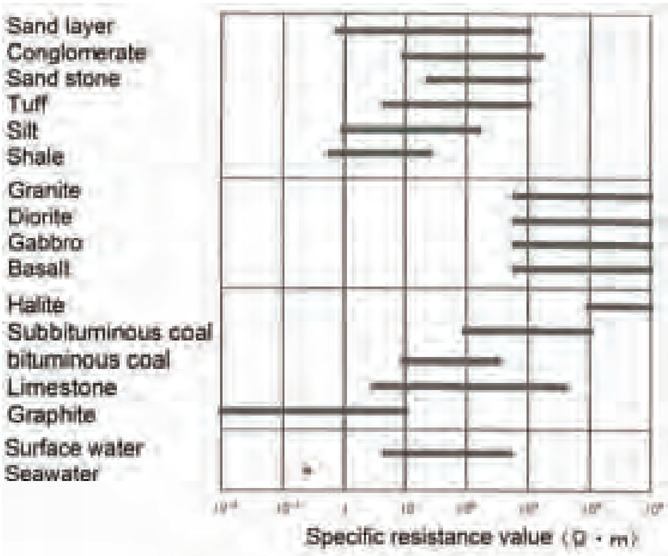


Figure 3.6.28 Related chart of rock and resistivity

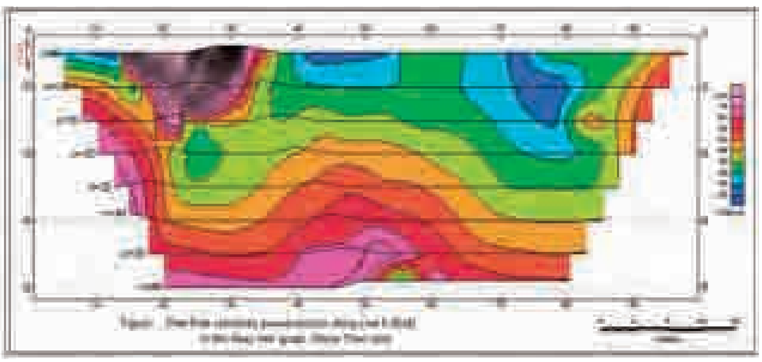


Figure 3.6.29 Resistivity Sectional View of BO-04

f.1.2 Cross Section BO-05(a)

Along this line, the resistivity is high by the road and the value decreases downward toward the upper slope. On the road side, limestone outcrops shallowly which also coincides with the resistivity value indicating that of limestone. Decrease in resistivity as the depth increases may a indicative of further weathering. On the other hand, continued low resistivity at the deep part of the upper slope, may suggest the existence of a water vein or rocks with low resistivity.

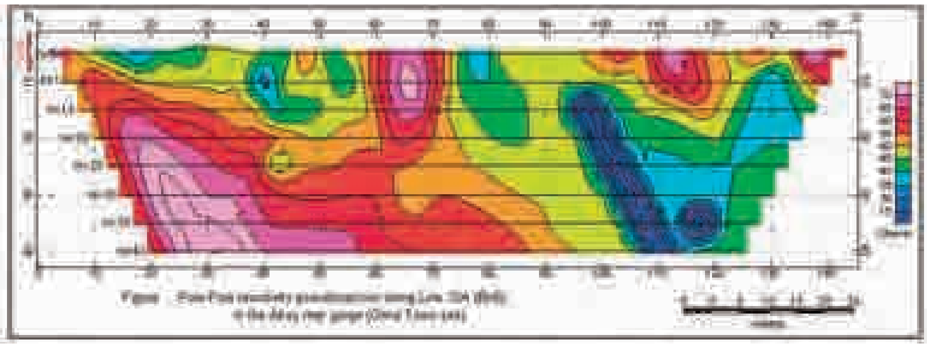


Figure 3.6.30 Resistivity Sectional View of BO-05(a)

f.1.3 Cross Section BO-05(b)

Along this line, the resistivity is high by the road side, and the value decreases toward the lower slope. It shows an opposite trend with BO-05(a) measuring line. The possible reason for this result may be due to 10m thick talus deposit in the lower slope. The low resistivity can be caused by high water-retaining degree or degree of saturation, and existence of groundwater in the talus deposits.

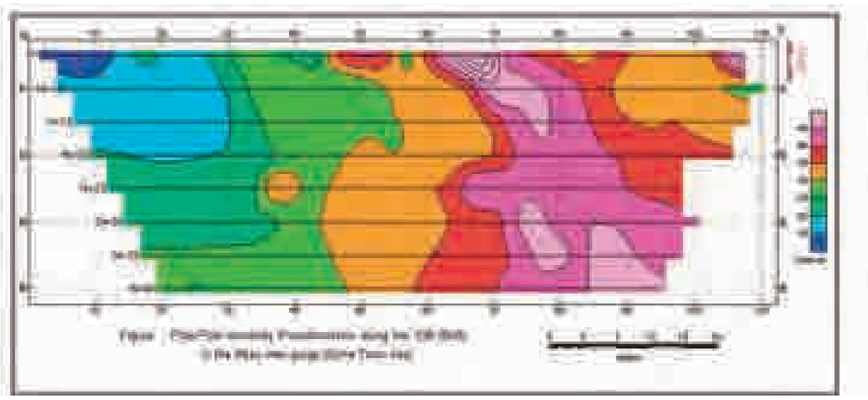


Figure 3.6.31 Resistivity Sectional View of BO-05(b)

f.1.4 Cross Section BO-06

In this measuring line, the resistivity values become larger with the depth. It shows a similar resistivity distribution as BO-05(a) measuring line generally, but a domain with high resistivity at the boundary between the road and cutting slope is confirmed. In the elastic wave exploration, a high velocity layer (larger than 3.0km/s) is detected at the same location, and the resistivity value corresponds to fresh limestone. In addition, at the gentle ground behind the cutting slope, it shows a low resistivity, which may be caused by surface water.

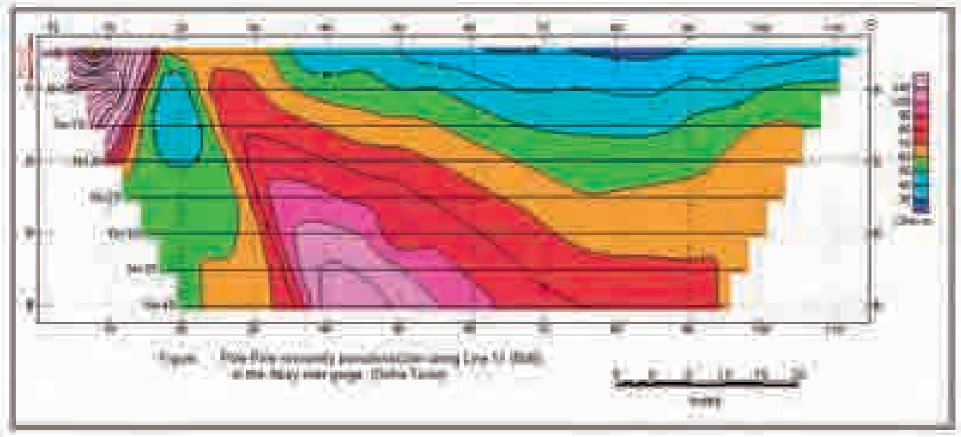


Figure 3.6.32 Resistivity Sectional View of BO-06

f.2 Location L/S 22

f.2.1 Cross Section BO-07

Along this line, the resistivity is high at the deep part of the lower slope, and it becomes smaller gradually toward surface. At the bore hole BH22-11, it is confirmed that refill layer and talus deposit are distributed at the ground surface, and sandstone is distributed near GL-18m. There is no groundwater here, so it can be estimated from the measured resistivity value that sandstone is distributed at the deep part, while talus deposit is distributed closer to the surface. Resistivity sectional view is shown in Figure 3.6.27.

f.3 Location L/S28

f.3.1 Cross Section BO-10

In this measuring line, the low resistivity zone and high resistivity zone are distributed regularly. Geologically, talus deposit consisting of limestone and sliding mass consisting of basalt are distributed thickly, and the groundwater level is low (GL-24.7m). The resistivity value is corresponding to limestone, but the regular changes may be caused by the degree of saturation or water content, and degree of compaction.

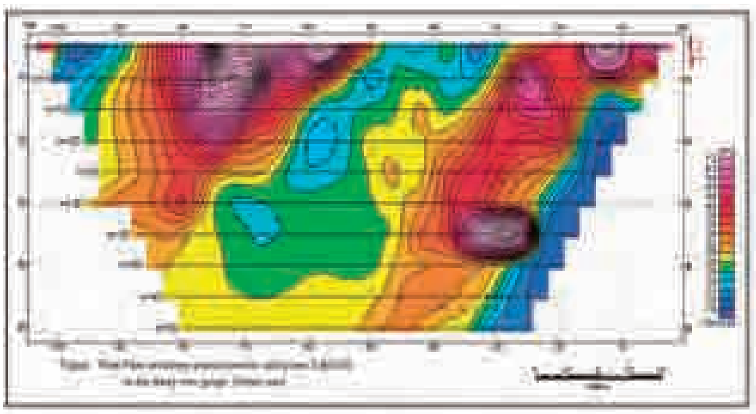


Figure 3.6.33 Resistivity Sectional View of BO-10

f.3.2 Cross Section BO-11(a)

Along this line, a high resistivity domain is distributed by the road at the distance range between 15 and 70m and in the deeper section of the ground. In addition, the same high resistivity value is distributed at the distance range between 90 and 100m. This part is corresponding to the thick talus deposit. On the other hand, a low resistivity zone is distributed at the distance range between 70 and 90m where the main scarp is located. The result may also be affected by the degree of compaction of the talus deposit.

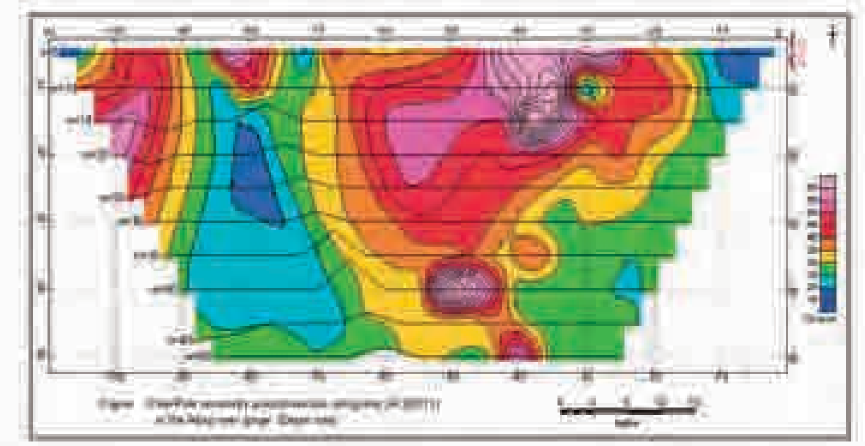


Figure 3.6.34 Resistivity Sectional View of BO-11(a)

f.3.3 Cross Section BO-11(b)

Along this measuring line, a bit high resistivity value is distributed by the road side (distance range: -160 to -270m) in the deep. At the road side, thick talus deposit is distributed, and it shows the same tendency as that along BO-11(a) line. On the other hand, a low resistivity domain shows a convex shape distribution at the distance range between -20m and -60m, between -110 and -170m. At this part, the elastic wave layer also shows a convex shape distribution. It is estimated that thin talus deposit is distributed in this part.

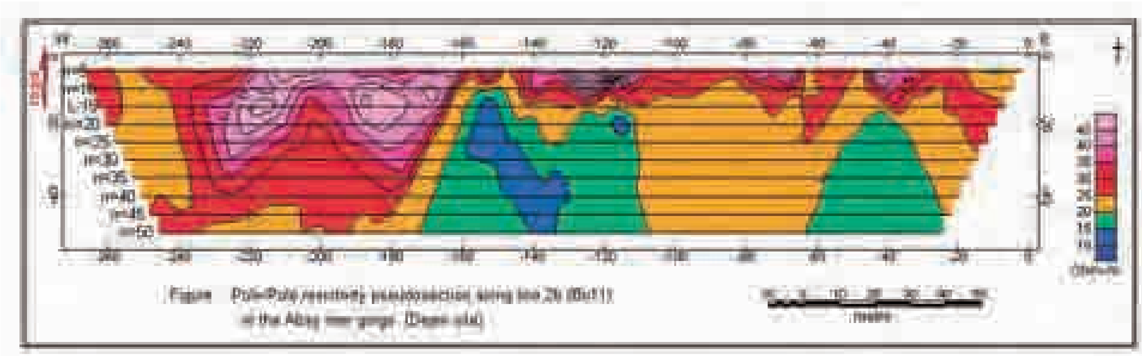


Figure 3.6.35 Resistivity Sectional View of BO-11(b)

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

a. Field drilling schedule for one borehole

An example of field drilling schedule for one borehole by two drilling parties is indicated in Figure 3.7.1. Though it depends on their drilling depth, it could take around one week.

Item No.	Contents of the filed drilling work	Day	1	2	3	4	5	6	7
1	Mobilization	0.50							
2	Site preparation	0.25							
3	Drilling rig set up (Depth 40m=10m/day)	0.25							
4	Core drilling by OD95mm diamond bit and standard intrusion test	3.00							
5	Casing OD88.9xID76.2 set up to bottom	0.5							
6	Installation of water level meter or extension meter	0.25							
7	Grouting and well head construction	0.5							
8	Machine checking and maintenance	0.25							
9	Loading & demobilization	0.5							
	Total 7 (6 working days+1holiday)	6							

Figure 3.7.1 Drilling schedule / two shifts / 1 well

b. Quantity and location

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 3.7.2-3.7.5.

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	

2010 drilling
2011 driiling

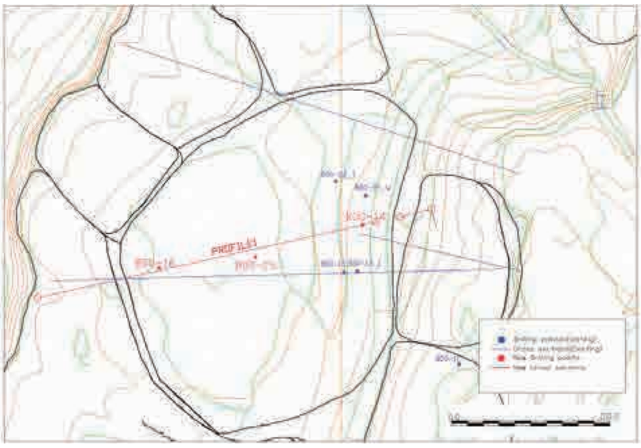


Figure 3.7.2 Survey locations in L/S00

Figure 3.7.3 Survey locations in L/S05

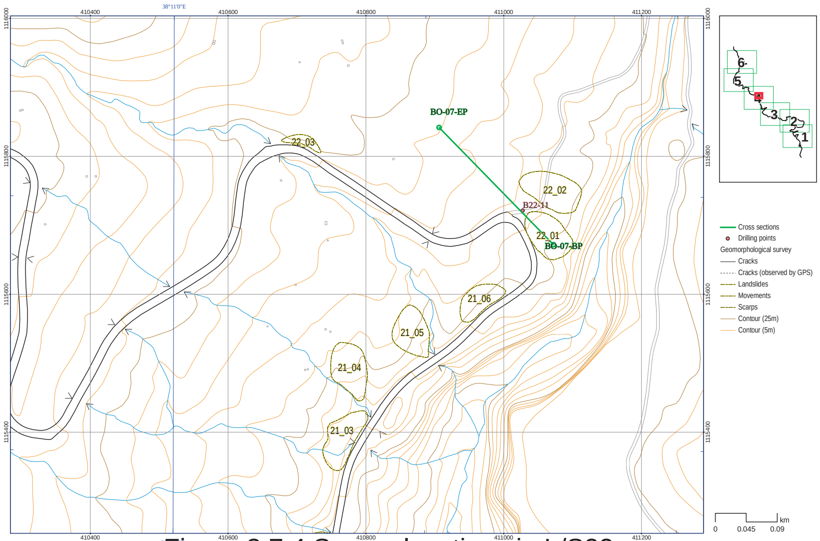


Figure 3.7.4 Survey locations in L/S22

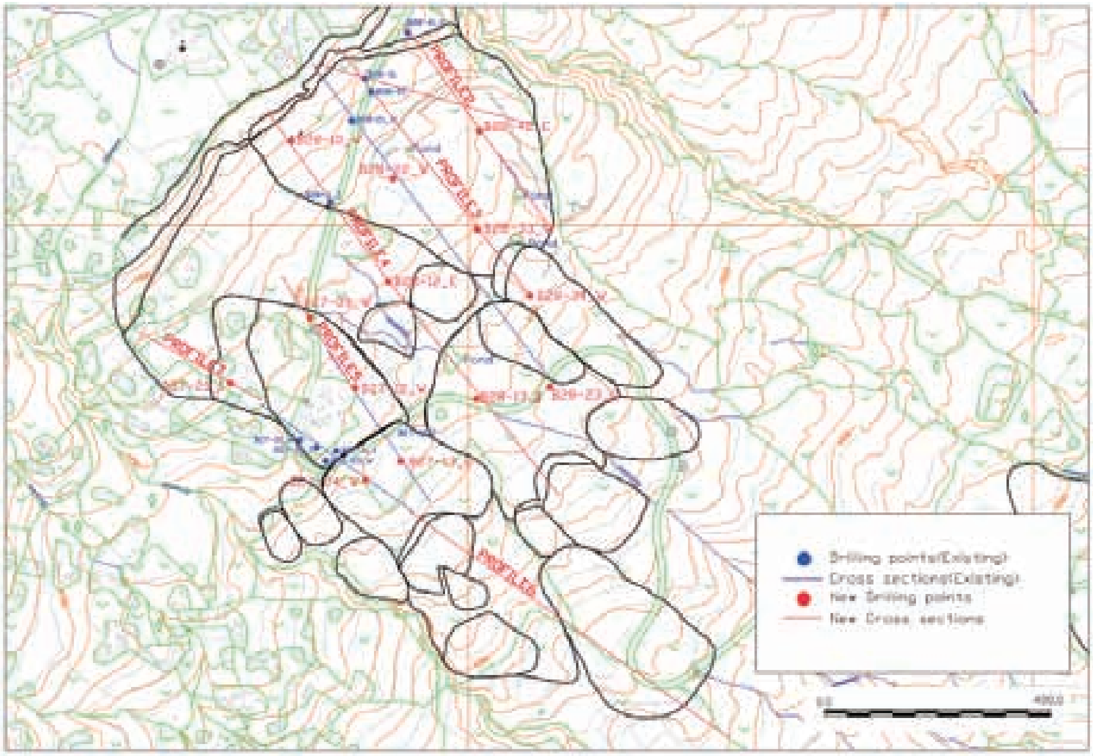


Figure 3.7.5 Survey locations in L/S27, L/S28

3.7.2 Core drilling

a. Drilling operation

Regarding core boring, twenty four boreholes were planned to be drilled in the Abay area. The drilling was carried out with a top head rotary wireline core drilling machine, named CRC (made in U.S.A.), and a TONE (made in Japan) with diamond bits of 96 mm diameter. The top head rotary wireline core drilling machine employed lubrication fluid and water circulation drilling method. Throughout all processes, both the fluid and water circulation drilling methods were employed with the CRC and TONE drilling rigs.

b. Classification of drilling machine

The drilling machines are generally classified into three categories which are a percussion type, a rotary type and a rotary percussion type. For usage of drilling machines in the Abay Gorge, the truck mounted top drive rotary drilling machines were selected. The drilling machines are owned by GSE.

c. Top drive rotary type drilling machine

For the Project, two kinds of top drive rotary drilling machine were provided by GSE Drilling Department for a wireline method. Two of them are all hydraulic functioned machines. One is US product CRC drilling machine and the other is TONE drilling machine which is made in Japan.

The component of all equipment is mounted on a four wheel drive truck. It is designed for gaining high efficiency and supporting convenient boring conditions. Also these have hydraulic accumulator systems and are powered by hydraulic motors. The primary functions of the drilling rig are controlled by centralized control panel that is located at the rear left of the rig. The rotary action and up and down vertical travel movement can be controlled by one place on the control panel.

The operation speed can easily be selected by the operator because the hydraulic oil system is controlled by nonstop variable revolving speed. For this reason, the drilling operation quickly keeps up with complex geology, also in collapsed or crushed zones.

Truck mounted drilling rig has superior portability and it can start boring immediately after arriving at a suitable place for core boring. In case of the Abay Gorge, it is important to secure the transporting road because the topographical condition and geological environment are quite severe for core boring field works.

d. Explanation of main machine components

d.1 The top-head drive type rotary drilling machine

As for the rotation part of top-head drive, hydraulic motor is directly connected to the swivel head and gives rotation power. The strength of the torque power is controlled by the mass of hydraulic oil pressure and oil volume. The hydraulic oil pump supplies power to the top-head assembly part. This power should support the top-drive part to make the rotations and up and down movements.

The top drive system is easy to control the rotation torque and speed which is necessary for sensitive core boring. The nonstop variable revolving control is one of the superior characters of the hydraulic oil system. It is equipped with suitable mechanism for core boring for complex geology.

d.2 Boring pump

A reciprocating type of piston-pump is used for boring pump. It is easy to control the discharge rate and high pressure conditions. The mechanism of the power transmission to the piston-pump is as follows;

By means of pinion gear on the crank shaft, and crank gear installed on crank shaft, the rotary power drives to the connecting rod which is installed eccentrically on the crank shaft. And then the rotary power is converted into reciprocating motion by the cross head provided at the end of the connecting rod. The cross head rod gives the reciprocating motion to the piston rod to which the piston is connected, and the piston that travel reciprocating, in being assisted by valves set in the valve box, suck and discharge out the fluid.

For the prevention of the pressure pulsation from discharged fluid, the air chamber is provided and for pressure adjustment of the fluid, safety valve is installed on the pump.

d.3 Diesel Engine

On diesel engines, air is drawn in, highly compressed in the combustion chamber and thereby heated. The right amount of fuel for the required power is injected into the highly compressed air. The fuel and air mixture is thus formed inside the combustion chamber.

The amount of diesel fuel injected into the combustion chamber is varied according to the engine power required: the air and fuel ratio of the resulting mixture is regulated by the mass of fuel used. As this process depends on the quality of the mixture, it is known as qualitative control.

The diesel engine requires a high-boiling, highly flammable fuel which ignites spontaneously when injected into the highly compressed, hot air. For this reason, the diesel engine is also known as the self-igniting engine.

e. Core sampling and method

About boring technology, there are lots of requests from geologists related to the precision of an investigation purpose. Improvement of the core recovery rate is regarded as the most important factor of geological investigation boring. In addition, it is important to grasp the geological data precisely and record the boring information and to submit the drilling report which is necessary for geological investigation analysis. There are core boring data such as geological conditions, change of stratums, situation of the clay which is related to landslides, situation of the groundwater seepages out and in, lost circulation zone, bit load, rotation speed, and core boring penetration rate.

e.1 Wireline core boring

Wireline core boring is a very effective and efficient method for improvement of boring penetration rate and core recovery rate. The mechanical equipment cost of the wireline system is a little bit expensive, but it can reduce the round trip times of the boring rods. Also, there are some additional merits for the suppression of disturbed borehole wall.

In addition, the elimination efficiency of cutting slime is good, because the clearance between borehole and wireline rod are quiet narrow. It can give the preferable annular velocity to lift up the cutting slime. Wireline core boring is a useful boring system which can prevent the troubles in the borehole, and there is a low incidence of accidents in the borehole. This is an effective method for the investigation boreholes and also observation holes.

The lithological core samples will provide suitable underground information that includes the continuative samples, landslide zones, and also slickensides such as clay. The wireline core boring method was applied and made investigation boreholes in the Abay area.

e.2 Diamond bit

Diamond bit was utilized for the core boring which is suitable for hard lithology in the Abay Gorge. Diamond is the hardest material, and it is installed in the surface of the diamond bit.

The comparatively large grains of diamond are selected for diamond bit. They are buried into the matrix on the bit surface. The casted bit is called a surface diamond bit. In addition, the diamond powder and the matrix are mixed up together and casted is called as impregnated bit. For the diamond characters, there are super-hard property, carbon crystal tight structures and strong anti-corrosion from the chemical products. Diamond bit is quiet useful for cutting the hard formation.

Diamonds used for the surface bit are mostly industrial products. Bort diamonds are widely used because of they are cheap and have a superior ability for cutting. The diamond grain size is around 1/10 to 1/60 carats, and diamond has a necessary sharp edge to cut the hard formation. Mostly synthetic diamonds are used for impregnated bits. For core boring in the Abay Gorge, surface diamond bit and impregnated bit are used according to the hardness of the formation and geological conditions.

e.3 Wireline core barrel

Wireline core barrels are run into the wide bore wireline rods. The large diameter pipe allows the inner tube to move up or down inside the rods. Wireline equipment allows to recover the inner tube and core it contains without having to withdraw the rod string. The standard form of the wireline core barrel is a stationary inner-tube or double-tube barrel. The standard wireline barrel may be converted to a triple-tube barrel by fitting the split liners and changing the core lifter and related parts, and the bit to suit the slightly smaller core size.

Wireline coring provides significant advantages in deep holes. Following items are advantages of the wireline core boring.

- Core is recovered without pulling the rods.
- Unstable formations are continually supported by the wireline rods.
- Improved stability and fewer trips.

e.4 Purpose of casing

Assume the underground geological conditions, casing programs are considered for the safety boring to achieve an intended boring purpose.

Installation of the casing pipe is performed by the boring purpose. At the Abay Gorge boring site, the temporary casing was used. The purpose is as follows.

- It was used to prevent borehole collapse.
- To prevent lost circulation zone and abnormal crushed zone.
- It was used to prevent vibration of the wireline tools.
- Temporary casing was used for centering pipe.
- It was used to settle the borehole-head, also its support base.
- It was used to decrease the frictional resistance between boring rods to borehole.

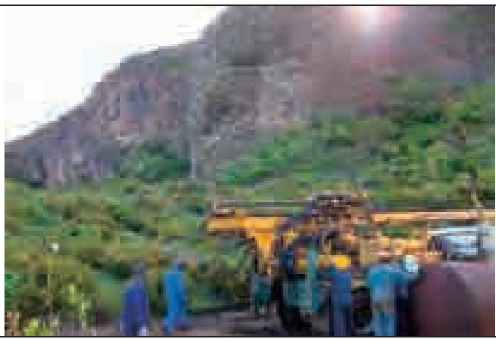
	
Site preparation	Mobilization
	
Core boring machine	Boring field works
	
Core inside of core-barrel	Clay core
	
Core box (claylike formation)	Demobilization

Photo 3.7.1 Field photograph for the core boring procedures

3.7.3 Device installation

Three kinds of observation boreholes were constructed in the Abay Gorge. They were borehole extensometer, inclinometer and water level meter.

a. Installation of the borehole extensometer (S & DL Borehole Extensometer: MODEL-4727)

Guidelines of the Installation Method for the Anchor Parts of Borehole Extensometer

i) Core boring bit size for the borehole extensometer borehole
ii) Understanding of the borehole condition
iii) Preparation works for the anchor parts of borehole extensometer
iv) Installation of the anchor parts of borehole extensometer up to bottom in the borehole
v) Backfilling works
vi) Cementing works for surrounding the borehole head

Detailed procedures on extensometer installation work

<u>i) Core boring bit size for the borehole extensometer borehole</u>

The core boring bit size, basically decided upon, is φ96mm in the Abay area. The φ96mm diameter of the borehole bit size or more which give more efficient works are recommendable for the observation borehole. If there is a collapsed zone in the borehole, install temporary protective casing up to cover that zone. At this time, the end of the protective casing pipe is attached with diamond- shoe which can cut the collapsed rock and disturbed formation.

<u>ii) Understanding of the borehole condition</u>

Before settling the drilling rig and also during boring time, should consider the ground conditions, formation conditions in the borehole, collapsed and weathered structures, natural water level and other special conditions.

<u>iii) Preparation works for the anchor part of borehole extensometer</u>

Polyvinyl tube pipe (3/4") diameter and pipe length is required for the total boring depth. Plastic rope for lowering the metal anchor which is part of the borehole extensometer (recommended plastic rope diameter is 8 to 10 mm, and the length required is for the total boring depth plus excess 5 m).

Supporting nylon rope fixing to the coated wire rope by fragile polyvinyl which affects the corrosion protection (diameter 4 mm and is required for total boring depth plus excess 5 m). Tools and working materials (plastic tape, cutter knife, tape measure 50 m or more).

<u>iv) Installation of the anchor parts of borehole extensometer at the bottom of the borehole</u>

a) Connect the iron anchor (10 kg) part of the borehole extensometer to the fragile polyvinyl coated wire rope. Screw up the thread to a suitable condition.

b) Fix the polyvinyl rope (diameter 8 to 10 mm) to the anchor part of the borehole extensometer. (Purposes of this procedure is protection for the fragile nylon-coated wire)

c) Through the nylon-coated wire into polyvinyl tube (3/4"diameter) down to the anchor part from the top. The length of polyvinyl tube pipe is required for the total boring depth.

d) Lower the metal anchor of the borehole extensometer slowly using the plastic rope. At the same time, the polyvinyl tube is lowered with the same plastic rope.

e) Land the anchor on the bottom of the borehole. And the polyvinyl tube (3/4") and nylon-coated wire are raised to the top of the borehole.

f) Fix the nylon-coated wire to the polyvinyl tube (3/4"). At this situation, steel pipe and nylon-coated wire might enable individual movement.

g) Withdraw the protective steel pipe from the bottom to the ground.

h) Connect with the nylon-coated wire to the plastic rope (diameter 4 mm). Knots in the nylon-coated wire and plastic rope should be made smaller size to pass through the polyvinyl tube (3/4").

i) Withdraw the polyvinyl tube (3/4") from the bottom of the borehole

j) Separate the plastic rope fixed to the nylon-coated wire (diameter 4 mm) from this wire. The wire is left in the ground.

k) The nylon-coated wire is fixed in the ground.

l) Next step is refilling the annulus part of the borehole.

v) Backfilling works

Consider to installation depth of the anchor, filling volume of the annulus part, and filling conditions. The annulus part which is the gap between borehole and nylon-coated wire in the borehole is filled by reddish quartz sand grains and filled up to the surface. During the filling process, be careful not to plug the borehole with the quartz sand grains.

vi) Cementing work for surrounding the borehole head

Prepare the cement mixing materials such as below.

- Portland cement produced in Ethiopia (price is about 200birr per 50Kg/sack).
- Crushed rock chips, product of Ethiopia (fine fragments of basalt; price is about 100birr per 50Kg/sack)
- Uniform reddish quartz sand.
- Board materials for the borehole head mold casing (if any)
- Shovel, bucket, trowel for making cement mixture.
- PVC short pipe which supports borehole head construction (diameter is about 100mm and length is 30cm long)

Place the suitable amount of cement mixture which is borehole tempered cement with crusher into the wooden mold.

	
Bottom anchor parts	Connect anchor to nylon rope
	
Stretch polyvinyl tube	Start installation works
	
Lowering anchor parts with rope	Check condition of anchor parts
	
Continue installation works	Final condition after filling work

Photo 3.7.2 Field photograph for the borehole extensometer

b. Installation of the borehole inclinometer (Borehole inclinometer: MODEL-4440)

Guidelines for Installation Method to the observation borehole of Borehole Inclinometer

i) Core boring bit size for the borehole extensometer borehole
ii) Understanding of the borehole conditions

iii) Procurement and preparatory works for necessities (preparedness)
iv) Management issues for boring and installation of the special casing pipe
v) Assembling the special casing pipe and install it into the borehole
vi) Backfilling works
vii) Cementing works for surrounding borehole head

Detail procedures on extensometer installation works

i) Core boring bit size for the borehole extensometer borehole

Basically settled on the core boring bit size is φ96mm in the Abay area. The φ96mm diameter of the borehole bit size or more which give more efficient works are recommendable for the observation borehole. If there is a collapse in the borehole, install temporary protective casing pipes up to cover the collapsed zone. At this time, the end of the protective casing pipe is attached with diamond-shoe which can cut the collapsed rock chips and disturbed formation.

ii) Understanding of the borehole conditions

Before settling the drilling rig also during boring time, should consider the underground geological conditions, such as fisher in borehole, collapse, weathered formation structures, fluctuations of groundwater and other special geological conditions.

iii) Procurement and preparatory works for necessities (preparedness)

Table 3.7.2 Material list for preparedness

Materials		Remarks
Installation materials for the observation borehole	Special casing pipe (Guide pipe)	OYO product is φ50mm and Length 3m.
	Rivet	Select the aluminum rivet or stainless steel rivet. According to the material of special casing pipe. Case of Abay is the aluminum rivet.
	Casing head cap	To prevent the contamination of unnecessary matters from the ground surface. It should be locked with key if necessary.
	Bottom cap	Contamination of unnecessary matters from the bottom hole.
	Tape sealer	Prevent water entering through the casing coupler edge and rivet joints.
	Butyl-rubber tape	Fixes on the tape sealer.
	Protection tape (anticorrosive)	Prevention for the tape peeling and breaking.
	Vinyl tape	There are many ways of application. Prepare it enough volume.
Setting materials	Water level meter	Groundwater level measure equipment.
	Hand riveter	For riveting
	Saw	It is classified according to the special casing materials. It should be prepared some spare blades.
	Cutter	Cut for the materials such as tapes and strings
Fillers	Uniformed quartz sand	It can be obtained at Goha Tsiyon in the Abay Gorge.
	Cement material	Normal Portland Cement.
	Water	For cement mixture, use river water or spring water from the valleys. If required for filling water inside of the special casing pipe, use clean water pouring into the pipe (compensated by buoyancy).

iv) Management issues for boring and installation of the special casing pipe

a) Core boring

Throughout the core boring, should take careful action not to create a borehole deviation. It is considered that the tolerance of hole deviation is known as typically 100 m in vertical hole per 0.5 ~ 1 degree. If severe deviation was caused inside of the borehole, it might be impossible to set up special casing pipe down to the bottom. Select and using the suitable boring diamond bits, and adjust the rotation speed also control the weight on bit for safety drilling.

Check the existence of caving during borehole boring. If the face is caving in, record the depth and geological condition. Check the geological formation for whether it is a lost circulation zone or groundwater is gushing into the borehole. If there is a change, record the boring depth and geological condition. It will be valuable information for casing installation works. Also check the borehole condition for whether there is a collapse or not. If there is a collapse inside the borehole, install the temporary protective casing pipe for protecting wall. Always check the pressure indicator which is hydraulic mud/water pump. In the landslide area, the mud/water pump pressure may increase effected by crush down clay. Check the water level fluctuations in the borehole. The water levels may be fluctuated by rock fissures and cracks in the water way vicinity of the landslides area.

Investigate the possibility of landslide movements. Fractured zones and the periphery of landslide zones are often observed in soft formations or clay.

b) Installation of the special casing pipe

If there are collapses in the borehole, use the protective casing pipe to prevent the borehole wall collapsing. This should make the condition inside the borehole safe. Before inserting the special casing pipe, check the accumulation of cutting slime at the bottom. If there is much slime, the special casing pipe cannot be inserted down to the bottom. Calculate the total length of drilling depth and estimate the special casing length. After confirming all conditions, start installation of the special casing pipe by lowering it to the bottom of the borehole.

Table 3.7.3 Spare parts for the aluminum coat casing

Item	Remarks	Parts No.
Coat casing 47mm dia.	φ47mm x 3m 1.9Kg/3m	04483-0508
Coupling for coat casing 47mm dia.	φ51mm x 30cm	04483-0507
Casing cap	For 47mm dia. Casing	04423-4012
Cap lock pin	For 47mm dia. Casing	04423-4010
Bottom cap	For 47mm dia. Casing	04423-4011
Aluminum rivet	TAP-435	16901-1011
Hand tool for riveting	7595	16901-7510

v) Assembling the special casing pipe and install it into borehole

a) Assemble special casing on the ground

Put the special casing pipe into the coupling joints firmly, and make sure that the rivet holes match with the guide tube hole. If it does not conform to the couples, then remake each hole to adjust the rivet holes.

b) Riveting methods

There are two ways of riveting; one is cross-riveting and the other is orbital-riveting. Cross riveting is recommendable for the special casing pipe, to prevent the gap between each rivet hole, also perpendicular to connect each to the special casing pipe.

c) Using tape sealer (waterproof material)

Fill the space gap between guide casing pipe, coupling and groove on the pipe.

d) Butyl-rubber tape

Butyl-rubber tape covers the tape sealer (waterproof material), and also to prevent peeling to the tape sealer and gaps. Secure to prevent the water infiltration from the borehole water pressure.

e) Protective tape (anti-corrosion type)

Protective tapes prevent peeling both the tape sealer and butyl-rubber tape. And it protects the damage which is caused by friction between guide pipe and borehole wall.

f) Attach the bottom cap to the bottom of special casing on the first pipe.

One by one connect the special casing pipes and insert it into the borehole. It is better to connect to one of two special casing pipes on the ground in order to improve the efficiency of installation works.

g) Insertion of the casing pipe

The special casing pipe is inserted into the natural water level. When the buoyancy affects the casing pipe raise it up toward the ground surface, pour the pure water into the special casing pipe by balancing the buoyancy and weight of special casing pipes.

h) Adjust the key of special casing pipe toward to the axis of landslide face

Slowly install the special casing pipes into the borehole, and pay attention to adjust the direction of landslide movement. If additional adjustment is required, slowly turn the chain of casing pipes which are floating condition apart from the borehole bottom, and after that settle the casing pipes without twisting. If you use a pipe wrench, it will affect the special casing pipes by deforming it. The direction of landslide movement does not always show the direction of maximum landslide slope. It is important to mark the key which shows the main direction of movement of the landslide on the ground in advance.

vi) Backfilling works

The annulus part which is the gap between borehole and special casing pipe in the borehole is filled by the uniformed reddish quartz sand and filled up to the surface.

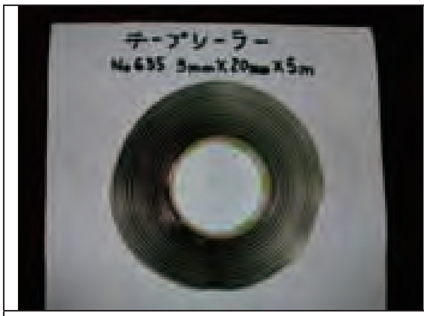
During the filling process, be careful not to plug at the halfway in the borehole with filling quartz sand grains.

vii) Cementing works for surrounding borehole head

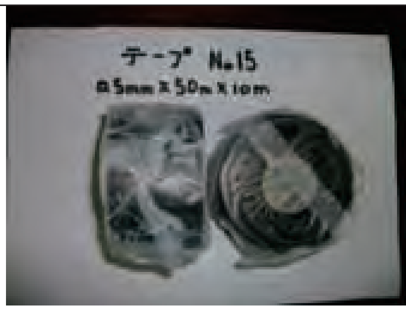
Prepare the cement mixing materials such as below.

- Portland cement produced by Ethiopia (price is about 200birr per 50Kg/sack)
- Crushed rock chips, product of Ethiopia (fine fragments of basalt; price is about 100birr per 50Kg/sack)
- Uniform reddish quartz sand
- Board materials for making the mold case (if any)
- Shovel, bucket, trowel for making cement mixture
- PVC short pipe which supports borehole head construction (diameter is about 100mm and length is 30cm long)

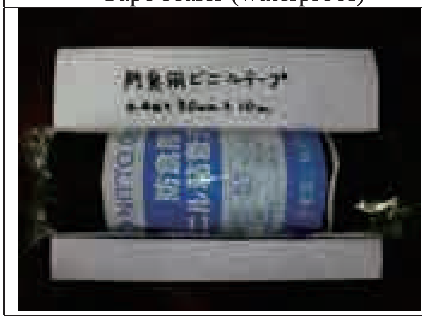
Place the suitable amount of cement mixture which is borehole tempered cement with crusher into the wooden mold.



Tape sealer (waterproof)



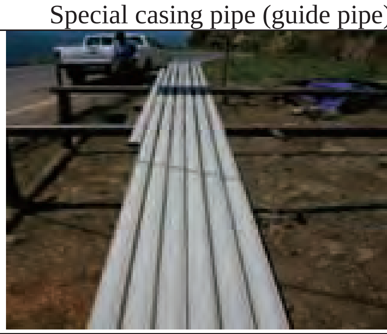
Butyl tape (soft rubber)



Protection tape (anti-corrosion)

Special casing pipe (guide pipe)

Connect two to one



Total length of casing pipe

Photo 3.7.3 Field photograph for the inclinometer (1)

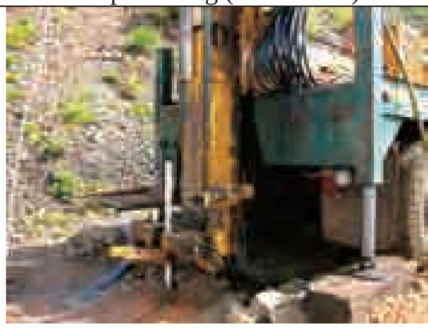
	
Riveting (usage of riveter)	Tape sealing (three kinds)
	
Backfilling (sand packing)	Have installed special casing
	
Cement mixing for surface	Set up the guide protector

Photo 3.7.4 Field photograph for the inclinometer (2)

c. Installation of the water level meter (Water level meter: MODEL-4640)

Guidelines on construction of the water level observation borehole.

i） Core boring bit size for the water level observation borehole
ii） Understanding of the borehole conditions
iii） Procurement and preparatory works for necessities (preparedness)
iv） Management issues for drilling and casing installation
v） Backfilling works
vi） Cementing works for surrounding borehole head

Detailed procedures on installation works of observation borehole

<u>i) Core boring bit size for the water level observation borehole.</u>

Basically settled on the core boring bit size is φ96mm in the Abay area. The φ96mm diameter of the borehole bit size or more which give more efficient works are recommended for the observation borehole. If there is a collapse in the borehole, install temporary protective casing pipes to cover the collapsed zone. At this time, the end of the protective casing pipe is attached with diamond-shoe which can cut the collapsed rock chips and disturbed formation.

ii) Understanding of the borehole conditions

Before settling the drilling rig also during boring time, should consider the underground geological conditions, such as fisher in borehole, collapse, weathered formation structures, fluctuations of groundwater and other special geological conditions.

iii) Procurement and preparatory works for necessities (preparedness)

Table 3.7.4 Material list for preparedness

<table>
<tr><th colspan="2">Materials</th><th>Remarks</th></tr>
<tr><td rowspan="6">Installation materials for observation hole for water level</td><td>PVC casing pipe</td><td>Ethiopian products Length=6m, ODφ50mm</td></tr>
<tr><td>PVC coupling socket</td><td>Make coupling socket according to PVC casing pipe.</td></tr>
<tr><td>Casing cap</td><td>To prevent the contamination of unnecessary matters from the ground surface. It should be locked with key if necessary.</td></tr>
<tr><td>Protect filter against sand inflow into borehole</td><td>Wind up the piece of cloth around PVC casing pipe after making strainer on the casing pipe</td></tr>
<tr><td>PVC Solvent</td><td>Use solvent to connect each PVC casing pipes.</td></tr>
<tr><td>Vinyl tape wide size</td><td>Reinforcement of the socket joint part and some other usages. Prepare enough amounts.</td></tr>
<tr><td rowspan="4">Materials</td><td>Water level meter</td><td>Measure the fluctuation of groundwater level.</td></tr>
<tr><td>Electric drill</td><td>Use it for strainer hole making.</td></tr>
<tr><td>Hand saw</td><td>For cutting materials. It might have enough strength. A spare blade is necessary.</td></tr>
<tr><td>Cutter</td><td>There are many usages such as cutting or processing of materials.</td></tr>
<tr><td rowspan="3">Materials</td><td>Uniformed red quartz sand</td><td>It can be obtained at Goha Tsiyon in the Abay Gorge.</td></tr>
<tr><td>Cement</td><td>Ethiopian normal Portland cement</td></tr>
<tr><td>Water</td><td>As making cement mixture, use river water or spring water from the valleys.</td></tr>
</table>

[Regarding the processes of PVC casing pipe]

a) The strainer pipe processing on the PVC pipe

Use electric drill equipment to make a round hole with a diameter of about φ3-5mm on the PVC pipe (φ 50mm). Make typical strainer pipe. The slit holes are around 5 to 10 places per one PVC casing pipe (6m). To observe the fluctuation of the water level precisely, should vary with suitable number of holes concerned for the geological conditions.

b) Filter processing for prevention of sand inflow through the strainer

For the surface treatment of PVC strainer pipe, process the filter to prevent the sand inflow. Use mesh-shaped nylon fiber for the filtering material. Wind up the long mesh-style nylon fiber around the surface of strainer PVC pipe. For fixing of the nylon fiber, wide plastic tape is more efficient.

c) Connect the short PVC pipe (about 30cm long) which makes original PVC coupling for

PVC casing pipe. Use the commercial adhesive for the plaster of PVC solvent.

After adhesive dried (about 10 minutes), wind the plastic tape onto the PVC pipe for reinforcement of the connection part. For the precedent of practical borehole record (Abay borehole number B05-31), installed the PVC strainer pipe down to 35m.The installation process using the Ethiopia made PVC pipe did not have any problems.

iv) Management issues for and casing installation

a) Core boring

Throughout the boring, should be careful not to create a borehole deviation. Select the suitable diamond bit and adjust the rotation speed and weight on bit for efficient core drilling.

Check the geological formation whether lost circulation zone or outputting water into the borehole. If there is a change, record the drilling depth and water volume. It will be valuable information for backfilling works. Check whether the borehole has a collapse or not. If there is a collapse inside of the borehole, install a temporary protective casing pipe in the borehole. Always check the hydraulic water pump pressure. In the landslide area, the water pump pressure may increase, affected by the crush down clay. Check the water level fluctuations in the borehole. The water levels may be fluctuated by the formation of fractures and cracks along the waterway vicinity of the landslide areas.

Investigate the possibility of landslide movements. The formation of fractured zone and periphery of landslide zone are often observed soft formation or clay. There is the possibility of blockages in this type of geological formation, therefore careful attention should be paid during core drilling.

b) Installation of PVC casing pipe into borehole.

Confirm the condition of slime stimulation at the borehole bottom before installing the PVC casing pipe. When there is a lot of slime at the bottom, PVC casing pipe cannot install up to end depth.

Calculate the total drilling depth and length of the PVC casing pipes, and after checking it start installation works of casing pipe. If there is a collapse inside the borehole, use protective casing pipe for borehole wall collapse. This maintains the safety of the borehole by inserting a PVC casing pipe down to the bottom.

v) Backfilling works

The annulus part which is the gap between borehole and special casing pipe in the borehole is filled by the uniform reddish quartz sand and filled up to the surface. During the filling process, be careful not to make a plugging halfway in the borehole with filling sand.

vi) Cementing works for surrounding borehole head

Prepare the cement mixing materials such as below.

- Portland cement produced by Ethiopia (price is about 200birr per 50Kg/sack, August 2010)
- Crushed rock chips, product of Ethiopia (fine fragments of basalt; price is about

100birr per 50Kg/sack).

- Uniform reddish quartz sand.
- Board materials for making a mold case (if any)
- Shovel, bucket, trowel for making cement mixture.
- PVC short pipe which supports borehole head construction (diameter is about 100mm and length is 30cm long)

	
Mobilization	Set up the boring rig and drilling
	
Make strainer and connection	Joint protection with wide tape
	
Pasting works with PVC solvent	Installation of the casing pipe
	
Make the cement mixture	Construction of the well head

Photo 3.7.5 Field photograph for the water level meter

3.7.4 Drilling results

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

Table 3.7.5 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

The quantity of the original plan of the core drilling in 2010 and 2011 was total 24 sites/695m and 20 sites/635m extension length respectively. However, the actual quantity in 2010 was made an adjustment depending on the site condition. The number of the actual core drilling in 2010 was total 22 sites and 678 m extension length.

The drillings in 2011 are mainly done outside road where are in the middle of fields or the top of slopes to identify the topography and the volume of the landslide blocks. The construction of temporary access roads is therefore necessary to contact the proposed drilling site, using a dozer. The number of the actual core drilling in 2011 was total 7 sites and 240 m extension length where the temporary access road is not needed. The remaining drilling sites where the temporary access road is needed are supposed to be implemented by GSE themselves since November 2011.

The results of drillings are summarized in drilling logs in Appendix. The interpretation such as geological cross section and slip surface is discussed in Chapter 4.4.

3.8 Rockfall Survey/Debris Flow Survey

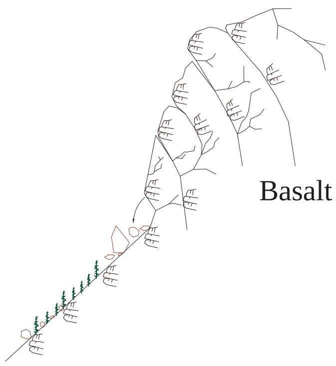
3.8.1 Rockfall Survey

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. The characteristics are described as follows.

A basaltic slope has a large-scale of detached rocks, which characteristically accompanies rock topple. The starting point areas are characterized as vertical slopes, many detached rocks with a few meters in diameters are scattered at the foot of the slopes. Joints and cracks develop on the basaltic rock, and some are exfoliated or detached in cubic forms as weathering progresses. This tendency is particularly observed in the cut slopes along roadsides.



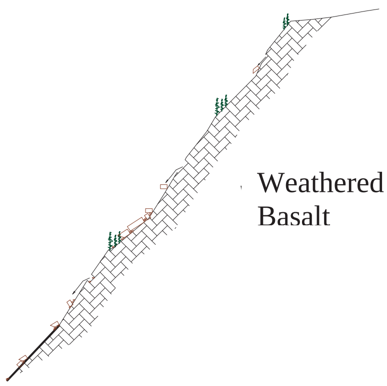
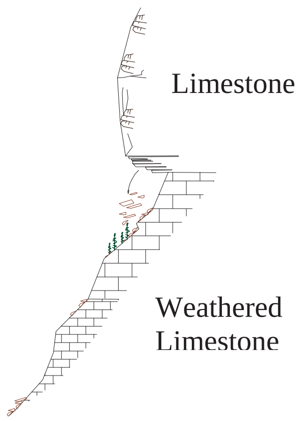


Figure 3.8.1 Rockfall due to rock failure (toppling) Figure 3.8.2 Rockfall due to weathered basalt fracture

Weathering is particularly noticeable on slopes mainly consisting of limestone or gypsum. In such a slope, un-weathered and hard layers of outcrops overhang as their fragments. Undulation is observed on the outcrops, and the upper part where rock blocks having exfoliated become more unstable. On the cut slope, rocks exfoliate as in cubic forms from alternate layers. In many cut slopes, rocks have weathered into debris.



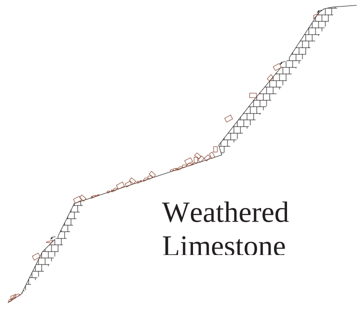


Figure 3.8.3 Rockfall due to exfoliation of limestone Figure 3.8.4 Rockfall due to exfoliation of weathered limestone

Slopes comprised mainly of sandstone are distributed around the Abay Gorge, where many rockfalls are occurring. The scale of rockfall is also huge. Large fallen rocks are distributed all along the lower part.

Geomorphologically, the upper part which is tight sandstone stands vertically, while the lower part consists of weathered sandstone with vegetation. Weathering has progressed on the cut slope which has partially weathered into debris.

For the upper part, rockfall pattern is mainly exfoliation type rockfall in which unstable loose rocks exfoliate from the slope surface and free-fall under gravity.

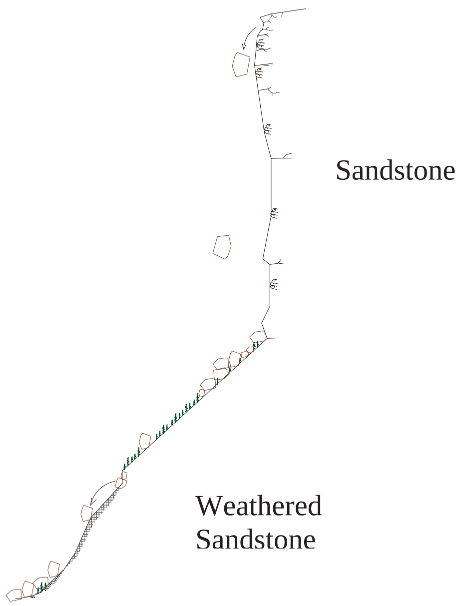


Figure 3.8.5 Exfoliation rockfall and fall-off rockfall of sandstone and weathered sandstone

On the other hand, “ fall-off type rockfall” where unstable rock blocks in the cut slope fall off was observed on the lower part. The diameter of most detached rocks ranges from 1m to 3m and the rockfall hazard locations are widely-distributed.

Fallen rocks are also observed on slopes consisting mainly of talus deposits.

These rocks mainly come from the loose rocks exfoliated from the upper part surface. On the cut slope, surface water causes erosion around each detached rock, which eventually loses its stability.

The talus slopes have moderate gradient with low height; however, further erosion could raise the rockfall potential.

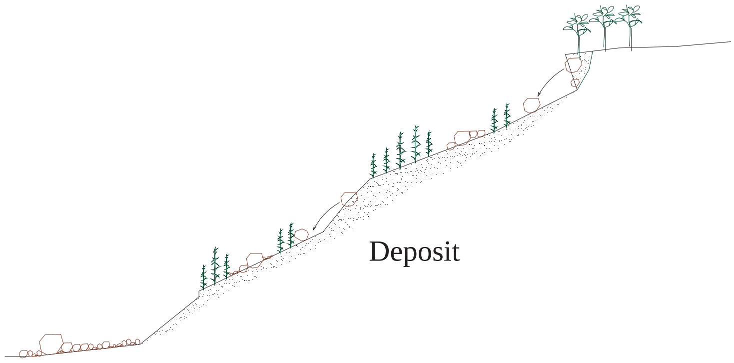


Figure 3.8.6 Fall-off rockfall of talus deposits

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).

RF16-1 (ST.16+680 － ST.18+860) is the largest, extending approximately 2.2 km in width, and the maximum slope height reaches 100 m or higher. Many rockfalls have occurred in this section in the past, where a few meters of fallen rocks are now scattered about along the road. The section RF19-1 (ST.19+900 – ST.20+520) also shows similar rockfall characteristics.

Weathering has progressed on most of the cut slopes along the road where cracks have developed and layers. Further weathering will decrease the stability of the cut slopes, resulting in an increase in rockfall disasters.

Table 3.8.1 Rockfall Hazard in each segment

RockFall	Station.No.	Slope Type	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.			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 topographic 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 topographic 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 topographic 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 topographic 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 topographic 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 topographic 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.

During the debris flow survey in the Project, multiple major tributaries for targets located along the 40-kilometer section of road connecting Goha Tsiyon and Dejen have been classified.   On those selected sites, channel bed gradients, channel widths, and conditions of sediment runoff were observed by interpreting topographic maps and satellite photographs.

Because there are more than 40 streams within the 40-kilometer section and it is impossible to survey details of all the channels, the most predominant ones were selected.

Recent debris flows were estimated based on the distributions of debris and sediment deposited in the crossing drainage works installed under the roads.

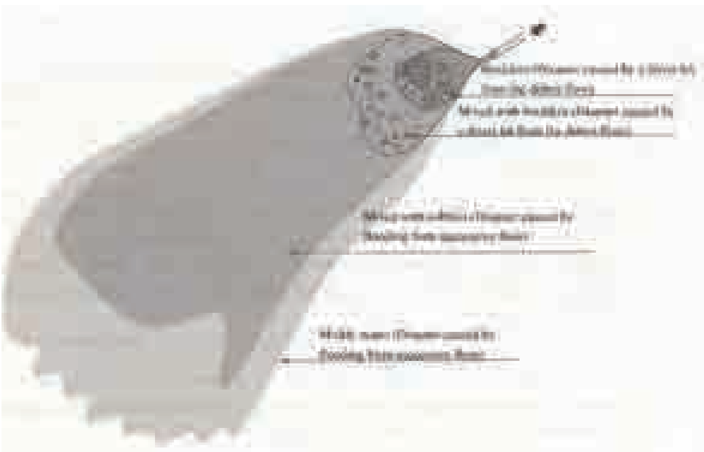


Figure 3.8.7 Conceptual diagram of debris flow flooding

Various channels exist along the 40-kilometer line such as small channels formed by development of gullies, and medium- to large-sized channels that hold large rock blocks. Small channels tend to be distributed in alluvial fans and along plateau base covered with talus deposits while medium to large-sized channels often flow down from upstream of the plateau and have waterfalls. Drainage network is the dendritic structure or parallel structure and they flow into the Abay Gorge.

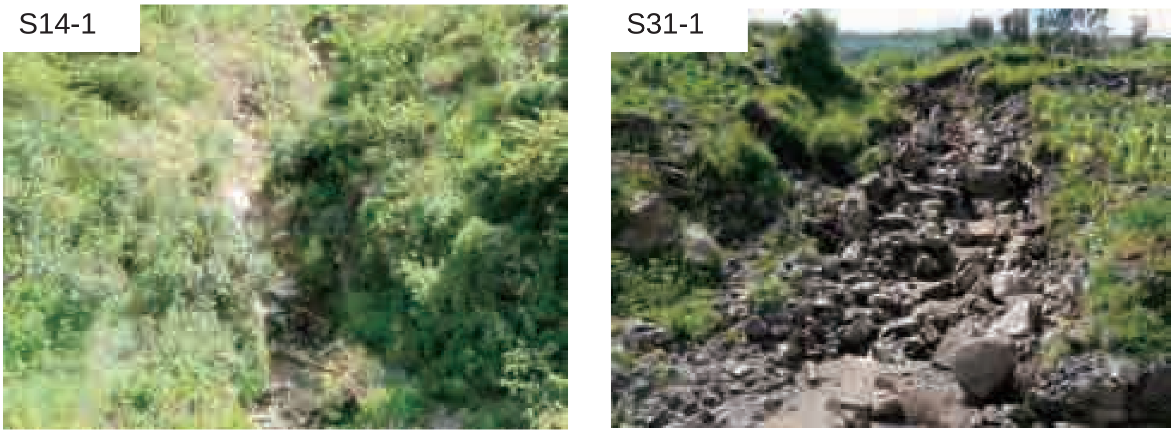


Photo 3.8.1 A small channel caused by the development of gullies

Photo 3.8.2 A large channel where large rocks are scattered

According to interviews conducted with the local residents, water levels sometimes rise at once even in small channels during heavy rainstorms, causing sediment spilling onto the road. This results in overland flow at early stage of rainfall. Meanwhile, large rock blocks in channels mainly consist of basalt, limestone, and sandstone whose diameters sometimes reach 5 m or more. These larger rocks were probably generated from the bedrock around the edges of the plateau which have been transported after being exfoliated and detached through weathering and/or surface erosion. Open cracks have developed on the bedrock around waterfalls and it is posing a rockfall risk.

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.

Survey was conducted at 41 channels (S01-1 – S33-3) in the area.

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.

In some channels, there are high risk potential of sediment runoff due to insufficient drainage management. In others, unstable thick sediment is discharged from the quarries and deposited in the channel.

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.

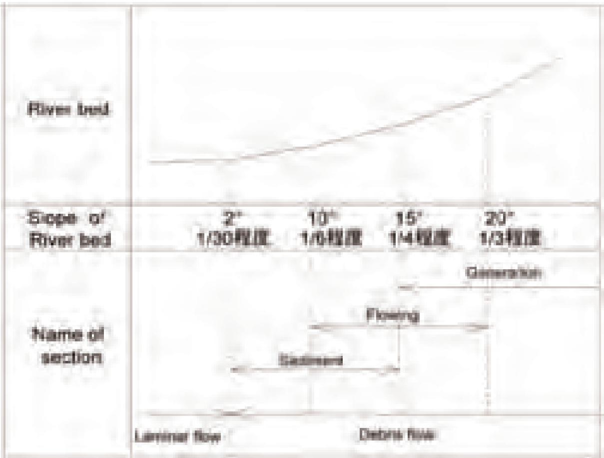


Figure 3.8.8 Guideline of moving forms of sediment based on channel bed gradients

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					Characteristics of slope			Existing counter structures and level of deposit		Road structures			History	Note
		Basin area (km2)	Stream length (km)	Areas with bed gradient >=15° (km2)	Steepest section Class	Bed gradient near roads (°)	Areas with slope gradient >=30° (km2)	Vegetated area (shrubs & grass) (km2)	Construction sites with unstable debris	Type	Level of deposit	Type	Stream width (m)	Vertical clearance (m)	Debris runoff	
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.