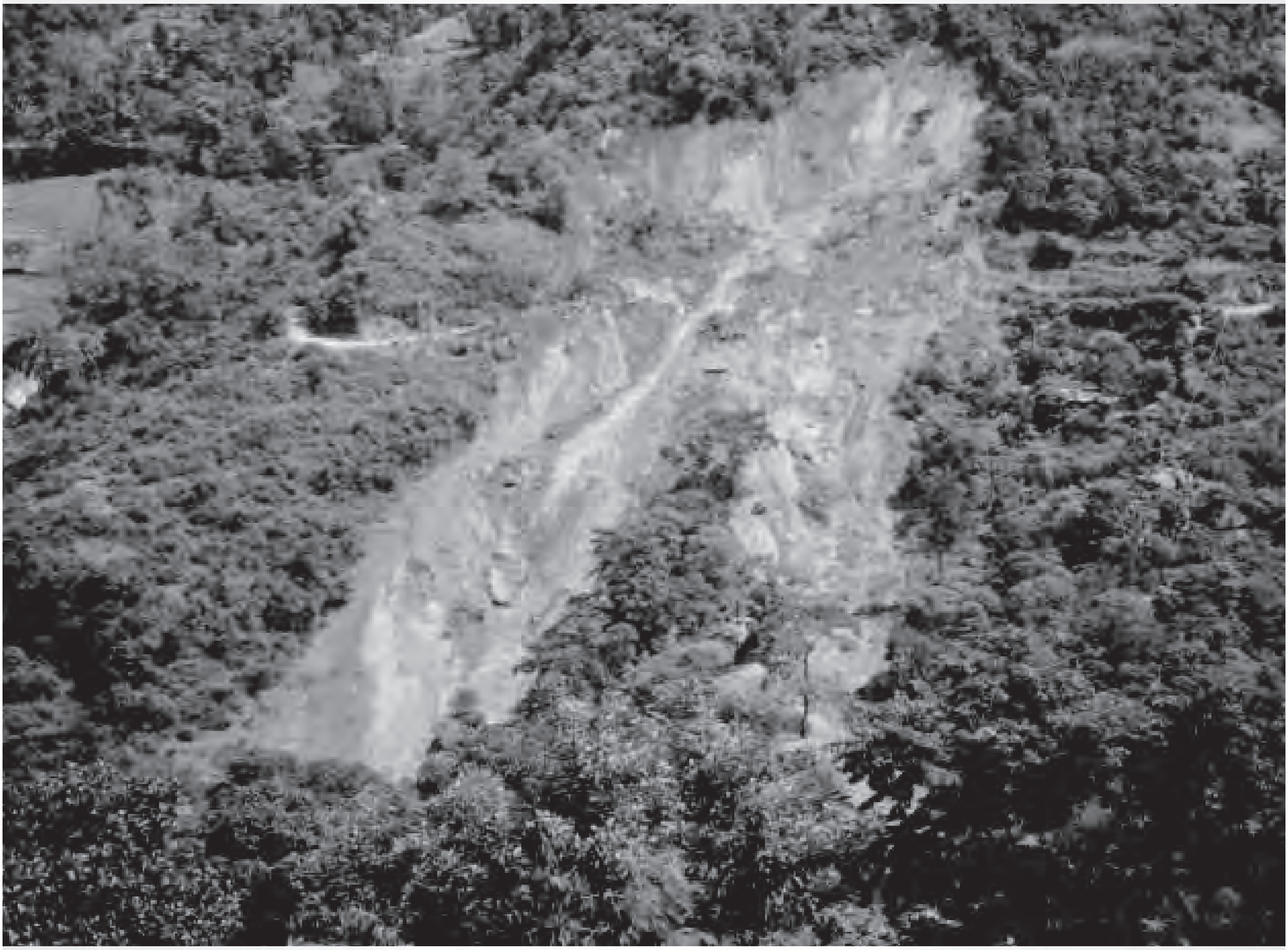
添付資料 3-1　　地すべり対策マニュアル

The Manual for Landslide Monitoring, Analysis and Countermeasure



NBRO & JICA DiMCEP

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Forward

The hilly country of Sri Lanka faces frequent landslides that cause enormous damages to the human lives, properties, infrastructure, and national economy. Nearly 20% of the total land mass (65,000 km^2) of Sri Lanka is considered to be prone to landslides. These landslide prone areas are spread over in Highland area, especially Badulla, Nuwara Eliya, Kandy, Ratnapura and Hanbantota districts. Due to change in land use practices, number of Cutting Failure incidences has been increasing at Gampaha and Colombo districts.

The landslide occurrence frequency has become severer. The current landslide density is approximately 1 or 2 /km^2. And there are normally one or two landslides or cutting failure occurrences at every rainfall event. In Sri Lanka, landslides are occurred due to natural causes and man-made causes.

Japan International Cooperation Agency (JICA) in cooperation with the Ministry of Disaster Management has organized various efforts to enhance the capacities in order to mitigate the landslide disasters in the region of Sri Lanka.

"The Manual for Landslide Monitoring, Analysis and Countermeasure" is a technical guidance for preliminary survey, main survey, analysis and countermeasure for the areas which are prone to landslides. This manual used the results of activities from “The Disaster Management Capacity Enhancement Project Adaptable to Climate Change (DiMCEP), 2010 - 2013” as a reference.

Using this manual, it is expected that the NBRO and local government of Sri Lanka conduct investigation, monitor their activities, and provide countermeasure works for more effective disaster mitigation.

"The Manual for Landslide Monitoring, Analysis and Countermeasure"

Table of Contents

Page

1. Introduction 1-1
   1.1 About this Manual 1-1
   1.2 What is "Landslide"? 1-1
      1.2.1 Definitions of Landslide 1-1
      1.2.2 Classification and Mechanism of Landslide 1-5
   1.3 Landslides in Sri Lanka 1-9
   1.4 Outlines of Landslides Survey and Countermeasures 1-14

2. Landslide Survey 2-1
   2.1 Introduction to Landslide Survey 2-1
      2.1.1 Landslide Survey 2-2
      2.1.2 Objectives of Slope Monitoring 2-2
   2.2 Preliminary Survey 2-3
      2.2.1 Objectives and Overview of Preliminary Survey 2-3
      2.2.2 Collection and Review of existing Data 2-3
      2.2.3 Photo Interpretation of Landslide Affected Areas 2-3
   2.3 Basic Survey 2-8
      2.3.1 Objectives of Basic Survey 2-8
      2.3.2 Site Reconnaissance 2-9
   2.4 Detailed Survey 2-14
      2.4.1 Objectives of Detailed Survey 2-14
      2.4.2 Topographical Survey 2-14
      2.4.3 Geological Survey (Drilling Survey) 2-15
      2.4.4 Slip Surface Survey 2-17
      2.4.5 Surface Anomaly Survey 2-23
      2.4.6 Monitoring 2-24
         2.4.6.1 Monitoring of Rainfall 2-27
         2.4.6.2 Monitoring of Groundwater Level 2-29
         2.4.6.3 Monitoring of Surface Deformation 2-31
         2.4.6.4 Monitoring of Subsurface (Slip Surface) Movement 2-36
      2.4.7 Laboratory Test 2-40
         2.4.7.1 Dynamic Test 2-41

2.4.7.2 Physical Test 2-42
2.4.7.3 Test for Mechanical Properties 2-43
2.5 Analysis........ 2-49
2.5.1 Identification of the Landslide Area 2-49
2.5.2 Classification of landslide 2-51
2.5.3 Basic factor and inducing factor of landslide 2-54
2.5.4 Identification of Slip Surface........ 2-54
2.5.5 Relationship between Groundwater and Rain Fall 2-56
2.5.6 Cross Sections of Landslide 2-56
2.5.7 Others 2-58

3. Plan and Design of Countermeasures for Landslides........ 3-1
3.1 Plan for Prevention of Landslide........ 3-1
3.1.1 General 3-1
3.1.2 Identification of the Objects to be protected 3-1
3.1.3 Determination of the Factor of Safety 3-1
3.1.4 Establishment of Emergency Measure Frameworks 3-1
3.1.5 Considerations for the Environment........ 3-2
3.2 Stability Analysis 3-2
3.2.1 General 3-2
3.2.2 Procedure of Stability Analysis 3-4
3.2.3 Analysis on the Sliding Mechanism 3-4
3.2.4 Factor of Safety and Groundwater Level 3-5
3.2.5 Selection of Stability Analysis Method 3-5
3.2.6 Choosing Soil Strength Parameters 3-7
3.2.7 3Evaluation of the countermeasures........ 3-11
3.3 Introduction to Countermeasures for the Landslide........ 3-12
3.4 Landslide Control Works 3-15
3.4.1 Surface Drainage 3-15
3.4.2 Shallow Groundwater Drainage 3-16
3.4.3 Deep Groundwater Drainage........ 3-18
3.4.4 Earth Removal and Buttress Fill........ 3-21
3.5 Retaining Works........ 3-23
3.5.1 Pile Work 3-23
3.5.2 Shaft Work........ 3-24
3.5.3 Anchor Work 3-25

4. Emergency Measures 4-1
4.1 Measures for Emergency Situation 4-1
4.1.1 General 4-1

4.1.2 Surveys during a emergency situation 4-1
4.1.3 Prediction of the Land Mass Movement 4-2
4.1.4 Measures for Emergency Situation 4-3
4.2 Early Warnings 4-3
4.2.2 Warning Signs 4-8

5. Example of Landslide Survey and Countermeasures (Result of Activities by DiMCEP) 5-1
5.1 Survey Results 5-1
5.1.1 Aerial Photo Interpretation 5-1
5.1.2 Site Investigation 5-2
5.1.3 Drilling Survey 5-4
5.1.4 Monitoring using Instruments 5-9
5.2 Plan and Design of Countermeasures 5-12
5.2.1 Facilities to be Protected 5-12
5.2.2 Safety Factors 5-13
5.3 Considerations for the Countermeasures 5-15
5.3.1 Surface Drainage Works 5-15
5.3.2 Groundwater Drainage Works 5-18
5.3.3 Open and Closed Channel Works 5-21
5.4 Schedule of Implementation 5-21
5.5 Evaluation of the Effectiveness 5-24
5.6 Operation and Maintenance 5-24
5.6.1 Drainage Works (Surface water and Groundwater) 5-24
5.6.2 Maintenance of Sensors 5-26
5.7 Emergency Measures (Early Warning Systems) 5-26

1. Introduction

1.1 About this Manual

This manual summarizes the methodology, procedures, and results, etc. through the DiMCEP activities, with literature surveys regarding general features of landslide in Japan which may be applicable Sri Lanka.

Landslide is a phenomenon of movement under the ground with close relationship with nearby its geology. This manual shall be revised in accordance with improvement and development of technologies in landslide sector.

This manual contains the phases of technical procedures that aim to help survey, analysis, and countermeasures of landslide. Types of landslides differ from each other, and therefore, procedures for survey, investigation and countermeasures for each landslide types are explained in this manual.

The manual is developed based on the guideline “Technical Guide and Instruction of Landslide prevention” by Ministry of Land, Infrastructure, Transport and Tourism (MLIT) and Public Works Research Institute (PWRI) in Japan (2008).

1.2 What is “Landslide”?

1.2.1 Definitions of Landslide

The term “Landslide” is defined by various literatures. For example, USGS (United States Geological Survey) defines “Landslide”, referring to Cruden, 1991, and Varnes 1996, as follows;

“A landslide is defined as "the movement of a mass of rock, debris, or earth down a slope". (Cruden, 1991). Landslides are a type of "mass wasting" which denotes any down slope movement of soil and rock under the direct influence of gravity. The term "landslide" encompasses events such as rock falls, topples, slides, spreads, and flows, such as debris flows commonly referred to as mudflows or mudslides (Varnes, 1996). Landslides can be initiated by rainfall, earthquakes, volcanic activity, changes in groundwater, disturbance and change of a slope by man-made construction activities, or any combination of these factors. Landslides can also occur in the underwater, causing tsunami waves and damage to coastal areas. These landslides are called submarine landslides”

- *Cruden, D.M., 1991. A Simple Definition of a Landslide. Bulletin of the International Association of Engineering Geology, No. 43, pp. 27-29.*

- *Varnes, D.J., 1996. Landslide Types and Processes, in Turner, A. K., and R.L. Schuster, Landslides: Investigation and Mitigation, Transportation Research Board Special Report 247, National Research Council, Washington, D.C.: National Academy Press.*

The classification by Varnes, 1978 through USGS is widely adopted worldwide. Table 1.2.1 is the classification of Landslides defined by the US DoE, 1990.

In Japan, landslide is officially defined as follows;

"Landslide is a slide and / or movement of land surface portions that is caused by change in groundwater condition" (Under the Act of "Landslide etc., Prevention Means", 1957, by the Ministry of Land, Infrastructure and Transportation). However, some researchers argue that the "Landslide" cannot be clearly defined due to its complexity of direct and indirect cause.

In general, following classification is used for research and investigation purpose.

a. Landslide

Definition of the "Landslide" in this manual is most closely explained by "SLIDE" in Table 1.2.1. Landslide is a phenomenon which the soil mass on one or more failure (slip) surfaces deep in the ground gradually shifts downward, triggered by heavy rain, earthquake, river erosion, and earthworks. Landslide zones often consist of a certain types of geological features. Differing to the "Slope Failure", the "Landslide" is a movement on gentler slope, forming landslide topography. The inclination angle of the slope is about 5 to 20 degrees.

b. Slope Failure

Definition of the "Slope Failure (Surface Failure)" can be explained by "FALLS" in Table 1.2.1. The slope failure is mass movement detached from steep slope or cliff along the ground surface, with little or no shear displacement. Unlike the "Landslide", the "Slope Failure" is the quick mass movement on the small-scale slope, with the inclination angle of 20 degrees and over.

NOTE: The "Rock fall" is not included in this classification.

c. Debris Flow

Definition of the "Debris Flow" is equivalent to "FLOWS" in Table 1.2.1. A Debris flow is a phenomenon of surface water or groundwater which flow downward with high speed through a mountain torrent as a result of saturation of soil and boulders. It usually generates a destructive energy force. The "Debris Flow" tends to occur at a steep torrent with massive sediment of unstable debris, especially at a time of heavy rainfall event.

d. Rock Fall

Definition of the “Rock Fall” is equivalent “TOPPLES” in Table 1.2.1. The “Rock Fall” is a phenomenon of foliated rocks and gravel to fall down a slope caused by enlarged cracks in the bedrock or outcropped rocks.

In this manual, definition of “SLOPE” explained on (1) landslide is used, since the definition best matches to the landslides in Sri Lanka.

Table 1.2.1 Classification and Types of Landslides (DoE,1990)

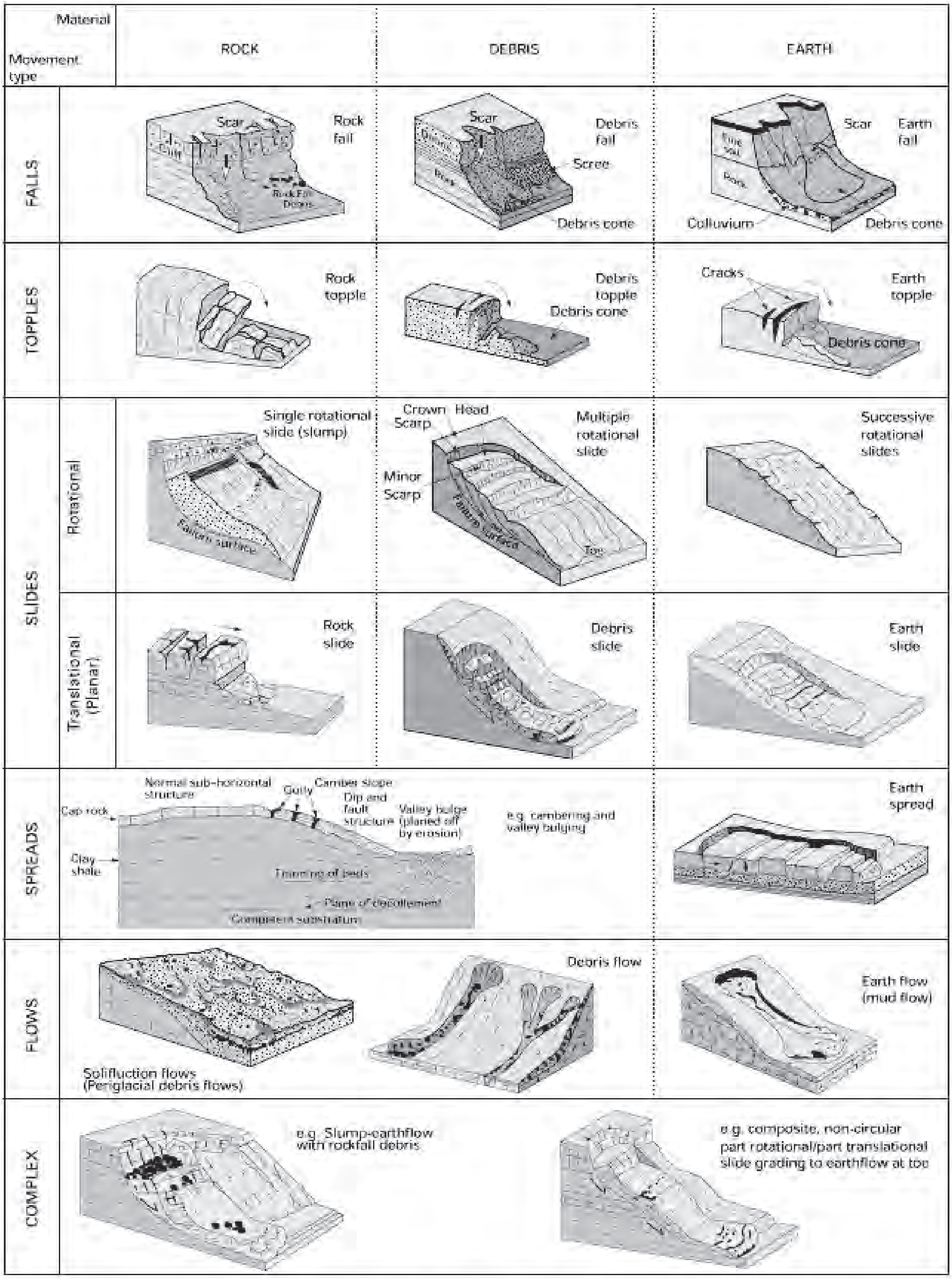


Figure 2 Classification of type of landslip (modified after Varnes, 1978 and DoE., 1990).

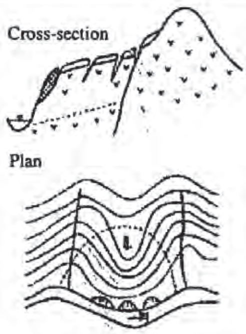
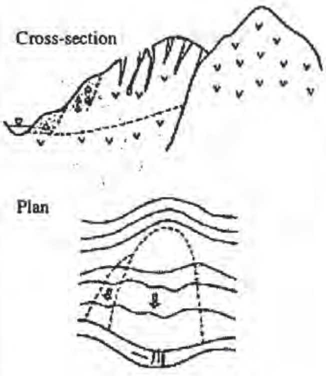
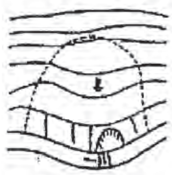
Falls mass detached from steep slope/cliff along surface with little or no shear displacement, descends mostly through the air by free fall, bouncing or rolling.
Topples forward rotation about a pivot point.
Rotational slides sliding outwards and downwards on one or more concave-upward failure surfaces.
Translational (planar) slides sliding on a planar failure surface running more-or less parallel to the slope.
Spreads fracturing and lateral extension of coherent rock or soil materials due to liquefaction or plastic flow of subjacent material.
Flows slow to rapid mass movements in saturated materials which advance by viscous flow, usually following initial sliding movement. Some flows may be bounded by basal and marginal shear surfaces but the dominan movement of the displaced mass is by flowage.
Complex slides slides involving two or more of the main movement types in combination.

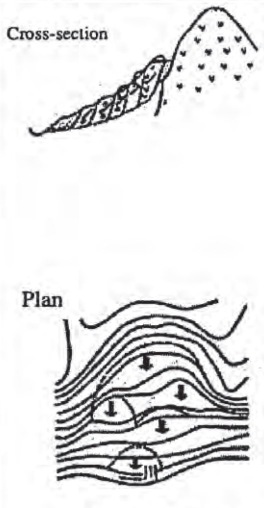
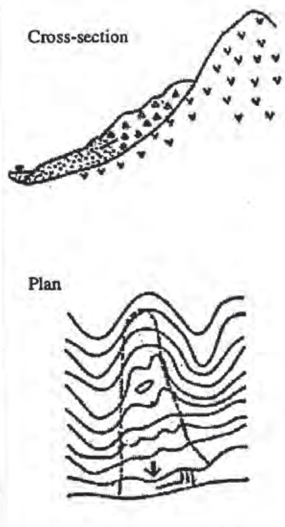
1.2.2 Classification and Mechanism of Landslide

a. Classification of Landslides

Table 1.2.2 explains the type of landslides which cause repeated surfaces slips. Landslides are classified into several types by topographical and geological characteristics. This classification can provide important features to estimate the cross-section, longitudinal profiles and depth of the landslides, which can be used for planning of landslide survey.

Table 1.2.2 Classification of Landslide [*1]

Category	Description	Schematic Drawing	Typical Geological Features	Remarks
(1) Bedrock Landslide	1) Convex ridge terrain with a chair or boat-type sliding surface; often starts at a saddle section 2) Bedrock or lightly weathered at the head and weathered rock at the bottom 3) Sudden occurrence makes its prediction very difficult; careful reconnaissance and a detailed survey are required	 Convex ridge terrain	Often affected by a fault or fracture zone; Tertiary formations, crystalline schist and Mesozoic and Paleozoic formations	Triggered by large-scale earthworks, submersion of part of the slope, earthquake or heavy rain
(2)Weathered Rock Landslide	1) Convex plateau terrain, single hill, concave plateau terrain with a chair or boat-type sliding surface 2) Weathered rock with many cracks at the head and sediment mixed with boulders at the bottom	 Single hill terrain  Concave plateau	Crystalline schist, Mesozoic/Paleozoic formations or Neogene formation affected by a fault or fracture zone	Triggered by a downpour, abnormal thawing, earthquake or medium-scale earthworks

(3) Colluvial Deposit Landslide	1) Multiple hill or concave plateau terrain with a stair or layer-type sliding surface which can be divided into 2 – 3 blocks 2) Mainly consists of sediment containing gravel and becomes clay at the bottom 3) Intermittent activity repeated every 5 – 20 years; landslide hysteresis is clear from the topographical point of view and can be checked with a topographical map of 1 to 5,000 or 1 to 10,000; interviews with local people are also useful	 Multiple hill terrain	Colluvial deposit from crystalline schist, Mesozoic/Paleozoic formations, Neogene formation or serpentinite	Triggered by thawing, typhoon, downpour or medium-scale earthworks
(4) Clayey Soil Landslide	1) Gently sloping concave terrain with a multi-blocked stair or layer type sliding surface; closer relation between the blocks than (3) 2) Mainly consists of clay or clay containing gravel 3) As landslide movement is semi-continuous with a recurrence every 1 – 5 years, its presence is well-known locally.	 Gently sloping concave terrain	Neogene formation, fracture zone and solfataric soil	Easily activated by a downpour, thawing, river erosion or small-scale earthworks

b. Mechanism of Landslides

Landslide is a phenomenon which the soil mass on one or more failure (slip) surfaces deep in the ground gradually shifts downward (Figure.1.2.1). One of the important characteristics of landslide is that the inclination angle is relatively low, approximately 5 to 20 degrees. The landslide mechanisms can be estimated by following considerations in the surrounding areas;

- Observation of surface anomaly such as existences of any small deformations, steps, subsidence or heaving
- Observation of main scarps, tension cracks, compression cracks, radial cracks, and lateral cracks
- Observation of deformation of building structures such as houses or walls
- Observation of anomaly of natural conditions such as bending of tree roots.

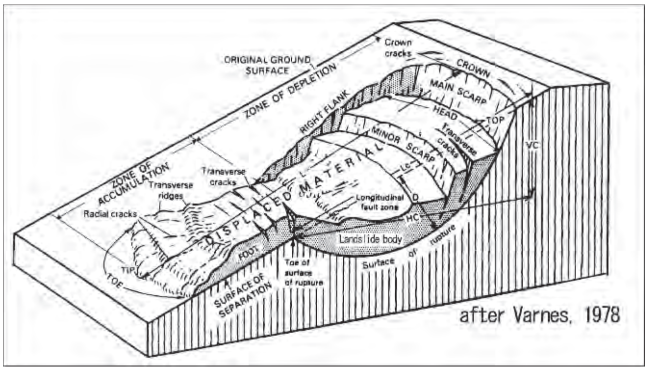


Figure 1.2.1 Structure of typical landslides *2

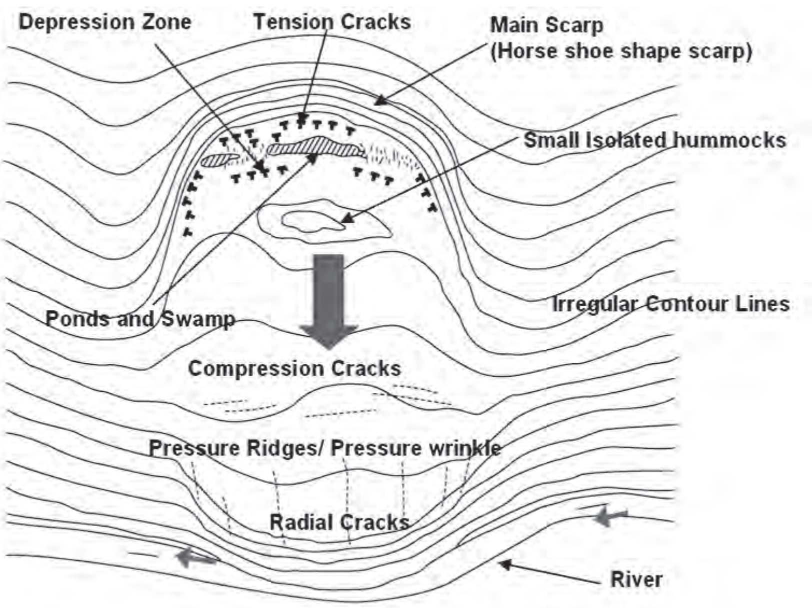


Figure 1.2.2 Schematic diagram of Landforms of Landslides *3

c. Factors to be considered

Mechanical Factor:

Basically, cause and severity of the landslides generally depend on the natural conditions of the areas. The basic factors to be considered are; 1) topographical features such as conditions of surface and ground water flows, 2) condition of slip surfaces such as existences of bedded structures, mud-clay layers, turfs, and thick loose formation at the unstable slope surface, and 3) geological structures such as faults, anticline, syncline, etc.

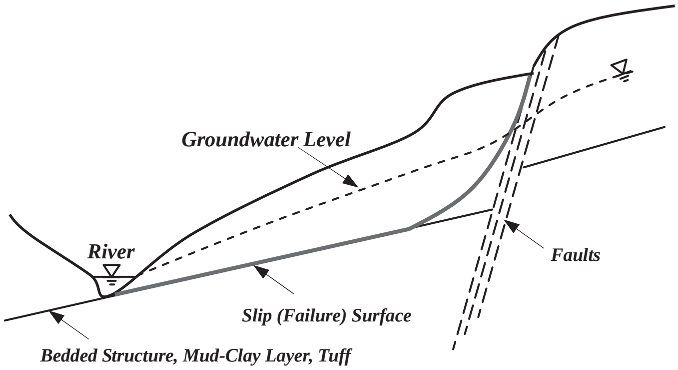


Figure 1.2.3 Schematic Cross Section of Landslide caused by Mechanical Factors [*4]

Climatic Factors:

Landslides are often caused floods during rainy seasons, by washing out of the slope toe, or by formation or blockage of waterways at surface or subsurface ground. The climatic factors shall be carefully examined in order to detect any possible triggers to the landslides.

Human Factors:

Construction of embankments may cause slope submersion under water and blockage of surface drain, which result in landslides.

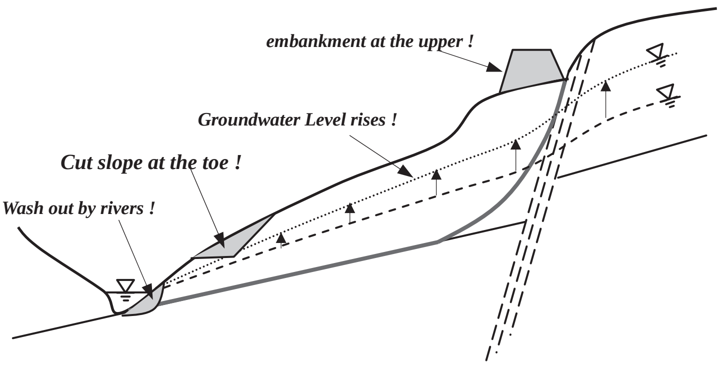


Figure 1.2.4 Schematic Cross Section of Landslides caused by Climatic and human Factors[*4]

1.3 Landslides in Sri Lanka

Most of the landslides, slope failures, rock fall and cutting failures occur at the hilly areas in central Sri Lanka. Ten major districts - Badulla, Nuwara-eliya, Rathnapura, Kegalle, Kandy, Matale, Kalutara, districts in the central hills, and Matara,Galle and Hambantota districts in the southern hills are identified as the areas prone to landslides. Among those, approximately 20,000 km^2 of the area is highly vulnerable to landslides, which extend over three districts (NBRO 1994). Not only the landslides but also slope failures and rock falls are the major natural disasters causing severe damages on human lives and properties in the hilly regions of Sri Lanka, resulting in negative impact on national economy. Large amount of rainfall is considered as the major cause of landslides in this region.

The basic data for landslides are collected and maintained by the national Building Research Organization (Sithamparapillai 1994). Previously, about 12,000 km^2, or 18% of the total land area of Sri Lanka was considered to be prone to landslides (NBRO 1995). But recent studies have revealed that the prone area has increased to 20,000 km^2, or 30% of the total land area of Sri Lanka, reflecting the 2003 landslide incidences at southern region. The NBRO has the dataset of 1:50,000 and 1:10,000 series landslide hazard maps for the central and southern regions, together with aerial-photograph coverage with various scales.

Locations of landslides are distributed as shown on Figure 1.3.1. The NBRO estimates that one or two landslides occur at every km^2 of the area. The landslides occur on any shapes of slopes, ranging from dip to sharp shapes. Most large scale landslides occur during monsoon seasons at northeast and southwest areas. Clay-rich colluvium (mixture of soil, sand, clay and rock fragments transported and deposited) above the bedrock of weathered gneiss generates the landslides. According to the aerial photographs and field studies, evidences of several palaeoslides which occurred around 1830 can be observed over the land. The palaeoslides occurred long before the deforestations for coffee, rubber and tee plantations.

The landslide frequency has been increased since the start of the plantations as well as due to the population increase in the areas (Gunathilaka 2007). In 2003, more than 600 incidences of landslides occurred after heavy rainfalls at hilly areas. And situations in years 2006 and 2007 are even severer. Records of data since 1880 (NBRO website) indicate that landslides generally occur during/after heavy rainfalls. Some landslides cause chain-reaction slides of old landslides.

The environmental conditions prior to 1830 provide significant implications for understanding the causes of landslide phenomena, since there were no anthropogenic factors during those periods.

Over 80% of the land was covered by dense forests before 1830 (Survey Dept. 1994); however, the evidence shows that there were significant numbers of landslides occurred especially at the highland of complex terrain, and at the wet to intermediate climatic zones of the central highlands during those time periods.

Currently, remaining scars of many of the landslides can be observed at ten districts - Badulla, NuwaraEliy, Kandy, Matale, Kegalle, Ratnapura, Kalutara of the central hilly regions, and Matara, Galle and Hambantota districts of the southern hilly regions. Landslides in Sri Lanka range in size from approximately 400 to 80,000 m^2, with the length extended to about 5 km. The landslide elevations range from 200 to 1,800 m. Most of the rock falls and rock slides occur at the high elevated areas, with slope of 15 to 40 degrees with a mode range of 25 to 30 degrees.

Factors affecting landslides, such as landforms, bedrock geology, slope gradients, hydrology, landuse on hill-slope, land management, are briefly explained by Bandara et al. (1994) and Abeykoon and Kumarapeli (1994). Bhandari and Kotuwegoda conducted research on geometries of landslides between 1962 and 1994, mapping on a scale of 1:10,000 and larger, in order to generalize the landslide movements. The records indicate that the landslides change the slope …

The database shows that in Sri Lanka, length ofmany landslides on natural slopes tend to become longer, with length/width ratios of 2–10 (mode of 3–6) but the colluvium depths of the sliding masses is generally less than 15 m. It indicates that the landslides in Sri Lanka is caused only at the surface of the slopes sliding down. (Bhandari and Kotuwegoda ,1994).

It is difficult to estimate the exact mass volume of loss because of non-uniform colluvium soil layers accumulated over years across the landslide areas. Therefore, it is appropriate to estimate the volumes by taking samples of thickness measurements from the database.

Due to the lack of data, it is difficult to estimate the volume of landslides in Sri Lanka. It is estimated that magnitude of the scarp slopes is two times larger than magnitude of the dip slops.. (Bhandari and Kotuwegoda, 1994).

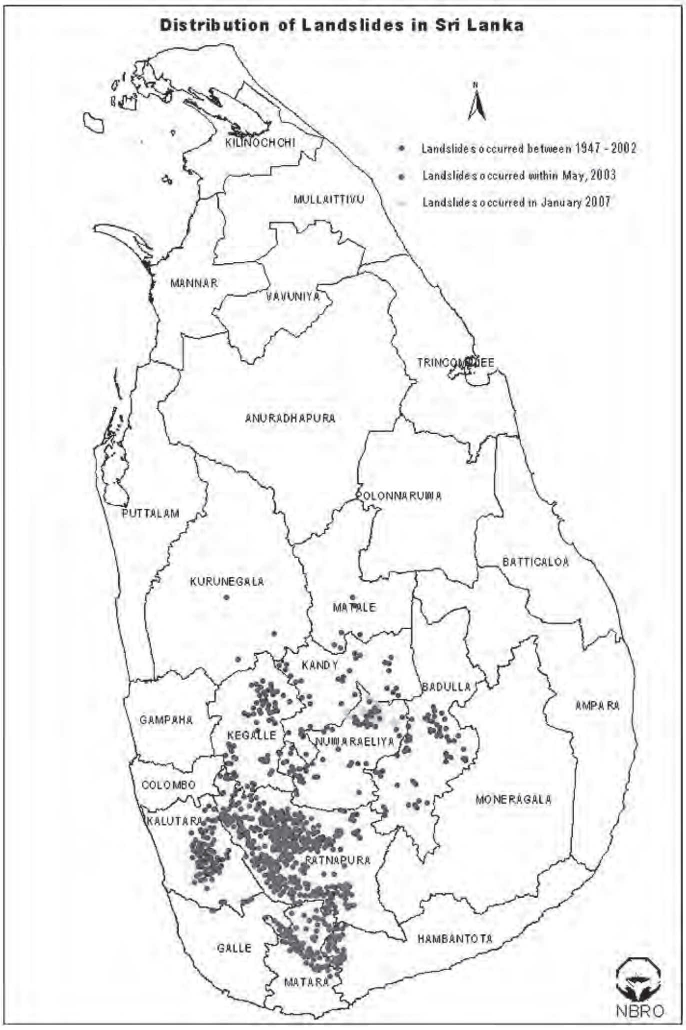


Figure 1.3.1 Distribution of landslides from 1947 to 2007 (NBRO)

Major Landslide Disasters in Sri Lanka:

a. Watawala Landslide, Nuwara Eliya District (3 June, 1992)

The landslide occurred on the southern slope of the Watawala ridge in the Nuwara Eliya District, at the Colombo-Badulla railroads. The slope has been crept for about 50 years, and it finally raptured on 3 June 1992, with total moving mass area of 33,120m^2. The Colombo-Badulla railroad was heavily damaged, with a large number of casualties, leaving significant damages on society and economy of the country.

Figure 1.3.2 Damaged Train by the Watawala Landslide (NBRO)

b. Helauda Landslide, Ratnapura District (8 October 1993)

On 8 October 1993, mass movement of earth occurred on a slope located at approximately 3 km north from the heart of Ratnapura city. The landslide instantly swallowed the roads and houses, located at the foot of slope, resulting in 31 casualties. On 24 August 2006, the same area was affected by a small-scale landslide because of consecutive rains on unstable slopes by accumulated soils.

(NBRO)

Figure 1.3.3 Earthflow at Helauda

c. Palawala Landslide Disaster, Ratnapura District (17 May 2003)

In Palawale, Ratnaputra District, large –scale landslides hit the gently sloped mountains, causing rapid mud flow through the river. The flows of debris reached to the opposite side of the river.

(2003, photo by NBRO)

Figure 1.3.4 Earthflow at Palawela

d. Walapane Sediment Disaster, Nuwara Eliya District, 12 January 2007

On 12 January 2007, a landslide due to heavy rainfall occurred at Nuwara Eliya District Walapane DS. Division and Hanguruketha DS. Especially,

Walapane National Highway B413 was affected by several landslides and debris flows due to cutting failures, causing 20 casualties. s

(JICA Consultant Team)

Figure 1.3.5 Landslide at Walapane

1.4 Outlines of Landslides Survey and Countermeasures

The following Figure1.4.1 shows the flow of landslide survey and analysis. The details of surveys, analysis, and countermeasures are explained later in this section.

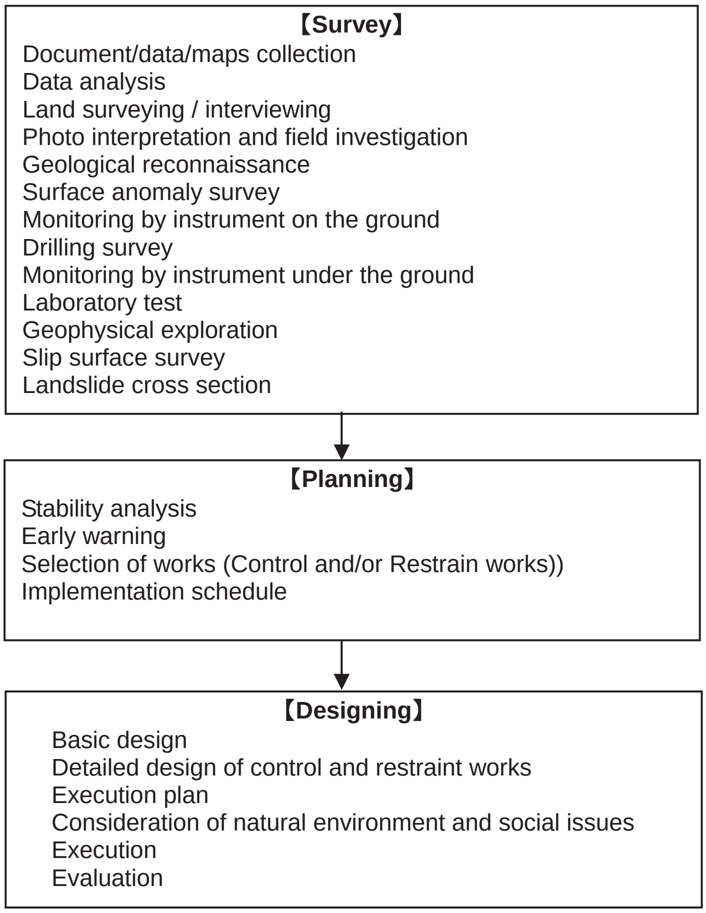


Figure 1.4.1 Flowchart of Landslides Survey and Analysis

a. Landslide Survey

Purpose of landslide survey is to establish the preventive plans and the countermeasures. The landslide survey is divided into two stages; preliminary survey and main survey.

The preliminary survey is composed of collecting and analyzing of documents, data, maps, and any related literature. In addition, field surveys including the hearing to local people at the landslide affected areas, shall be included.

The main survey consists of; hydrological, geomorphologic, geological, drilling and slip surface surveys, and physical testing, monitoring and geophysical exploration. If required,, the results from the main survey shall be compiled as a geophysical information within a GIS (Geophysical Information System) to easily understand the landslide mechanism and the monitoring results.

b. Landslide Analysis

Analyses for landslide, such as preparation of geological cross sections, establishment of safety factor and stability analysis, shall be implemented based on the results obtained from the surveys.

c. Countermeasures

Landslide countermeasures include; control works and restraint works. Appropriate countermeasures shall be selected or designed based on the results obtained from the survey and the analysis.

The execution plan for the landslide disaster management shall be prepared considering the social, environmental, and economical perspective.

Monitoring activities shall be continued in order to evaluate the effectiveness of the countermeasures. The monitoring results shall be utilized for the stability analysis by establishing the safety factors.

References

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*2 Varnes, D.J., 1978, Slope movement 43. types and processes, in Schuster, R.L., and Krizek, R.J., eds., Landslides—Analysis and control: Transportation Research Board Special Report 176, National Research Council, Washington, D.C., p. 11–23.

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2. Landslide Survey

2.1 Introduction to Landslide Survey

It is difficult for the communities, living in landslide prone areas, to understand the landslide mechanism. They have been living in those areas for a long period of time, assuming that the areas would continue to be safe.

Therefore, the countermeasures for landslides are needed in order to protect the people's lives, their properties, and the public infrastructures. It is important to identify the target areas by geological surveys.

The landslide survey shall be conducted in order to lead to the appropriate countermeasures to the respective site with particular geographical and topographical characteristics.

Following diagram indicates the landslide survey in Japan. (referred from *1).

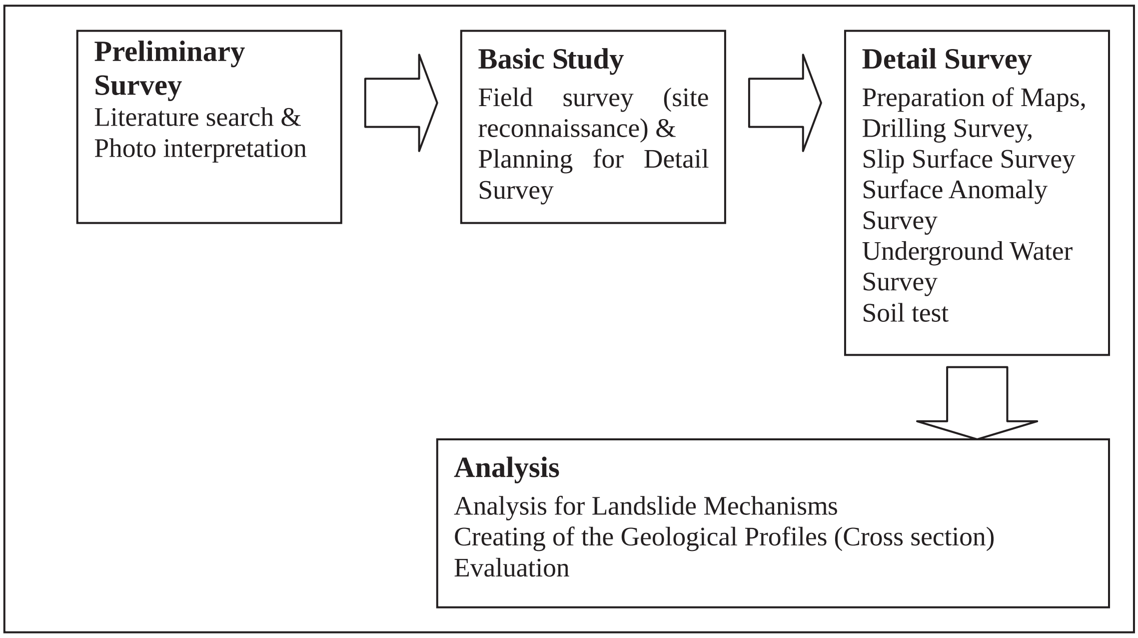


Figure 2.1 Schematic Block Diagram of Landslide Survey in Japan

The Landslide Survey is subdivided into three categories; 1) Preliminary Survey, 2) Basic Survey, and 3) Detailed Survey. The preliminary survey shall be conducted in order to grasp the site conditions or identify the possibilities of landslides using documents or aerial photos. The basic survey shall be conducted on site. The detailed survey shall be conducted on site, in order to identify the landslide mechanism following after the preliminary and basic surveys.

After analyzing the results obtained from the surveys, a map with scoping and profiling can provide a clear knowledge of basic factors of landslides.

2.1.1 Landslide Survey

Landslide tends to occur frequently in the areas with a certain geology or geological zone. Such areas have a certain feature of landforms due to the past landslide activities. Landslides are frequently induced by human activities such as slope cuttings and improper water treatment such as inappropriate drainage system. Landslide areas can be easily identified by aerial photographs and field survey. Following features shall be investigated by the surveys; Landslide survey is carried out to obtain the following types of features.

1. Hazardous areas including landslide zones
2. Direction and velocity of possible sliding and existence of steep slopes
3. Stability of existing slopes and any influences from the human activities
4. Any landslide inducing factors such as the seepages of groundwater
5. Suitable locations of monitoring devices

It is considered that the landslides are caused by rainfall and the resulting rise of ground water level. Types of the rainfall influences vary depending on its topography, geology and hydro-geological conditions in the area.

2.1.2 Objectives of Slope Monitoring

It is almost impossible to identify the landslide behaviors in advance because of a number of factors accompanying the uncertainties. Therefore, it is extremely important to monitor and identify any changes which may give us ideas of future landslides.

The "Landslide Hazard Mapping SLR/89/001 Instrumentation", prepared by the NBRO under UNDP project can be utilized for the purpose of the following perspectives.;

- Determining of in-situ state of stress and pore water pressure within a slope or a sliding mass, for figuring out of initial ground conditions at any point of time
- Estimating of depth and shape of the slip surface of landslide
- Identification of plane boundaries of possible sliding
- Monitoring of structure-foundation-slope behavior system or of an unstable slope, in order to identify any required countermeasures. Installation of the measuring instruments can be implemented for evaluating the effectiveness of the countermeasures and the identifying the indicators for the risk measurement at every stage
- Measuring of any lateral and vertical movements of surface and sub-surface slope
- Keeping records of evidence for possible impact in the social environment

2.2 Preliminary Survey

2.2.1 Objectives and Overview of Preliminary Survey

Purpose of preliminary survey is to grasp the overall information such as geology and groundwater in the landslide area.

The Preliminary survey consists of Document Surveys and Photo Interpretation.

2.2.2 Collection and Review of existing Data

It is important to utilize the exiting data (topographic maps, aerial photographs, satellite images, geological maps, records of damage, restoration works and previous reports, etc.) to understand general features of landslides and to plan the investigation procedures. It is also important to understand their relationship with geological factors such as periods of activity, hydro-geological conditions and other factors which may be related with the slope deformation, which is surrounding the survey area prior to performing a detailed investigation.

2.2.3 Photo Interpretation of Landslide Affected Areas

Most active landslides appear in landslide prone areas, and accompany with certain micro landforms. Therefore landslide survey generally starts with topographical and geo-morphological surveys. Geomorphologic survey begins with topographic map reading and aerial photo interpretation, then leads to identify the landslides and potential landslide areas. The results shall be compiled into the landslide distribution maps. Then, the maps shall be used to the field survey. The field survey is conducted to grasp the geo-morphology, geology, soil condition, surface anomalies and slip surface on site. Then the form and depth of the landslide shall be estimated.

The stereo images can be obtained from stereo type photographs by using a stereoscope. The micro landforms caused by landslide movement and geomorphologic features can be identified from the stereo image,.

(NBRO)

Figure 2.2.1 Aerial Photo Interpretation by Stereo Scopes

By aerial photograph interpretation, landform area, chronology of the landforms, land use, and vegetation can be observed and the relationship between those features and landslide can be examined. Using a large scale aerial photograph such as 1:10,000 or larger, micro landforms caused by landslide movement can be interpreted.

The Aerial photograph interpretation is a useful method of finding several causes of landslides over a wide area with various perspectives.

The legends used in aerial photograph interpretation are shown in Figure 2.2.2 and Figure 2.2.3. The result of aerial photograph interpretation summarized as photo-map of landslide is shown in Figure 2.2.4.

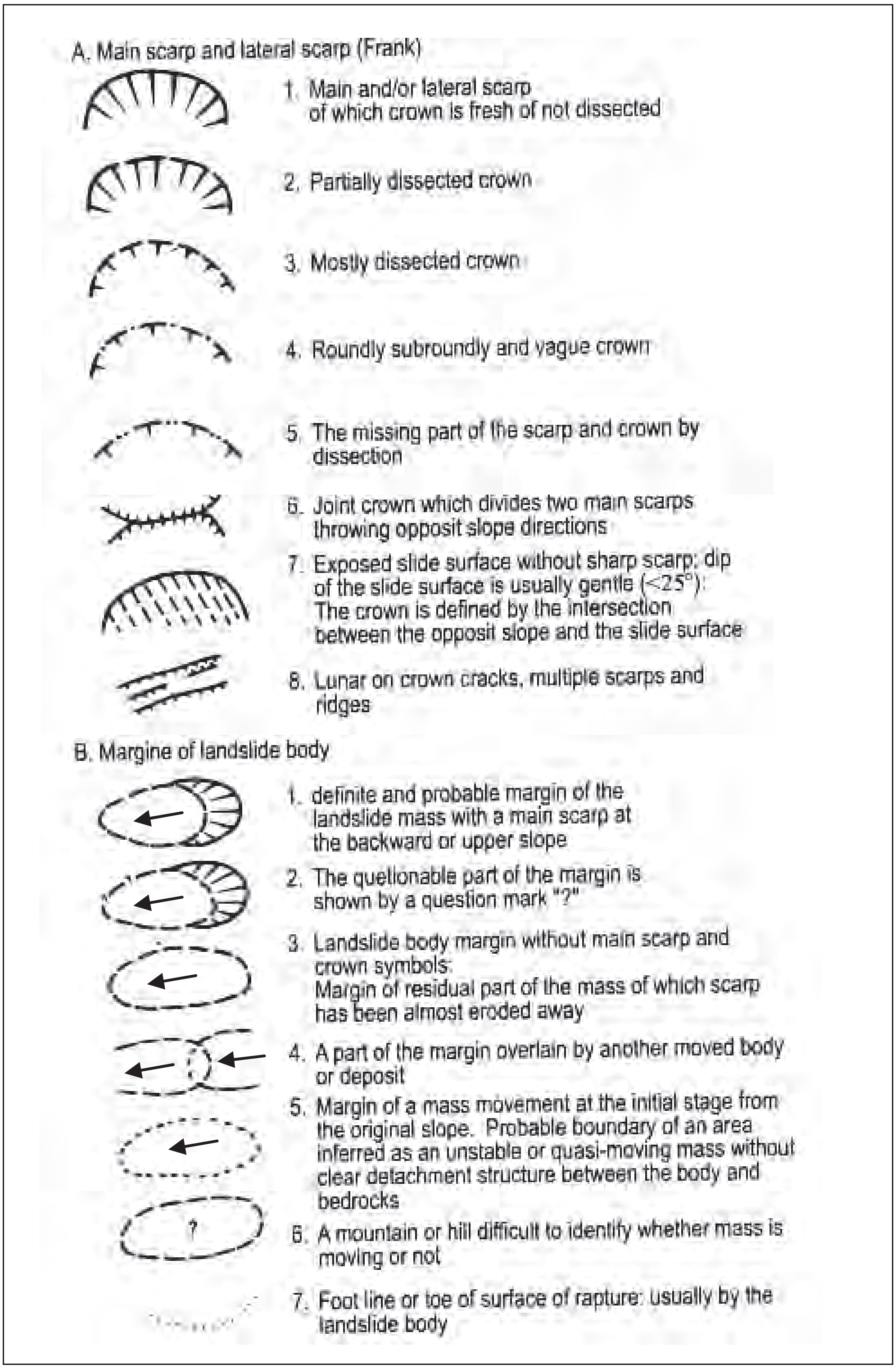


Figure 2.2.2 Legend of Aerial Photograph Interpretation (1) [*13]

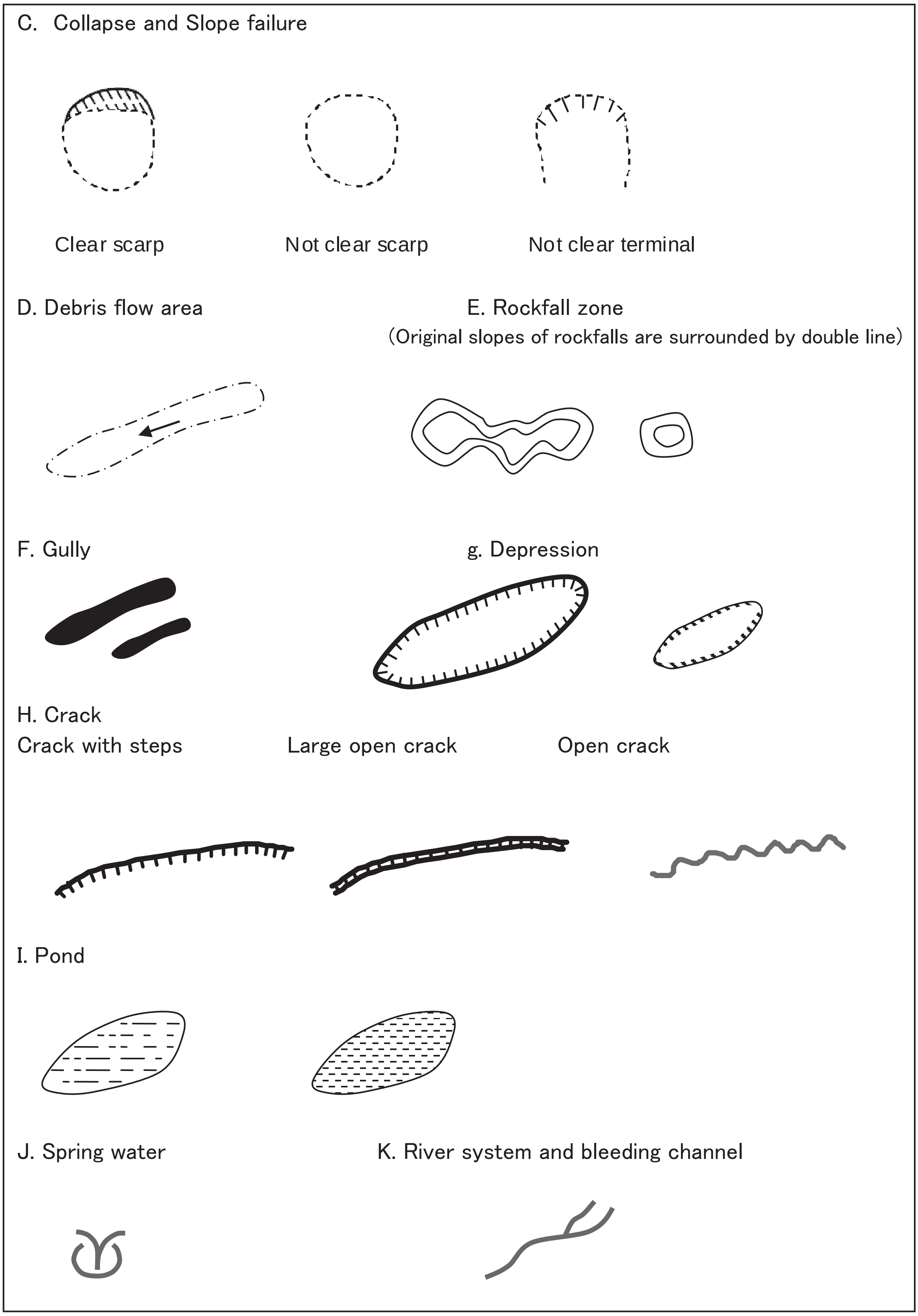


Figure 2.2.3 Legend of Aerial Photograph Interpretation (2) [*13]

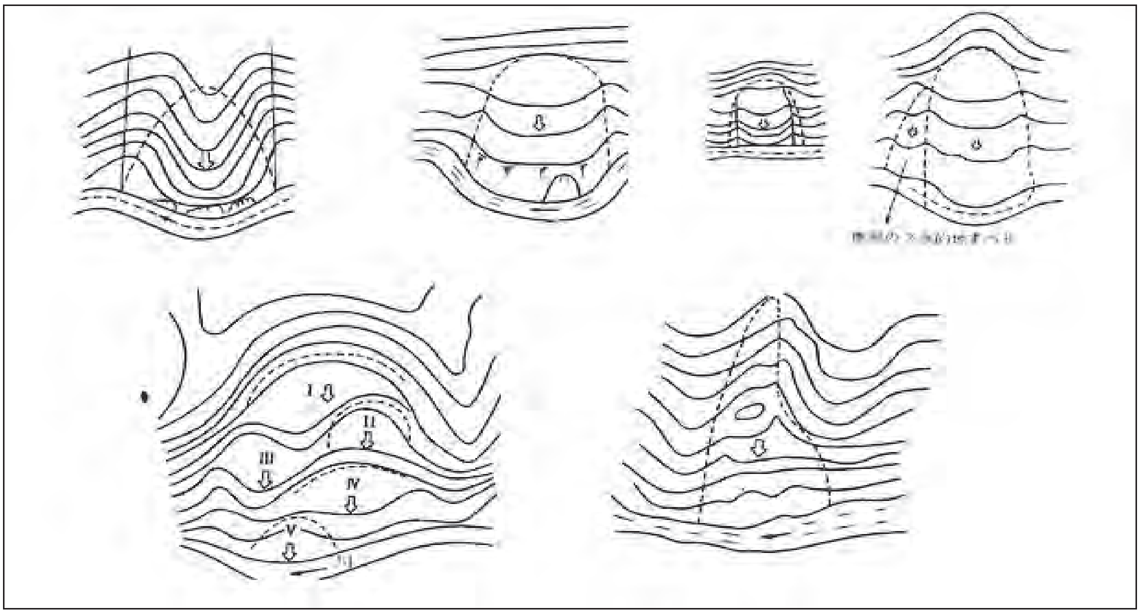


Figure 2.2.4 Sample of the Aerial Photo Interpretation (referred from *2)

Topographical maps on a scale of 1/50,000, aerial photographs and satellite images shall be used to select the survey areas. If available, the larger scale of topography map, such as 1/10,000 or larger, shall be used. If not, then any insufficient information which cannot be obtained from the map interpretation shall be supplemented or verified at the field survey (Field Reconnaissance Survey). Characteristics of the conditions which may cause landslides are shown below;

1. The topography map can provide information of the slope conditions such as steep or gentle in an area
2. Irregular and winding contour lines on topographic map
3. Scarps, steps, cracks, depressions, ponds and swamps on the gentle slope.
4. No major or visible stream lines

Landslide areas can be identified by analyzing topographical features, as in the following figure.

Figure 2.2.5 Comparison of Contour Lines on a Landslide Area (left) and an Area with no Landslides (right) [*13]

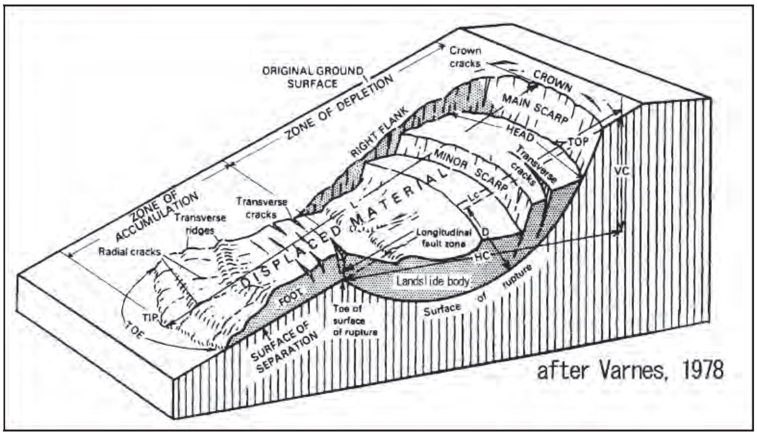


Figure 2.2.6 Block Diagram of Landslide [*12]

2.3 Basic Survey

2.3.1 Objectives of Basic Survey

Purpose of the Basic Surveys:

1. To provide a quick inspection to determine if the urgent countermeasures are needed
2. To prepare for the detailed survey.

The basic survey shall confirm the followings;

1. Extension of the landslide
2. Scale of the landslide
3. Direction of the landslides

The basic study shall be implemented on site.

2.3.2 Site Reconnaissance

After understanding the overall geomorphologic features of the spatial extent of the landslide, and providing a trace of landslide movement on the ground surface, a detailed field investigation plan can be developed. The field investigation can provide more detailed information such as geological structures, causes of landslide, and possible landslides for the assessment.

The field investigation shall be conducted following after analyzing of existing data and interpreting of aerial photograph. The Field investigation should include the areas where aerial photograph is not available or unclear. It also shall include the areas that could help understanding the particular geomorphologic features and characteristics. Items of field investigation are shown in Table 2.3.1.

Table 2.3.1 Field Investigation Items

Geomorphological information	Landslide landform	Distribution and orientation of main scarps, Distribution and orientation of steps and cracks Distribution and orientation of mounds and depressions
	Slope failure landform	Type and size of slope failure Past slope failures
	Erosion landform	Gullies and rills, erosion caused by stream
Geological information	Surface geology	Materials, hardness, thickness, and stability of soil,
	Base rock	Types, shapes, hardness, and age of rocks, metamorphism and weathering condition
	Structure	Distribution and orientation of faults and fracture, strike and dip, joint,
Hydrological information	Surface water	Existence of Stream water channel, pond, swamp
	Ground water	Existence of the spring water
History of activities and damage	Activities	Rate and duration of the movement
	Damage	Date and period of damages, type of damage, countermeasure work
Susceptibility of landslide		Activities that may influence the landslides for example, construction of roads and houses Provide Risk Evaluation

The geological field reconnaissance shall be conducted to figure out the mechanisms of triggering landslides. It is also necessary to study the previous research documents and identify the geological conditions of the site before the field surveys. Followings shall be identified during the reconnaissance survey;

- Hazardous Areas including the landslide areas
- Geological features and structures
- Geomorphologic structures (which may consist of small deformations and a large landform)
- Existence of Groundwater

- Landslide Mechanism
- Trigger of Landslide
- Potential Landslide Movement
- Risk Assessment
- Emergency Response

a. Hazardous Areas including the landslide Areas

It is preferable to get topographical maps and aerial/satellite photos around the landslide area for the identification of the site. Macro scope observation is vital for the estimation of the landslide area and hazard area. Broad view from hill/upland is useful for the macro scope observation. Based on the observation results with the broad view and surface anomalies such as cracks and heaving/subsidence on landslide, landslide active area and hazard area should be estimated.

b. Geological Features and Structures

The past landslides and their mechanisms can be estimated from the following soil characteristics, together with the other geological features;

- Constituent of soil materials and their grain sizes
- Lithology and configuration of gravels
- Color of clay

The observation of the outcropped base rock at around landslide zones can help understanding the geology, stratigraphy, dip and strike. That can be used to grasp the geological structure that may be related to landslide mechanism (Figure 2.3.1). In the case where there are faults or fracture zones around the targeted landslide zones, it is very important to consider whether they are involved with the landslide or not by clarifying the distribution of the faults or fracture zones.

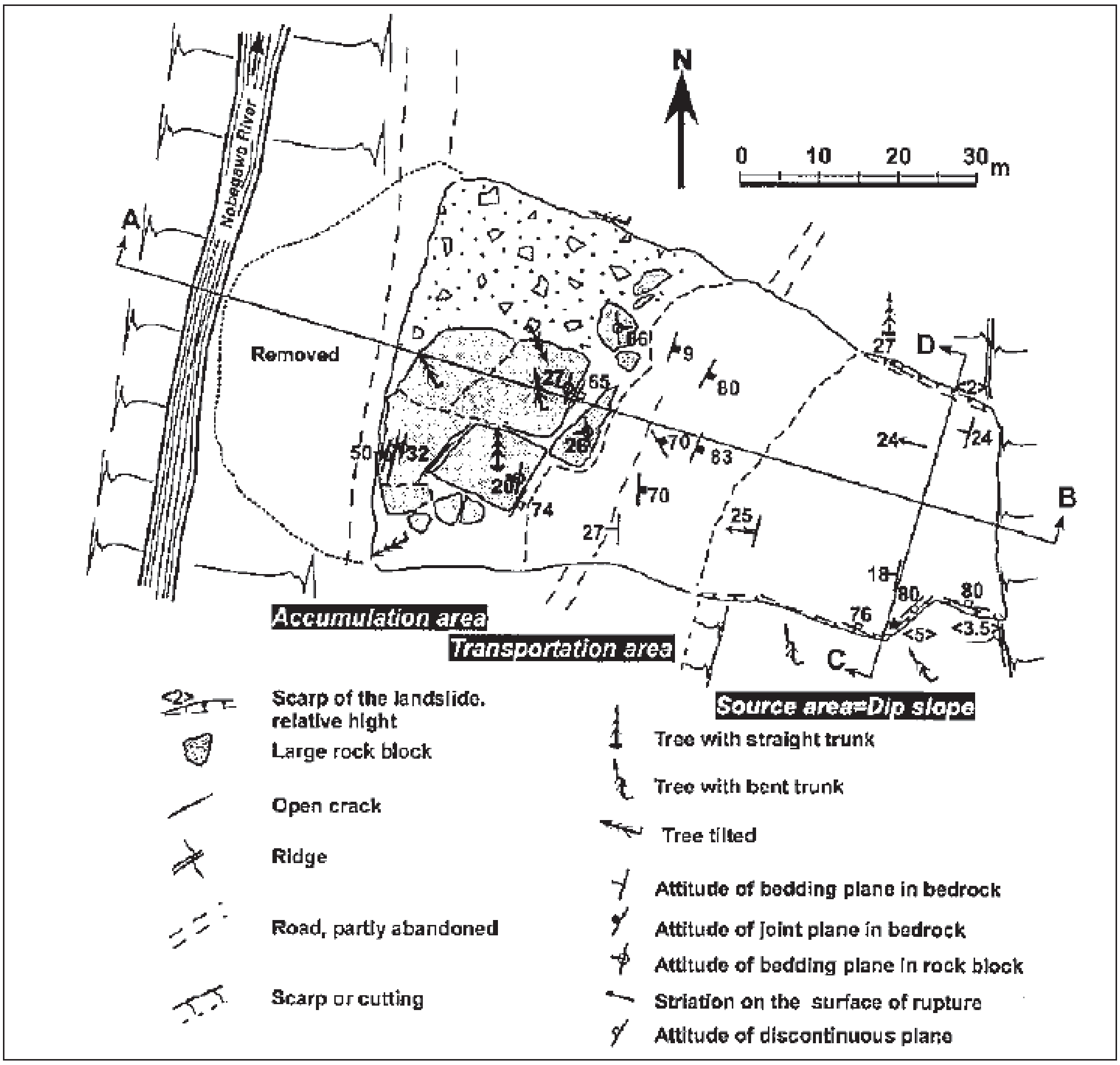


Figure 2.3.1 Geological Information and Geological Map of Landslide, Japan[*4]

c. Geomorphologic Structures (which may consist of small deformations and a large landform)

The Geomorphologic Structures can be understood by observation and analysis of small deformation and wide range landform on topography. Characteristic of deformation and landform for landslide are shown in Figure 2.3.2

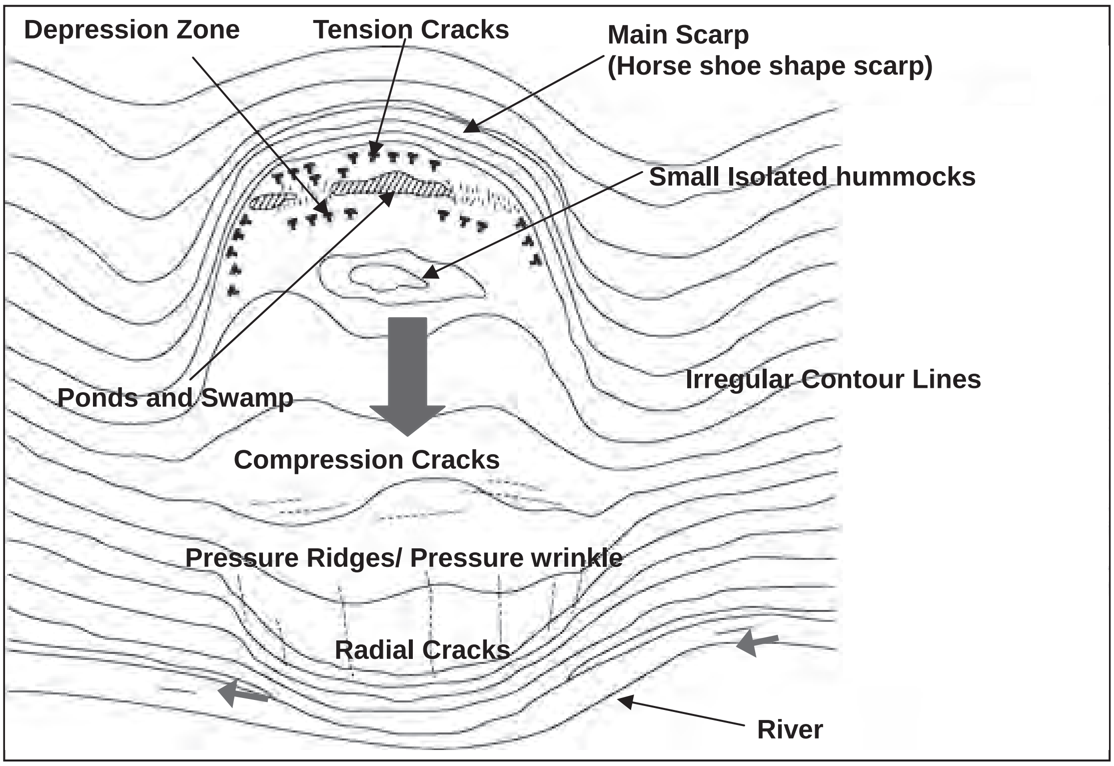


Figure 2.3.2 Formation of Landslides [*14]

d. Existence of Groundwater

Existence of ponds, swamps, wetlands and spring water points shall be evaluated in and around the landslide areas. The relationship between amount of rainfall and water level in pond, swamp or spring water helps us understand the groundwater condition. And the direct cause (shallow or deep groundwater) of the landslides shall be identified.

e. Landslide Mechanism

Following factors shall be used to understand the mechanism of landslides;

- Any small deformation and surface anomaly such as steps, subsidence
- Main scarp, tension crack, compression crack, radial crack, lateral crack
- Deformation of artificial building such as house or stone wall
- Anomaly of vegetation such as bending of tree root.

f. Trigger of Landslides

Since the weather could be one of the main trigger of landslides, the weather condition shall be identified at the time of landslides. Followings are considered to be the triggers of landslides;

f.1 Rainfall

- Continuous rainfall (especially during a rainy season)
- Heavy rainfall in a short term (especially during a rainy season)

f.2 Surface Condition

- River or lake erosion at the bottom of slope
- Change in surface or ground water flows

f.3 Human Causes

- Earth excavation at the bottom of slope
- Earth fills on top of slope
- Poor drainage system

f.4 Others

- Earthquake
- Volcanic activity

It shall be mentioned that many landslides are caused not only by a single trigger but also by combined or multiple triggers.

g. Potential Landslide Movement

The probability of the landslide occurrences can be estimated by close observation of the geological characteristics. For example, observation of any changes on rock cracks or bedding planes may show signs of landslides. Therefore, it is important to continue monitoring the site conditions.

h. Risk Assessment

If possible occurrences of landslides are estimated based on the survey, then the hazardous areas and degree of hazards shall be identified by the risk assessment activities. The risk assessment shall be used to identify the appropriate countermeasures such as establishment of early warning systems or evacuation systems.

The hazardous areas could be not just limited to the lower land of debris deposited areas but also the upper land. It is important to pay attention to the secondary movement of the deposited debris from the initial landslides due to heavy rainfall. Deposit of debris in the river bed could cause the flood along the river areas (Figure 2.3.3).

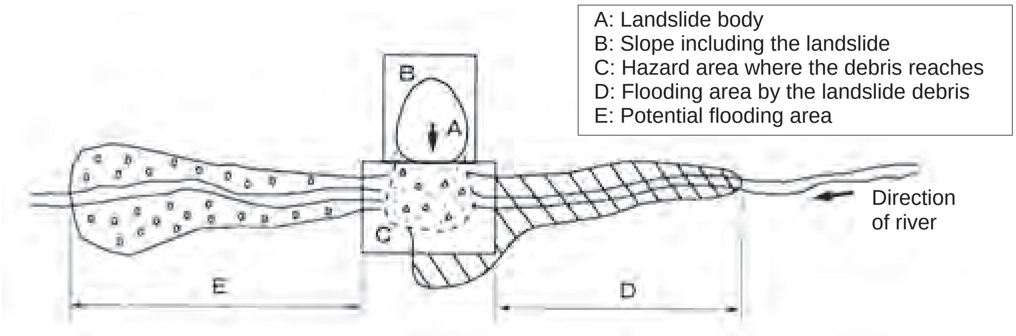


Figure 2.3.3 Affecting Area of Landslide*1

i. Emergency Response

After the surveys, the appropriate countermeasures shall be identified. The Countermeasures include the emergency responses such as construction of gabion walls, establishment of early warning systems, evacuation systems and monitoring systems.

2.4 Detailed Survey

2.4.1 Objectives of Detailed Survey

After preliminary and basic surveys, the detailed survey shall be conducted in order to clarify the occurrences and mechanisms of the landslides. The detail survey shall include;

1. Topographical Survey
2. Geological Survey
3. Slip Surface Survey
4. Surface Anomaly Survey
5. Monitoring of Groundwater Level
6. Laboratory Test

2.4.2 Topographical Survey

The Topographical survey includes creating the topographical mapping that covers a whole landslide area including the periphery. The laser profiler can be used to provide more precise map(Figure 2.4.1) .

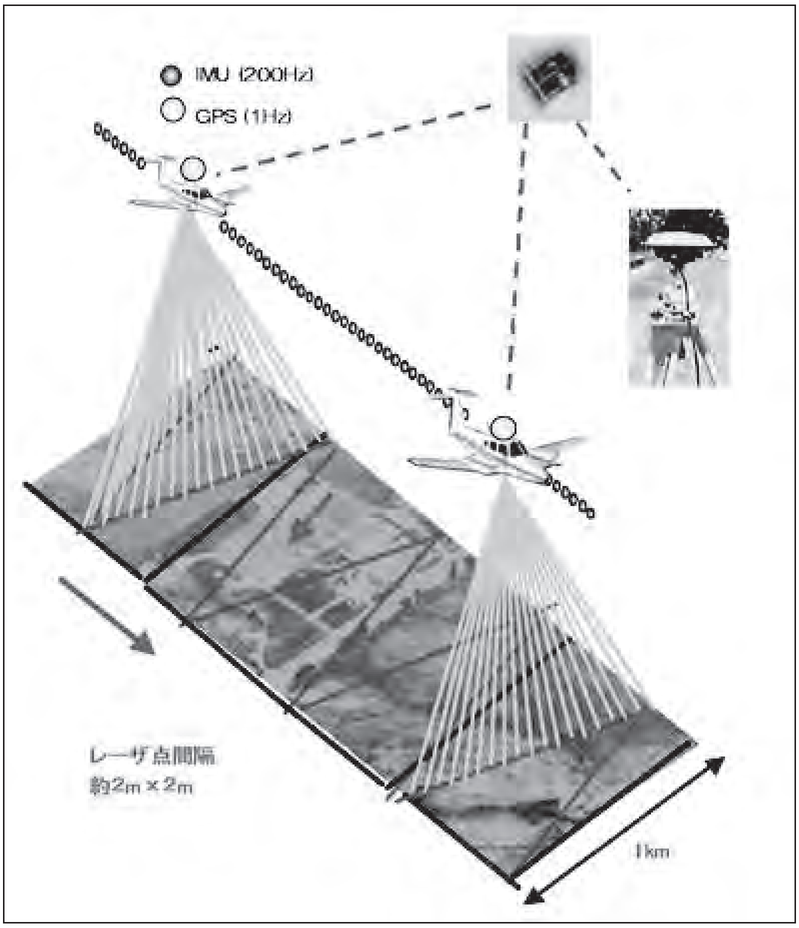


Figure 2.4.1 Schematic Image of Laser Profiler [*2]

2.4.3 Geological Survey (Drilling Survey)

The drilling survey is to take soil samples in order to clarify the geological structures and the slip surfaces. The borehole diameter depends on the instruments such as; inclinometer, pipe strain gauge, groundwater level meter, and groundwater loggings.

a. Location and Quantity of Drilling Survey

Borehole points shall be located along the center line of the direction of landslide movement. At least one borehole at the upper part and three boreholes at the lower part on the main line shall be located with the interval of 30 to 50 m. (Figure 2.4.2). Additionally, sub-lines shall be added with the boreholes of 30 to 50 m intervals for large scale landslide areas. For small scale landslide areas, at least 2 boreholes shall be installed in order to understand the geological condition of the area. Supplemental drillings may be required if there are any complicated structures such as faults or fracture zones.

Each drilling shall have enough length to reach the stable base rock with penetration depth of 3 to 5 m for core sample. At least one deep bore shall be drilled in order to avoid any errors in making judgment.

Therefore, location and number of boring plan shall be revised based on site conditions.

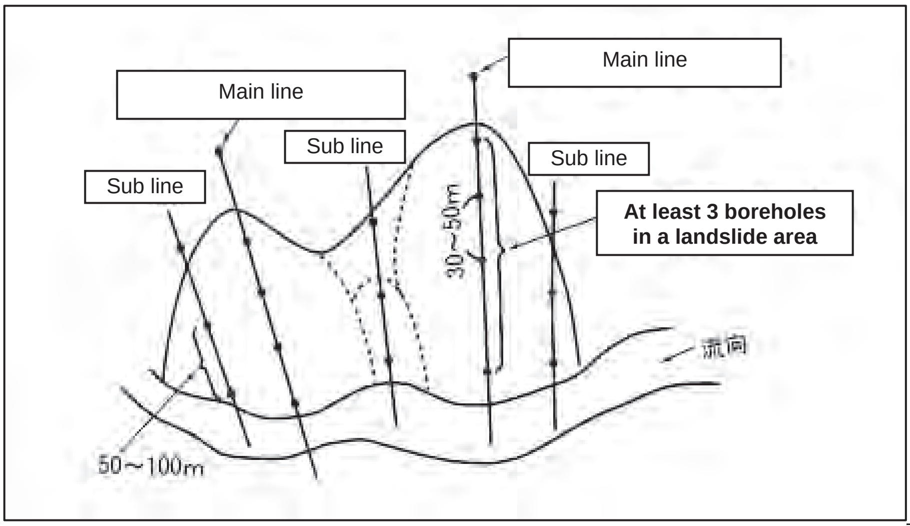


Figure 2.4.2 Location and Quantity of Drilling Survey [*1]

b. Core Drilling

b1. Classification of drilling machines

There are three types of drilling machines; 1) percussion type, 2) rotary type, and 3) rotary percussion type.

b2. Core Sampling Method

The rotary type drilling machines are used for core sampling. Improvement of core recovery factor is one of the most critical factors for obtaining the precise geological data. In addition, the obtained geological data shall be properly recorded for the analysis. The core samples from the boring can provide geological conditions, change of stratums, condition of clay layers (which may cause landslides), condition of groundwater seepages, lost circulation zones, rotation speed, and core boring penetration rate.

b3. Purpose of Casing

Purpose of the casing installation is to maintain the site safety during construction work. Followings shall be focused;

- Prevent the borehole collapse
- Prevent the lost circulation zone and abnormal crushed zone
- Temporary casing shall be used for centering of pipe

- Secure the borehole-head and support base
- Decrease the frictional resistance between boring rods and borehole

2.4.4 Slip Surface Survey

The slip surface survey shall consist of analysis of drilled core sampling and monitoring data by instruments. Followings are the process of the slip surface survey..

a. Provide analysis on the results obtained from the core sampling

Following geological factors shall be examined in order to detect the existence of the slip surface;

A) Fractured zone (Fractured rocks is one of the causes of landslides.)
B) Existence of clay materials or weathering of drilled core
C) Oxidation of the drilled core due to the fluctuation of groundwater

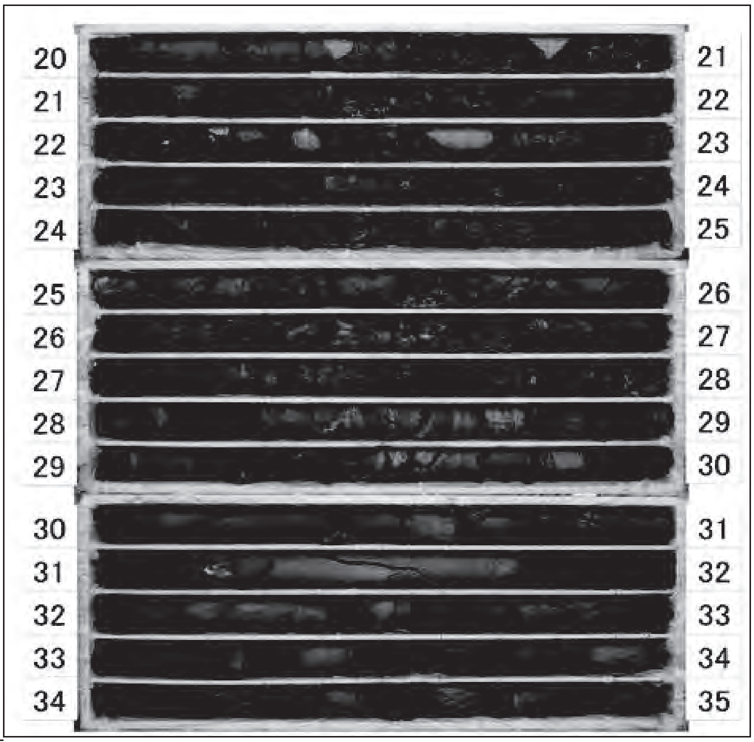


Figure 2.4.3 Typical drilled core in the landslide
(The slip surface is considered to exist from 24m to 25m) *2

b. Monitoring results by instruments

The pipe strain meter is used to estimate the slip surface depth.

There are several measuring instruments such as pipe strain gauge, bore holes inclinometer and bore hole extensometer sensor described as below.

The stopping ring is a primitive method for checking the bending point, which produces shear strength on the slip surface. The ring is connected to the wire that has the measuring indicator. Once after the slip surface is created, the ring is pulled up to the slip surface depth, and it stops. The wire indicator records the depth of the slip surface.

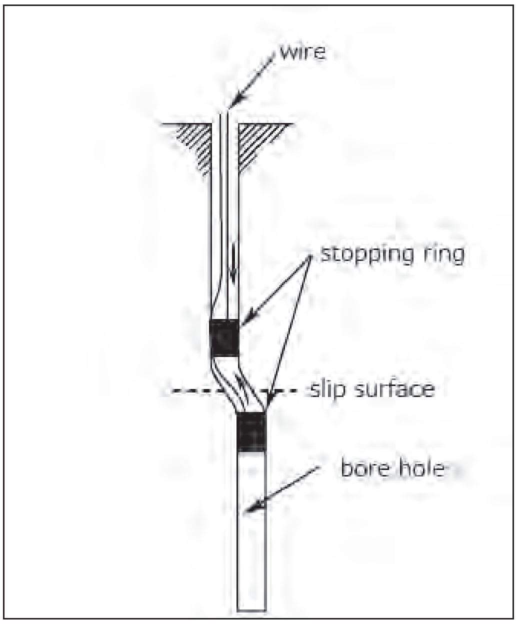


Figure 2.4.4 The schematic view of the usage where the stopping ring utilized [*1]

The pipe strain meter is used to estimate the depth of the slip surface.

As shown in Figure 2.4.5 the pipe strain can be measured by the couple of strain gauges attached on the (PVC) pipes with the interval of one or two meters. The direction of the gauge shall be the same as the landslide movement. The depth of the slip surface can be recorded at the depth of strain accumulation (Figure2.4.7).

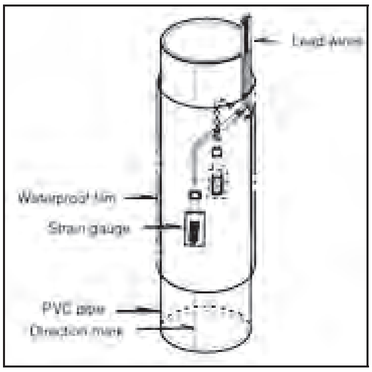


Figure 2.4.5 Setup of Pipe strain gauge[*1]

	
Connection of gauge pipes	Setting of strain sensor cables
	
Filling the borehole with sand	Setting of borehole strain gauge
	
Setting the strain gauge at the top of borehole	Set up the initial condition by data logger

Figure 2.4.6 Installation of Pipe Strain (NBRO and JICA Consultant Team)

b1. Equipment Set Ups

1) The PVC pipe for strain gauge is more suitable for the active landslides, because of availability and suitability to the site installation.

2) Pipe strain gauge has a short life-span, of 1 to 2 years, because surface of the strain gauges easily peels off and the cords are detached.

3) It takes about 7 days until the pipe strain gauges start measuring accurate values.

b2. Time Intervals for the Data Readings

Pipe strain gauges can record the data consecutively. The data shall be taken once a day.

b3. Evaluations of the Results

The strain data obtained from the pipe strain gauges is shown in Figure 2.4.7. The X-axis is the location and amount of strain change. The Y-axis is the depth of boring. The plots show the changes in stain over time. The slip surface can be detected from the most significant changes in the plot.

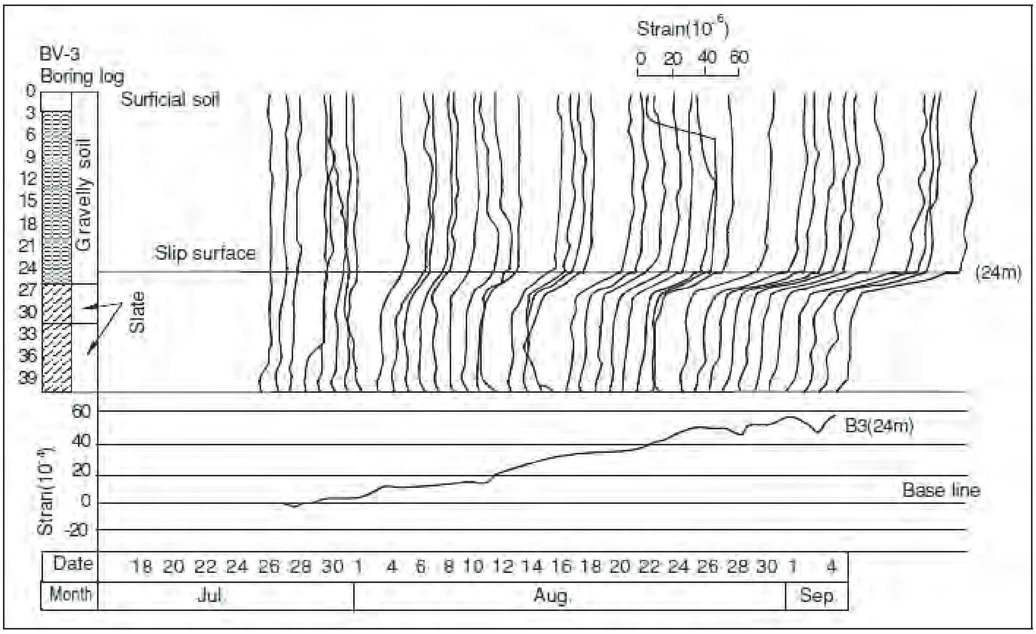


Figure 2.4.7 Plot of Pipe Strain Gauge and Indication of the Slip Surface *1

The bore hole inclinometer shall be inserted after the guiding with the prove. The prove is used to record the inclination. The slip surface is accumulated as the land mass movement progress. The example is shown in Figure 2.4.8a/b.

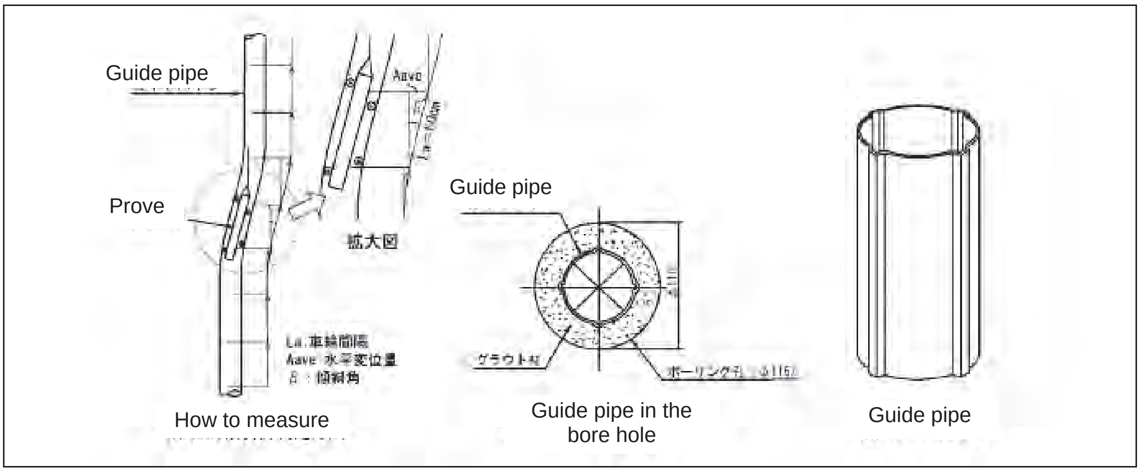


Figure 2.4.8a The schematic view of the bore hole inclinometer[*1]

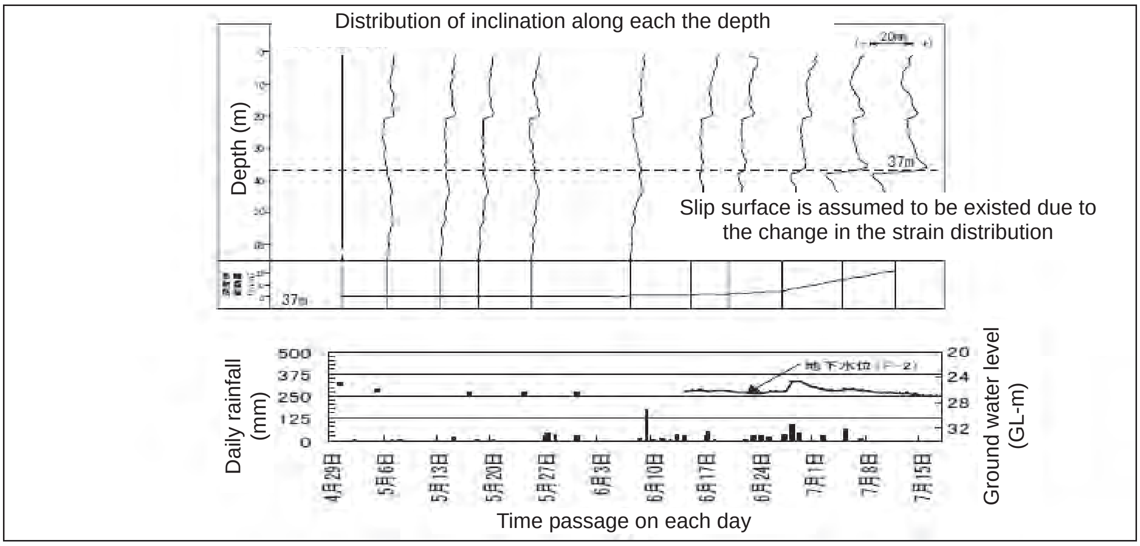


Figure 2.4.8b The distribution of the inclination with comparison of the rainfall [*1]

The mounted type inclinometer is also used for the real time monitoring at all the depth along the bore hole (Figure2.4.9).

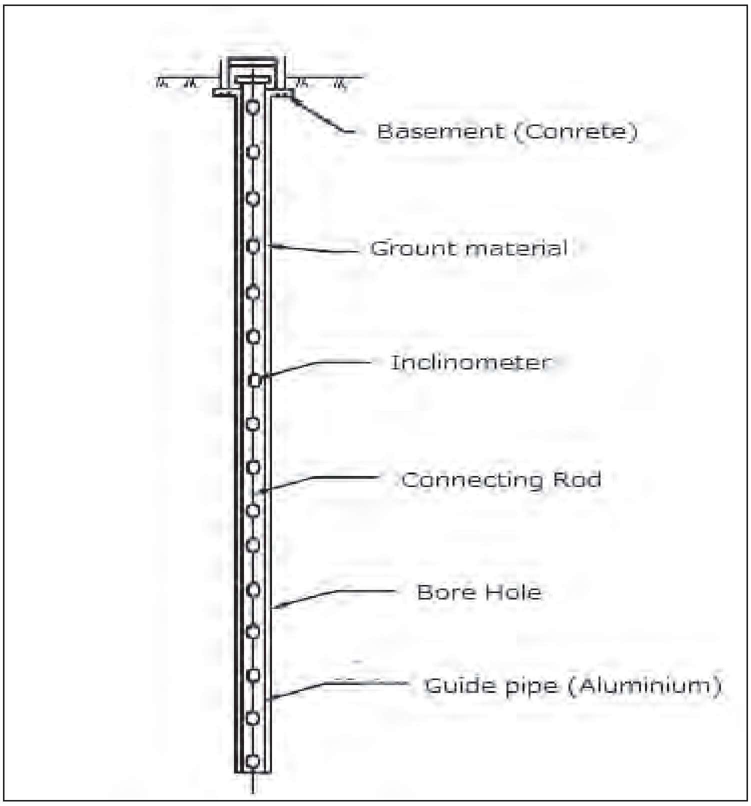


Figure 2.4.9 The mounted type inclinometer[*1]

The borehole extensometer is converted from the surface extensometer into the borehole application by connecting the wire to the bottom of the bore hole. The wire is pulled along the slip surface by the shear on the surface (Figure2.4.10).

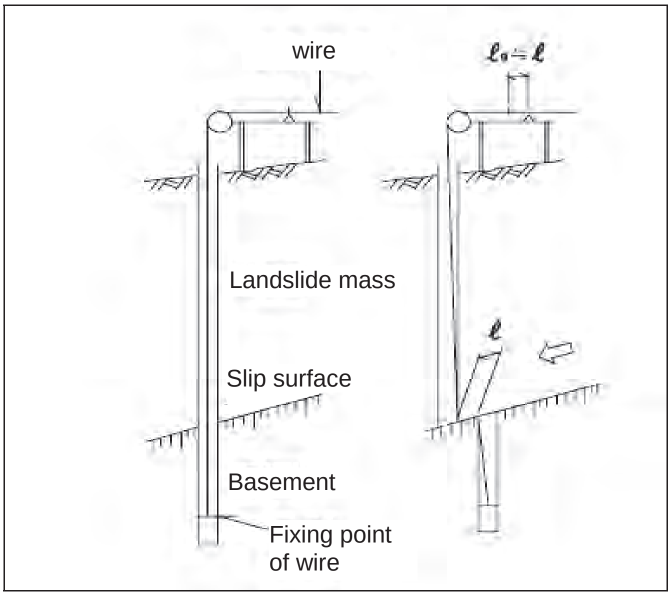


Figure 2.4.10 The image of the bore hole extensometer [*1]

The characteristics of these instruments described above are explained in the table below. The survey to seek the slip surface includes the two aspects, that are the depth of the slip surface and the displacement along the slip surface. The below table show the typical performance each instrument can fulfill. For the effective monitoring the consideration into the site condition and specification of each instrument should be needed.

Table 2.4.1 The characteristics each instruments can produce

Instrument	Item on measuring			
	The depth of slip surface		The displacement of the slide	
	The minimum interval each instrument can set	The maximum depth each instrument can reach	The accuracy each instrument can provide	The maximum range each instrument can provide
Pipe strain meter	1.0 [m]	Approx. 50 [m]		
Bore hole inclinometer	0.5 [m]	Approx. 50[m]	1.0 [m]	Approx.10[cm]
Bore hole extensometer	Can't be measured		Not applicable	Approx.200[cm]

2.4.5 Surface Anomaly Survey

Surface anomalies are one of the most important indicators to detect the symptoms of the landslides and its movement.

Major surface anomalies are listed as follows, and their photos are shown in Figure 2.4.17 in the later section.

- Cracks with various opening sizes
- Undulating terrain
- Deformation of artificial structure (eg. roads, and houses)

Following instruments can be used to measure the surface anomalies.

1. Extensometer
2. Surface Inclinometer
3. Total Station or GPS

The extensometer (Figure 2.4.11) is commonly used in Japan because of accuracy, reliability and easy usage. The extensometer is installed at the ground cracks caused by landslides, which does not require drilling boreholes.

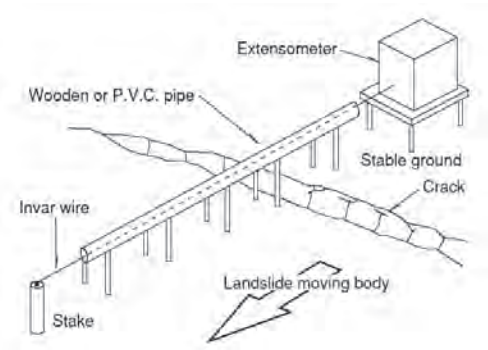


Figure 2.4.11 Setup of Extensometer [*15]

2.4.6 Monitoring

The landslide mechanism, such as magnitude of movement, condition of slip surface, change of groundwater levels, can be observed by continuation of monitoring using the appropriate measuring devices. (e.g. depth of slip surface, slide direction and the slipping velocity) from the results. In addition, the landslides may be predicted by monitoring, and as a result, the human lives are protected.

Following factors shall be monitored for the landslides

a. Rainfall
b. Surface Deformation
c. Ground Water Level
d. Subsurface (Slip Surface) Movement

Monitoring devices are shown in Figure 2.4.12 and Table 2.4.1 In this section, installations of each monitoring device are explained.

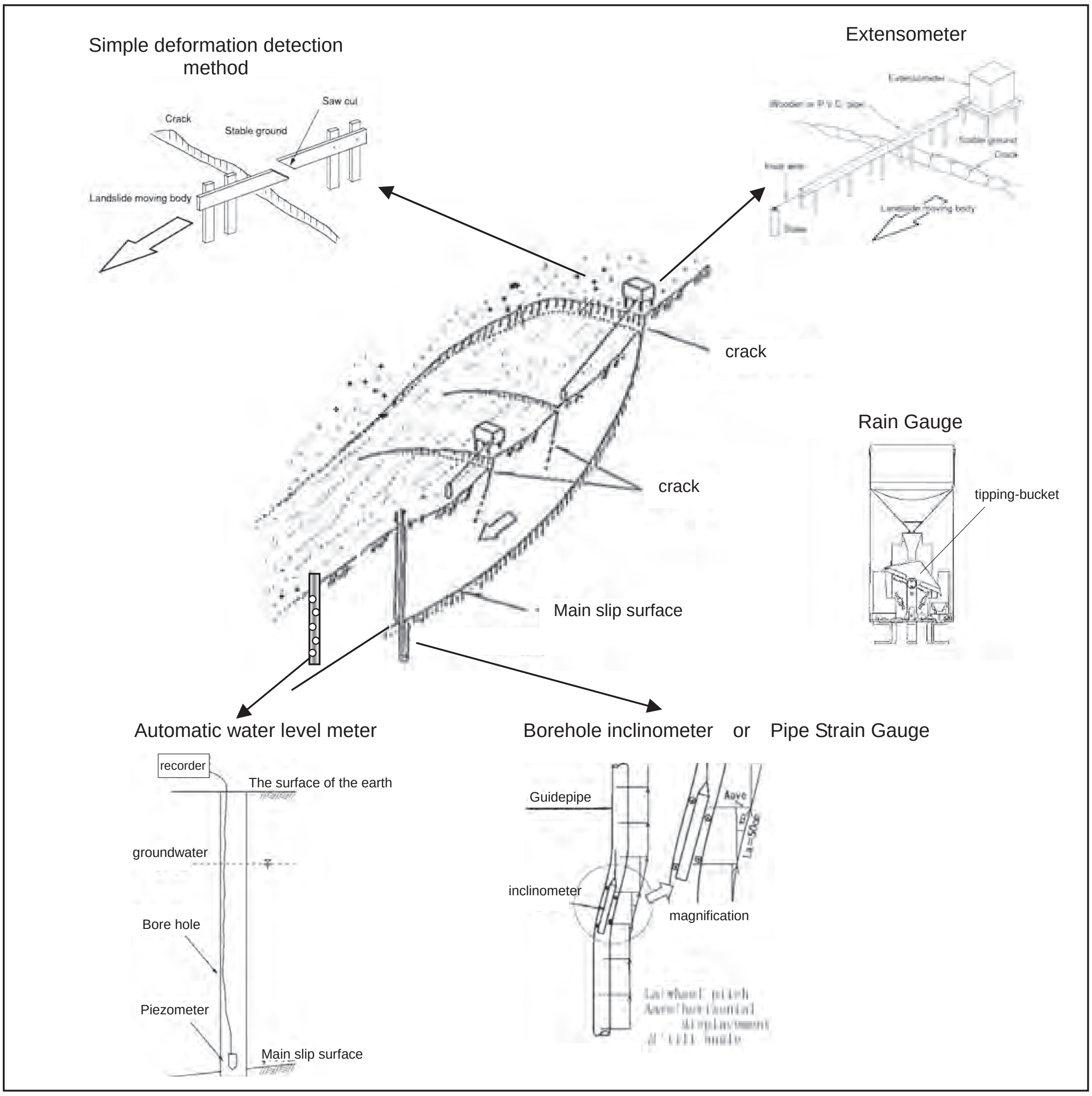
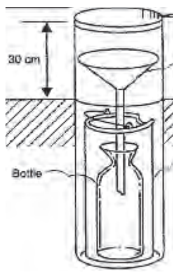
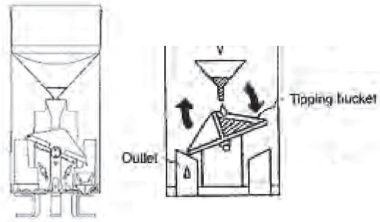
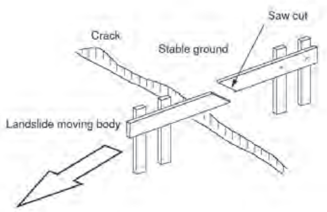
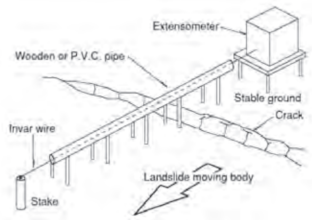
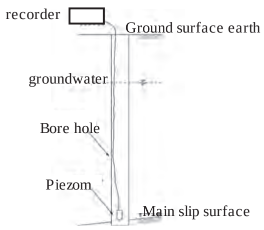
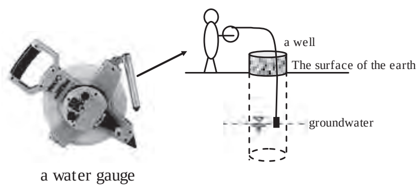
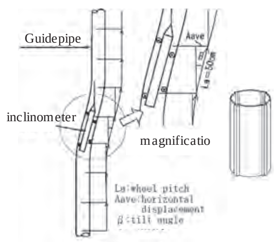
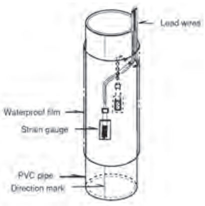


Figure 2.4.12 Monitoring Set-Ups *13

Table 2.4.2 Types of Monitoring Devices [*13]

Observation type	Equipment	
a. Monitoring rainfall	Standard rain gauge (reservoir-type): Rain is collected in the container and the cylinder reads the accumulated amount of rainfall. 	Tipping-bucket rain gauge : The tipping bucket falls once the rainfall fills in the device. 
b. Monitoring surface deformation	Extensometer: The device is used to measure the magnitude of land movement over time.ously 	Simple deformation detection board:This is a simplified extensometer 
c. Monitoring ground water level	Automatic water level meter:The device is used to measure the ground water level and aquifer characteristics in the distributed areas.. 	※:The device is used to measure the parameters of groundwater. 
d. Monitoring subsurface (slip surface) movement	Borehole inclinometer:The device is used to measure the slip surface movement. It can be used only for inactive landslides. 	Pipe Strain Gauge:The device is used to measure the landslide movement and a position of a slip surface, and record the data for 1 to 2 years. It can be used for active landslides. 

2.4.6.1 Monitoring of Rainfall

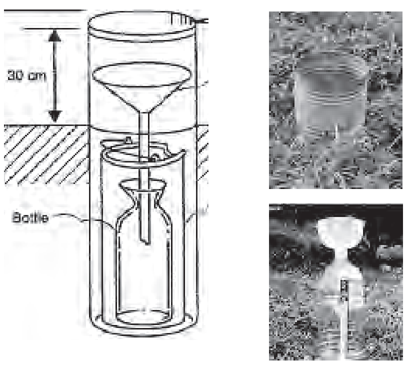
a. Rain Gauge Station

- Standard Rain Gauge (Reservoir-Type)

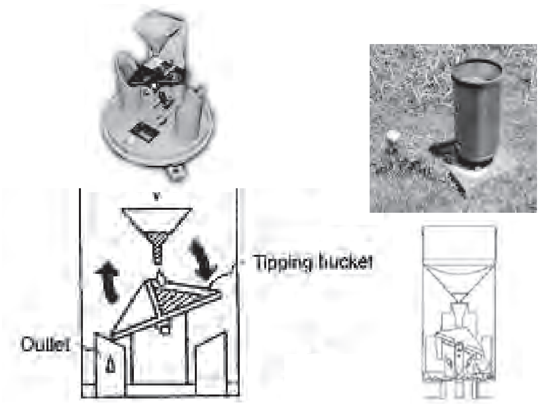
Rainfall is collected in the container and the rainfall amount is measured by the cylinder over time. The measuring accuracy is 0.1 mm.

- Tipping-Bucket Rain Gauge

The tipping bucket falls automatically once the device is filled with rainfall. Simultaneously the pulse signals for 0.1 to 0.15 seconds are transmitted to the recording system. The totalizing chronographer is used for the recording system. The measuring accuracy is 0.1 to 0.5 mm.



Standard Rain Gauge



Bucket Type Rain Gauge

Rain Gauge of DiMCEP

Figure 2.4.13 Types of Rain Gages

(JICA Consultant Team)

b. Installations of Devices

Locations of Installation: Location of the installation shall be selected at flat surface with no obstacles such as buildings, trees or winds. Wherever possible, the devices shall be kept free from the other obstacles by a distance of at least four times the height of the obstacle. Moreover, the grass shall be planted around the device, or the rain receiver shall be set higher than the surroundings so that the water does not drip into the gauge which might influence the readings. If possible, the open area of at least 10m x 10m shall be selected for the device installation.

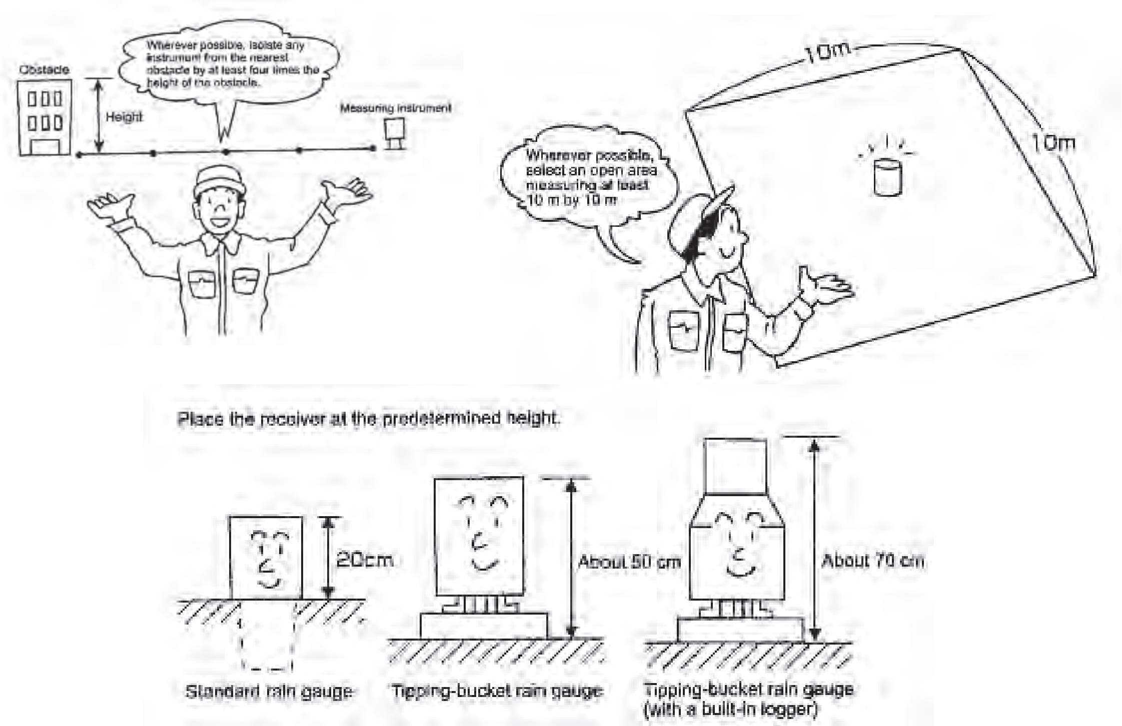


Figure 2.4.14 Remarks for installation of rain gauge *13

c. Measuring Method

The standard rain gauge (reservoir-type) is a manually measuring device. The measurements shall be taken several days since the amount of rainfall storage is limited, especially during a heavy rain.

The tripping-bucket rain gauge is an automatic recording device, which requires a system for data recording and storage on site.

d. Operation and Maintenance

The operation and maintenance for the rain gauge device include;

1. Clearing of fallen leaves and dust around the rain gauge.
2. Cleaning of inside of tipping bucket.
3. Repairing of any damages at the loose connections, cut, and rusted electric wiring
4. Power batteries for the devices.

e. Data Management

Standard unit for rainfall is millimeter (mm). Daily rainfall (Figur.2.4.15) amounts are expressed on a bar chart with respect to time, and the chart is can be combined with change in landslide movement, or groundwater level for comparison. The hourly accumulated or effective rainfalls can be estimated from the chart.

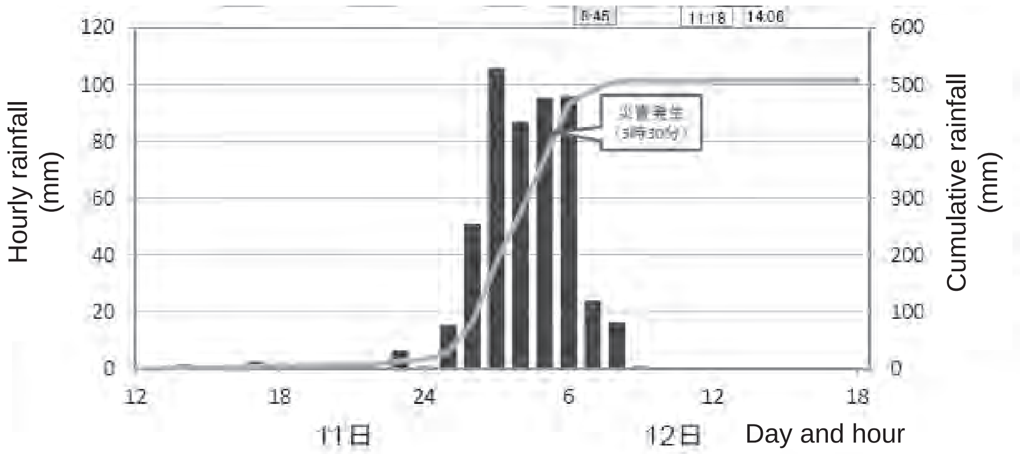


Figure 2.4.15　Dairy Precipitation Analysis

2.4.6.2　Monitoring of Groundwater Level

The groundwater shall be monitored in order to identify the area of groundwater distribution and direction of the flow. The obtained data can be used to provide stability analysis and countermeasure plans.

a.　Automatic Measuring Device for the Water Level

The automatic measuring device for the water level shall be installed in the boreholes. The measurements are used to analyze the correlation of rainfalls and groundwater. The correlation analysis can provide information to predict the landslide occurrence based on the groundwater behavior.

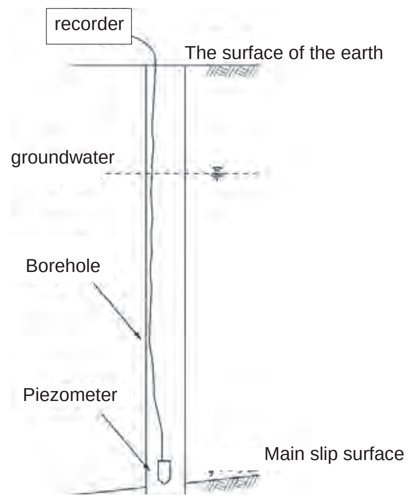


Figure 2.4.16　Automatic Water Level [*1]

a1. Equipment Set Ups

The water levels shall be monitored in order to identify the areas of water distribution and groundwater conditions.

a2. Time intervals for the Data Readings

The automatic measuring device can record the data consecutively. The interval of the device shall be set so as to take the hourly data, which is the most appropriate interval for the analysis of groundwater level and landslides.

a3. Data Collection

The data shall be collected once a month, in order to avoid the possible mechanical errors. During rainy seasons when the landslides may become more active, the data shall be collected twice a month.

a4. Evaluation of the Data Obtained

The obtained data of water level and groundwater level shall be plotted in a graph together with the daily rainfall data (Figure 2.4.17), because the groundwater level could be linked to rainfall behavior. They should be shown together to assess the landslide characteristics.

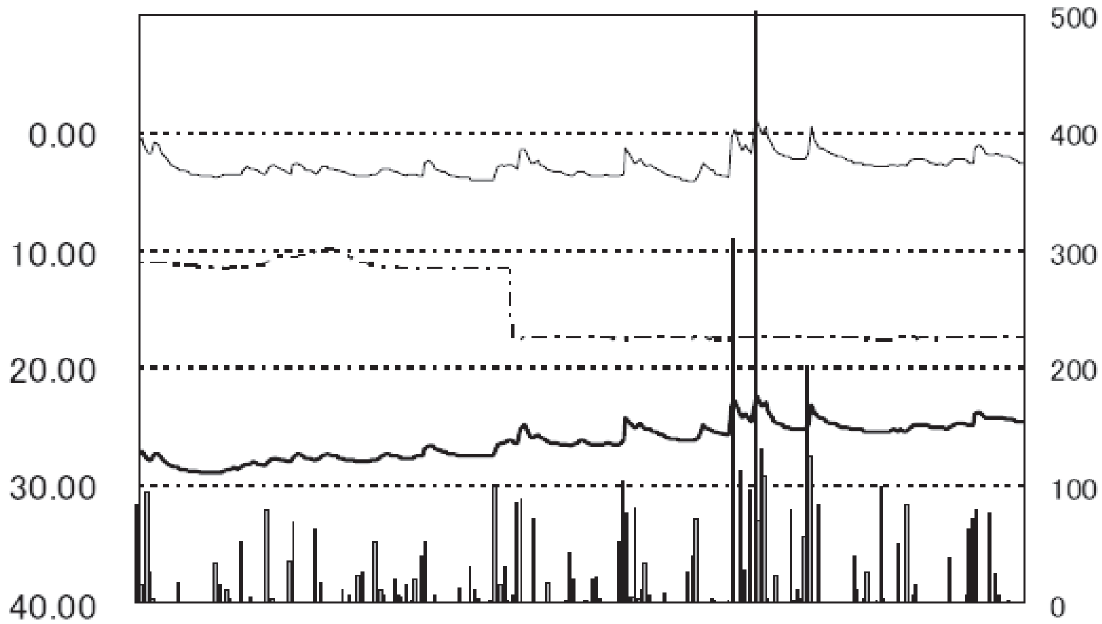


Figure 2.4.17 Relationship between Rainfall and Groundwater Level *1

Figure 2.4.17 shows that the groundwater level increases during a rainfall event. It indicates that there is a close correlation between rainfall and groundwater. The results imply that lowering of the groundwater level shall be the objective of the countermeasures for the landslide mitigation.

a5. Batteries

The Battery shall be replaced when the voltage becomes below 3.0V (for example. The criterion is normally designated for respective instrument.). The voltage shall be verified at the time of data collection.

b. Use of Groundwater

The groundwater is used by the surrounding communities in the landslide areas. For example a piezometer shall be used for the groundwater investigation (Figure 2.4.18). The piezometer is the instrument where the piezo-electric device is mounted in the sensor to quantify the static water height by converting the water pressure into the electricity (voltage). The landslide countermeasures shall be designated so as to decrease in the groundwater level.

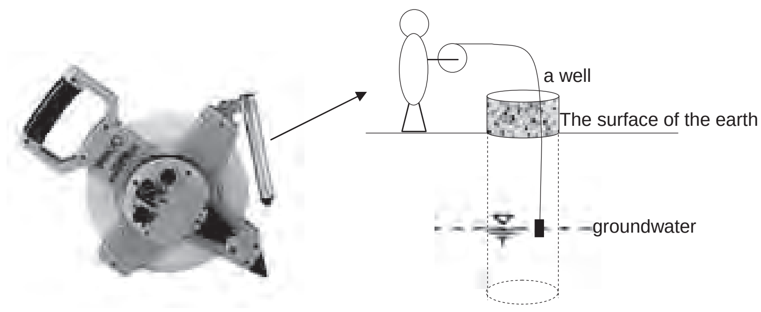


Figure 2.4.18 Water Level Measurement (Manual) *13

2.4.6.3 Monitoring of Surface Deformation

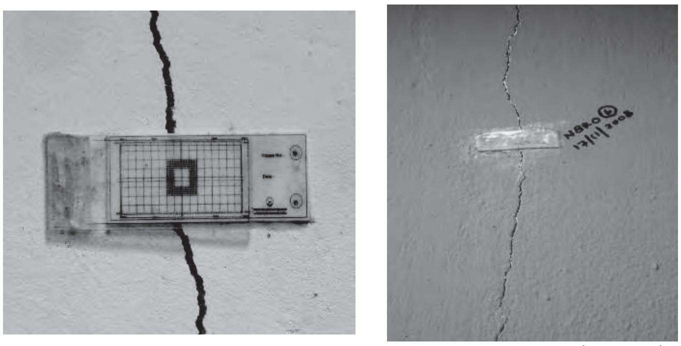
As mentioned in Section 2.4.5, the surface anomalies are one of the most critical indicators to detect the symptoms of the landslides and its movement. In this section, examples of surface anomalies which are considered to be the direct causes of landslide movement are explained.

Major surface anomalies are listed as follows, and their photos are shown in Figure 2.4.17

- Cracks with various opening sizes
- Undulating Terrains
- Deformation of artificial structure (eg. roads and houses)

1) Crack monitoring by simple methods

In landslide areas, the cracks quickly developed on the building walls may be an indication of another landslides. There are several causes for developing cracks; therefore, it is important for the communities to understand the mechanisms of crack development which may result in landslides nearby the communities. Cracks can be found on the walls or the floors of houses. Therefore, the community members shall be trained to monitor the cracks in order to predict the potential landslides. The crack-gauge provided by the NBRO can monitor the tension cracks by measuring the expansion of the cracks on the walls due to the active landslides (Figure2.4.19). The advantages of this device are; reliability of measurement, easy usage, simple installation method, minimum maintenance requirements and reasonable price.



(NBRO)

Figure 2.4.19 Crack Gauge Installed to Measure the Movement of Cracks on the Walls

(JICA Consultant Team)

Figure 2.4.20 Measuring the distance between cracks

The extensometer and the Simple Movement Detection Board shall be used to measure the distances between cracks on the ground.

a. Extensometer

As shown in Figure 2.4.21, the extensometer is installed across a crack caused by a landslide. Because the installation does not require drilling boreholes, several extensometers can be used to monitor the landslide movement.

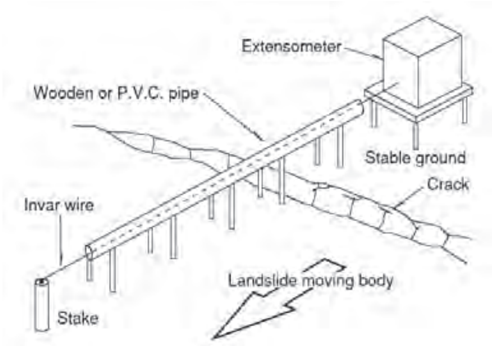


Figure 2.4.21 Setup of Extensometer (referred from *15)

Location of the extensometer shall be selected as followings;

<u>Crown of Landslide</u>

The crown of landslide is the most active part, generating a huge amount of soil mass movement. Therefore, an extensometer shall be installed in this zone. Soil mass slides down by gravity force along the slope, generating tension stress at the surface of rupture. Compression stress may be generated when the soil mass fall over from the upper area of slope.

<u>Middle of Landslide</u>

The extensometer shall be installed across the boundaries of the segmented blocks, which enables to record both compression and tension stress in the middle of landslides.

<u>Toe of Landslide</u>

Compression stress is generated at a toe of landslide slope. The amount of soil mass fall down and accumulated at a toe is smaller than the soil mass ruptured at the crown of landslide. When the tension force is recorded in this area, it indicates that another landslide may be generated towards the lower zones of the slope. The soil mass accumulated at the toe shall expand and create the traverse ridges in the direction of soil movement.

a.1 Equipment Set Ups

The length of invar wire connected to the extensometer can be adjusted by changes in temperature variations. The maximum invar length is 15 m (typical).

a.2 Data Recording intervals

The Extensometer can record the data consecutively. It shall record the hourly data.

a.3 Data Collection

The data shall be collected once a month in order to avoid any errors. During rainy season when the landslides become more active, the data shall be collected twice a month.

a.4 Data Management

The data obtained from the extensometer are recorded as a cumulative data (Figure 2.4.22). The Rainfall data shall be plotted on the same graph so as to compare the relationship between rainfall and landslide behavior.

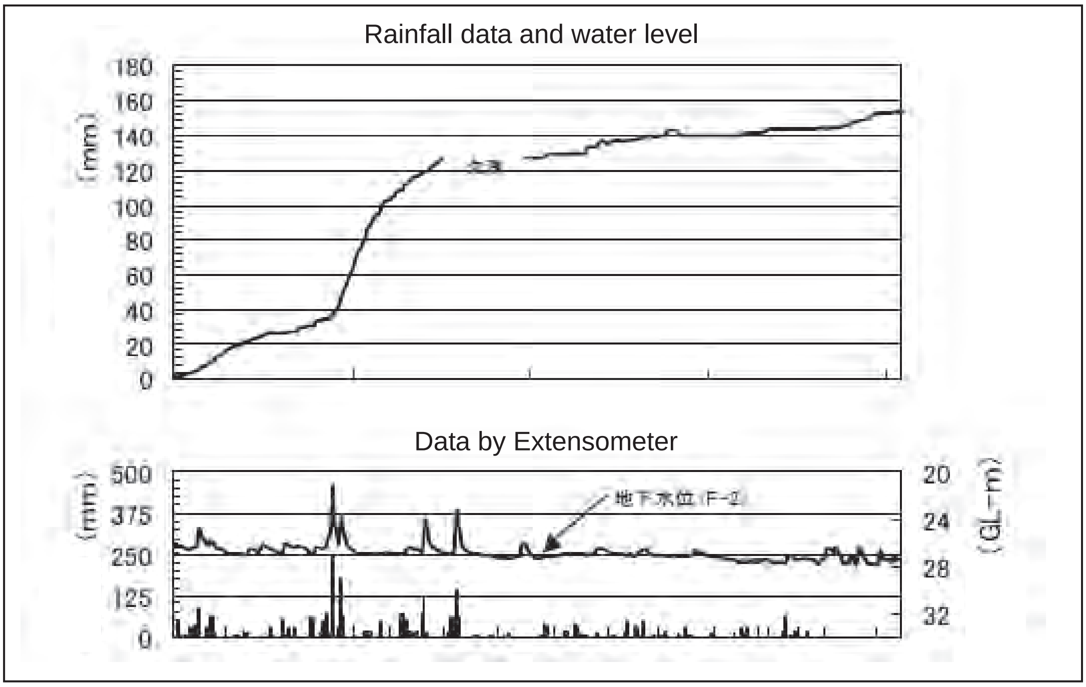


Figure 2.4.22 Data obtained from the Extensometer, Rainfall and Water Level [*1]

a.5 Evaluation of the Results

Table 2.4.3 shows the criteria which can be used for the landslide hazard analysis. The evaluation shall be conducted for all the results obtained from the various devices.

Table 2.4.3　Evaluation of the Results obtained from the Extensometer

Movement Level	Movement per day (mm)	Movement per month (mm)	Sediment Accumulation
Emergency Level	over 2×10^{1}	over 5×10^{2}	Very Obvious
Defined Level	over 1×10^{0}	over 1×10^{1}	Obvious
Quasi-defined Level	over 1×10^{-1}	over 2×10^{0}	a little Obvious
Potential Level	over 2×10^{-2}	over 5×10^{-1}	Invisible

(Simplified from *14)

b. Crack Monitoring

The past landslides can be identified by finding the existing bulges and cracks on the surface ground. The landslide surveys need mapping of all existing tension cracks and surface bulges which may be covered by vegetation. The vegetation shall be cleared in order to measure any changes in width and length of those remarks and their locations.

The simple crack gauge (Figure 2.4.23 and Figure 2.4.24) shall be a substitute or alternative for the extensometer under the condition where the emergency on site needs some kind of monitoring activity. This tool is simple to construct and easy to handle in order to measure the expansion of the crack by measuring the distance between the markers on the side plate. But there is the limitation related to the accurate evaluation of the landslide behavior because data is not recorded automatically and not digitized for precise evaluation.

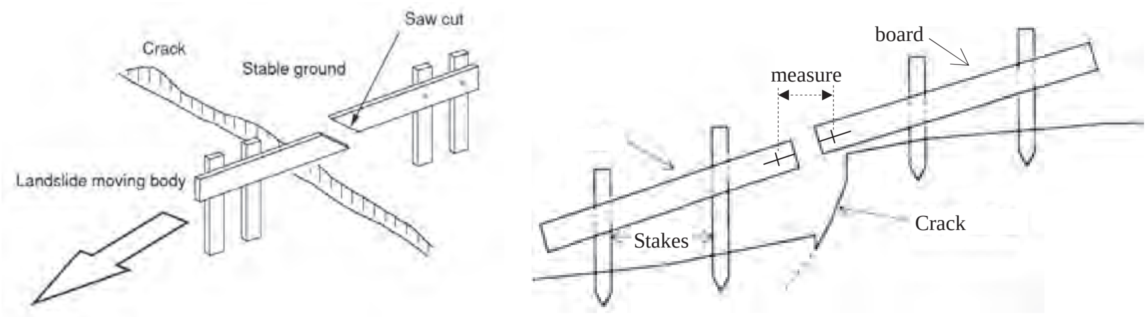


Figure 2.4.23　Simple Crack Gauges *13

(JICA Consultant Team)

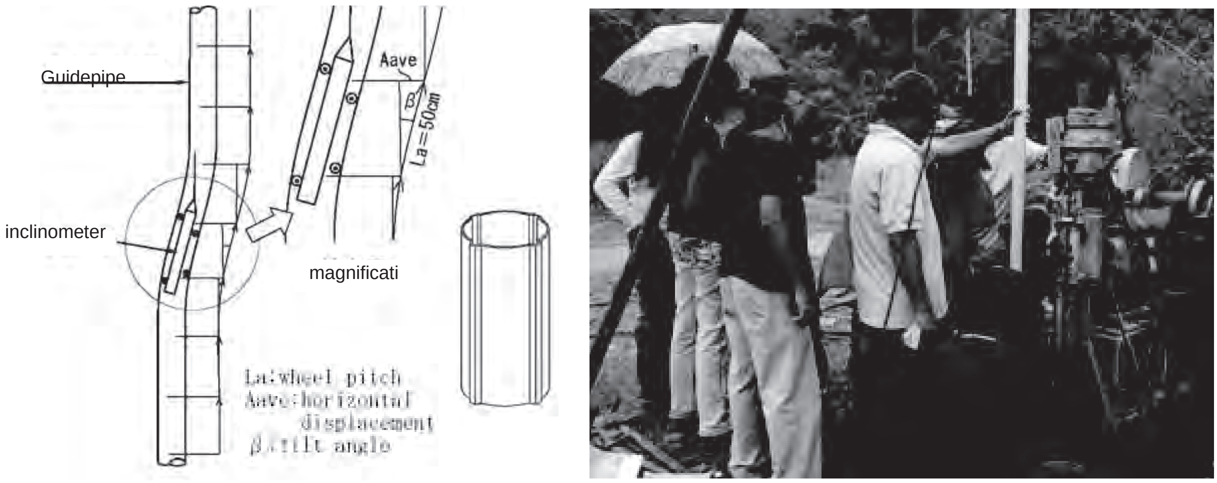
Figure 2.4.24　Simple Crack Gauge at Mahawewa Site

2.4.6.4 Monitoring of Subsurface (Slip Surface) Movement

The borehole inclinometer is a method of measurements to estimate the magnitude mechanisms of landslides. Borehole inclinometer and pipe strain gauge are used for this measurements.

a. Borehole Inclinometer

The Borehole Inclinometer is used to investigate the depth of a slip surface which may cause landslides (Figure 2.4.25). The inclination of the borehole is measured continuously by inserting a probe into guide pipes inside the borehole. This device can estimate the position of a slip surface which may activate landslide.



(JICA Consultant Team)

Figure 2.4.25 Borehole Inclinometer

a1. Installation of Borehole Inclinometer

1) Casing Pipe Installation
The casing pipes shall be installed in order to protect the boreholes walls from collapsing. Prior to the installation, verify that there is no slime at the bottom of the borehole. Before the installation, estimate the required casing length by from the length of the borehole.

2) Backfilling
The annulus space between the walls of borehole and casing pipe shall be filled with uniform reddish quartz sand. When filling, be careful not to create air pockets in the space.

3) Cementing works
Followings are required for the cement works;
- Portland Cement

- Crushed Rock Chips
- Uniform Reddish Quartz Sand
- Board for Concrete Formwork (if necessary)
- Tools such as shovel, bucket, trowel for making cement mixture
- PVC pipes which support borehole head construction (diameter of 100mm and length of 30cm)

Construct reinforced concrete foundation by placing the suitable amount of cement mixture into the wooden mold.

	
Tape Sealing	Riveting
	
Placing Cement	Setting of guide protector
	
Data Sampling	Installation of Inclinometer Cable

Figure 2.4.26 Inclinometer Installation

a2. Equipment Set Ups

1) Borehole inclinometer takes measurement by moving a probe with gradient sensors up and down. The probe is inserted into the guide pipes inside bore holes. When the guide pipe is bent by the external forces such as landslides, the measurements cannot be taken. Therefore, when there is active landslide, the other methods of measurements, such as pipe strain gauge, shall be employed.

2) It takes about 7 days for the borehole inclinometer to take measurements.

3) Due to the temperature variation, the values indicated by the inclinometer sensor at the bottom of boreholes may fluctuate at the beginning of the measurement. Measurements shall not start until the values become stable.

a3. Data Recording Intervals

It takes about 7 days for the borehole inclinometer to start taking accurate measurements. The data recording intervals shall be established based on the site condition. The data shall be collected once a month but during rainy season, the data shall be taken more frequently in order to avoid any possible errors.

a4. Data Management

The analysis results of the data obtained from the borehole inclinometer is shown in Figure 2.4.27. The X-axis is the amount of gradient change, and the Y-axis is the depth of borehole. The rate of change in gradient can be estimated. The highest rate of change is considered to be location where the slip surface may occur.

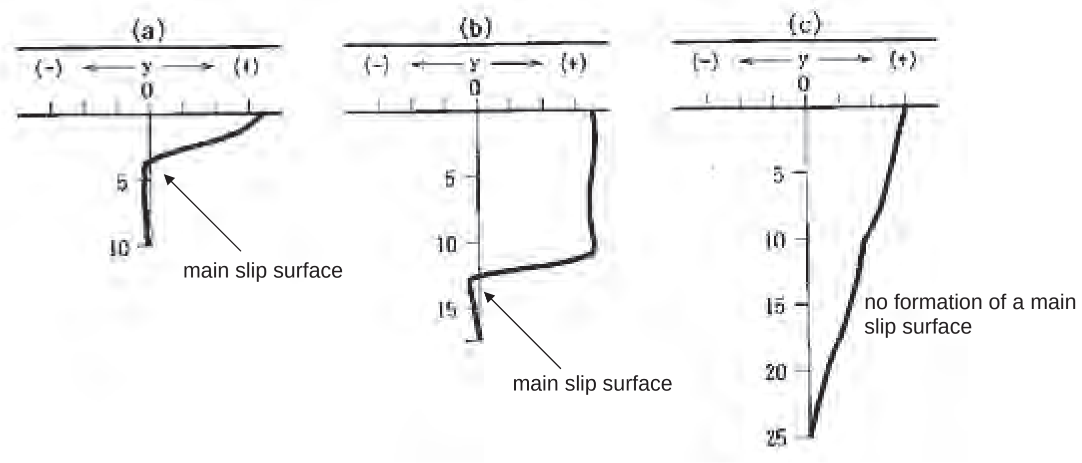


Figure 2.4.27 Determination of a Slip Surface Position using Borehole Inclinometer[*1]

From Figure 2.4.27 indicates that there are signs of slip surface in (a) and (b), where there is a sudden change in the rate of gradient. There is no slip surface in (c). From (a) and (b), depth of the slip surface is estimated to be GL-4m and GL-13 respectively.

b. Pipe strain gauge

As shown in Figure 2.4.28, the gauge shall be attached to the PVC pipe so as to face the direction of the landslide flow. The slip surface can be estimated by reading the depth of accumulation of strain read from the gauge.

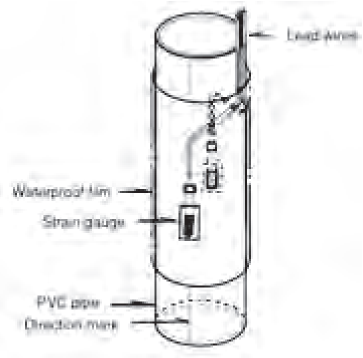


Figure 2.4.28 Pipe Strain Gauge [*1]

b1. Equipment Set Ups

1) The PVC pipe for strain gauge is more suitable for the active landslides, because of availability and suitability to the site installation.

2) Pipe strain gauge has a short life-span of 1 to 2 years, because surface of the strain gauges easily peels off and the isolation between the cords is broken.

3) It takes about 7 days until the pipe strain gauges start measuring accurate values.

b2. Time Intervals for the Data Readings

Pipe strain gauges can record the data consecutively. The data shall be taken once a day.

b3. Evaluations of the Results

The strain data obtained from the pipe strain gauges is shown in Figure 2.4.29. The X-axis is the time serial of the vertical measured profile of strain change. The Y-axis is the depth of boring. The plots show the changes in stain over time. The slip surface can be detected from the most significant changes in the plot.

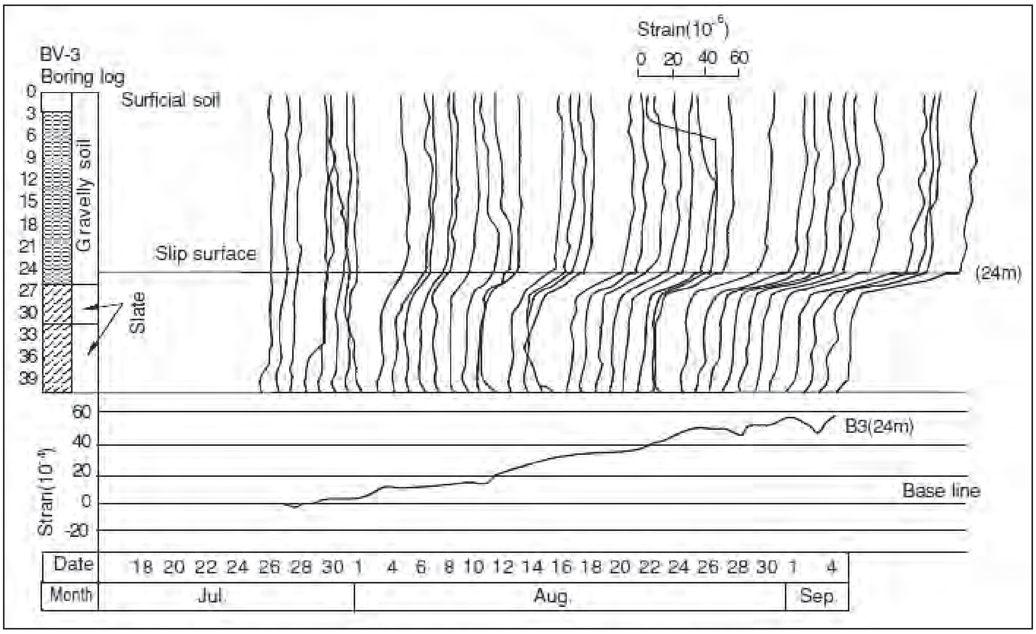


Figure 2.4.29 Plots of Pipe Strain Gauge and Indication of the Slip Surface[*1]

Table 2.4.4 shows the one example of definition of the assessment for the landslide behavior used by the monitoring results of pipe strain gauge. The reference of these monitored data shall serve for the evacuation activity. Detailed boring core checks are important to decide the position of a slip surface.

Table 2.4.4 Monitoring Results of Pipe Strain Gauge

Movement Level	daily movement (μ)	monthly movement (μ/month)	Movement Feature		Geological or Geographical possibility of sliding surface	Over all Judgment
			Trend	Feature		
Defined Level	over 10^2	over 5×10^3	prominence	continuation	Tension and Compression	Sliding definitely
Quasi-defined Level	over 10^2	over 10^3	semi -prominence	continuation	Tension and Compression	Sliding slowly
Potential Level	under 10^2	over 10^2	a little moved	continuation intermittence disturbing recursion	Tension and Compression	Sliding potentially
anomaly movement	under 10^2	over 10^3	none	intermittence disturbing recursion	none	Movement by another factor

Modified from*1

2.4.7 Laboratory Test

After the site investigation, laboratory tests may be recommended. The laboratory tests include; 1) physical tests which are used to estimate the slip surface strength, and 2) dynamic test. Both tests are used to examine the stability of landslide, and to review the test results and grasp the general characteristics of the ground.

2.4.7.1 Dynamic Test

Shear strength of soil decreases from its maximum strength to the residual strength as the shear deformation progress. (Figure 2.4.30) It is assumed that the landslides have occurred repeatedly in the past geological ages. Therefore, when the shear strength is estimated from the soil test, the residual strength shall be used. The maximum shear strength shall be used for the areas with relatively new landforms. The shear strength for clay soil changes its strength based on the characteristics of the soils (accumulation, erosion, etc.) which the samples are taken.

The single share or ring share strength tests shall be conducted in order to measure the resistance strength of the slip surface. (see Table 2.4.5). The undisturbed soil shall be used for the proper soil tests.

The dynamic test needs the undisturbed soil samples. Taking mass block samples from open surface or from a large-diameter well is considered to be good soil sampling procedure.

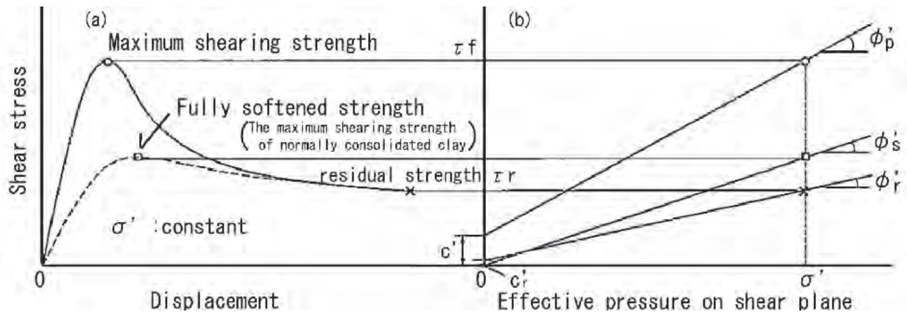


Figure 2.4.30 Peak Strength and Residual Strength [*6]

Table 2.4.5 Soil Strength and Mechanical Property Test [*6]

Test item for mechanical properties	Method		
	triaxial shear test	box shear test	ring shear test
Residual strength[*1]	△[*2]	○[*3]	○
Fully softened strength[*4]	○	○	△
Peak strength of undisturbed sample	○	△	△

○: most appropriate test method. △: apporopriate test method

*1: Residual strength are not so much affected by stress record, because of this, it is able to acquire enough correct value even from disturbed sample.

*2: When it estimate of residual strength from the sample, it need particular machinery, that is why, it is better to apply the box shear method or ring shear method for this kind of investigation.

*3: When it estimate of residual strength by box shear test, it require a cyclic shear tests.

*4: This strength is after to reach the maximum shearing strength by slurry sample or peak strength by massive sample, then at last the sample indicate neither water content increase nor volumetric strain difference by dilatancy.

2.4.7.2 Physical Test

a. Particle Size Analysis

The Particle size distribution analysis (ISO 17892-4) can provide the information on the particle size distribution of the soil at slip surface. Screen analysis and precipitation test can be used for the smaller particle sizes. (Density of fine grained soils and solid particles (ISO 17892-2, ISO 17892-3) and Water content (ISO 17892-1)).

The particle size of soil at the slip surface in the typical geological zones in Japan is shown in Figure 2.4.31. High content of clay materials can be found at the Tertiary and thermal regions, and sand and gravels can be found at crystalline schist. The test samples shall be collected from the slip surface areas, since the particle sizes may differ if the samples are taken from different locations. However, it is difficult to collect enough soil samples without disturbing the thin soil layer.

The screen test shall be used for the soil particle size of less than 425μm if the disturbed soils are used when verifying the liquid limit or plastic index.

The results obtained from the particle size distribution analysis are used to verify the adequacy of the sample selection, grain size adjustment for the testing, and the analysis of dynamic tests.

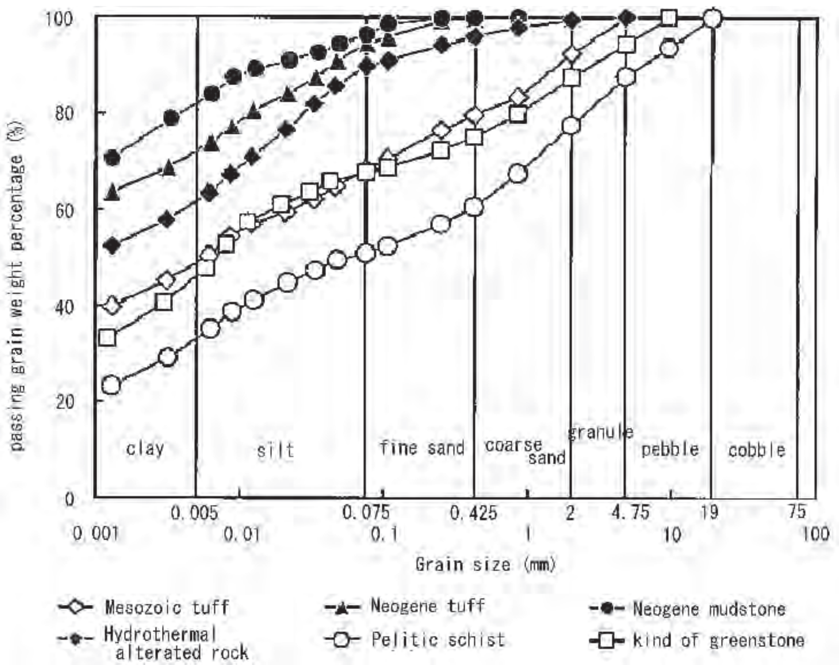


Figure 2.4.31 Particle Size Distribution of Slip Surface by Typical Geological Zones in Japan [*7]

b. Atterberg Limits

The Atterberg Limits comprise the liquid limit and plastic limit which are used to estimate the consistency of the soil at the slip surface (ISO 17892-12) Figure 2.4.31 shows the relationship between plastic index (PI) of slip surface clay at various geological zones and residual shear resistance angle (φ,r') for comparing the particle size below 425μm. The soil distribution map indicates that the methods of sampling and analysis conducted are adequate, which can lead to the proper physical tests. Another finding is that the soil sample with particle of below PI/2μm contains the swelling clay minerals.

Results obtained from the dynamic test shall be combined with various test results, such as soil size distribution, for further use of analysis.

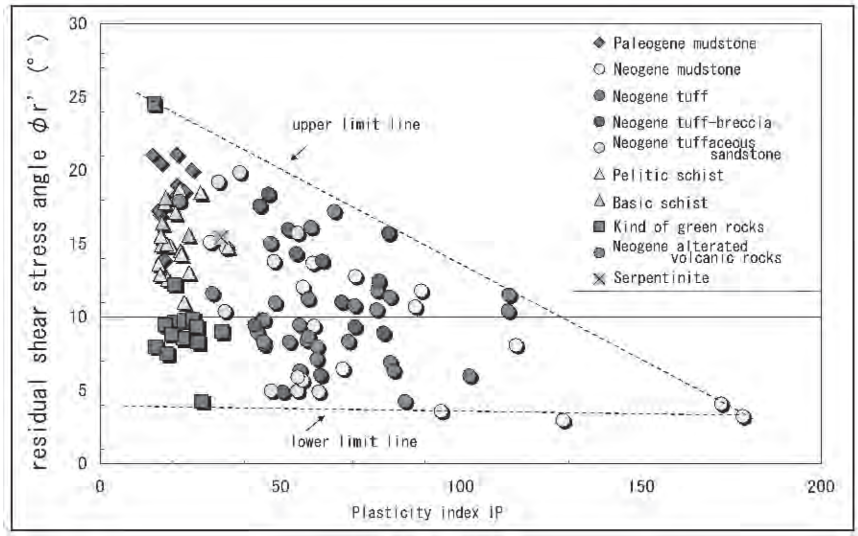


Figure 2.4.32 Relationship of Plasticity Index and Residual Shear Stress Angle by various Geological Provinces. [*8]

2.4.7.3 Test for Mechanical Properties

Mechanical test is implemented for estimating the soil strength, which is used to identify the slope stability analysis. Shear strength is divided into; peak strength, fully decreased strength, and residual strength. There have been various researches regarding the stability analysis; however, there is no clear solution for the slope stability. The shear strength shall be analyzed with a macro perspective, by selecting some representative values, since the data with different values spread over on the slip surface. The analysis results shall be considered as a reference value, and the reverse calculation shall be conducted to obtain the solution.

Table 2.4.6 shows the testing methods for each shear strength type. The peak strength can be estimated by unconsolidated tri-axial test, cyclic shear test, and ring shear test, using undisturbed sample. The value of decreased strength can be determined by unconsolidated tri-axial test, minor cyclic shear test, or ring shear test of remolded and undisturbed samples. The residual strength can be measured by cyclic shear test or ring shear test.

The shear strength shall be estimated by conducting the strength test for the samples taken from the actual site even though such method may lack accuracy of the analysis.

Table 2.4.6 Various Test Methods and Results[*16]

strength / Sample	peak strength	fully softened sterength	residual strength	Method of shear test
Undisturbed	○、$\overline{CU}$	×	×	Triaxial shear
	△、CD、Ⅲ	△、CD、Ⅱ	○、CD、Ⅰ	Cyclic shear
	△、CD、Ⅲ	△、CD、Ⅱ	○、CD、Ⅰ	Ring shear
Slurry	×	○、$\overline{CU}$	×	Triaxial shear
	×	△、CD、Ⅲ	○、CD、Ⅰ	Cyclic shear
	×	△、CD、Ⅲ	○、CD、Ⅰ	Ring shear
Precut	×	×	×	Triaxial shear
	×	×	○、CD、Ⅱ	Cyclic shear
	×	×	○、CD、Ⅱ	Ring shear
contain slipsurface	△、$\overline{CU}$、 or CD			Triaxial shear
	○、CD、Ⅱ			Cyclic shear
	○、CD、Ⅱ			Ring shear

measured intensity
○ : available
△ : available with conditions
× : not available

testing condition
$\overline{CU}$: consolidated-undrained (pore pressure measurement)
CD : consolidated-drained

displascement amount by shear
Ⅰ : much large
Ⅱ : large
Ⅲ : small

a. Cyclic Direct Shear Test

The test is performed with three to four specimens taken from relatively undisturbed soil sample. A specimen is placed in a shear box which has two stacked rings to hold the sample; the contact between the two rings shall be placed at the mid-height of the sample. A confining stress is applied vertically to the specimen, and the upper ring is pulled laterally until the sample fails, or until the time when the strain reaches to the recorded value. The load applied and the strains induced are recorded to determine a stress-strain curve for the compression stress.

The Cyclic direct shear tests can be performed under several specific conditions. The sample is normally saturated before the test in order to maintain the in-situ moisture content. Various rate of strain shall be applied to produce the results in un-drained or drained condition, depending on whether the strain is applied slowly enough for water in the sample to prevent pore-water pressure buildup.

Several specimens are tested at varying confining stresses to determine the shear strength parameters, the soil cohesion (c) and the angle of internal friction (commonly friction angle) (φ). The results of the tests on each specimen are plotted on a graph with the peak (or residual) stress on the x-axis and the confining stress on the y-axis. The y-intercept of the curve and the test results is the cohesion, and the slope of the line or curve is the friction angle.

Figure 2.4.33 and Figure 2.4.34 shows the device of a cyclic shear test, and relation between shear stress and accumulative shear displacement.

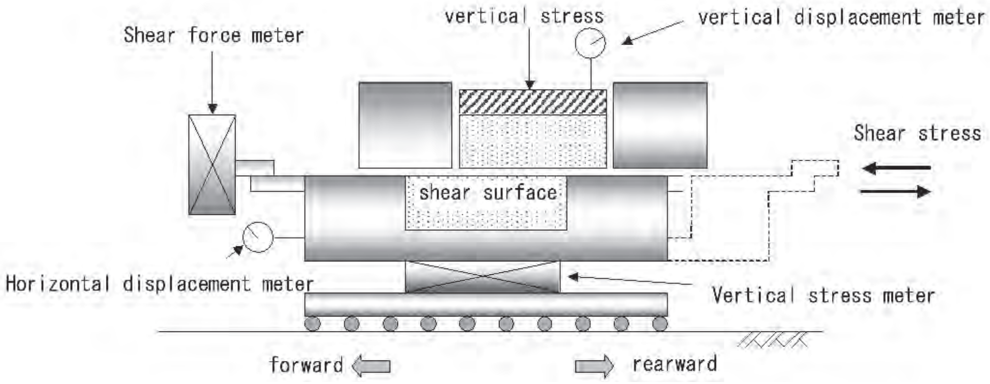
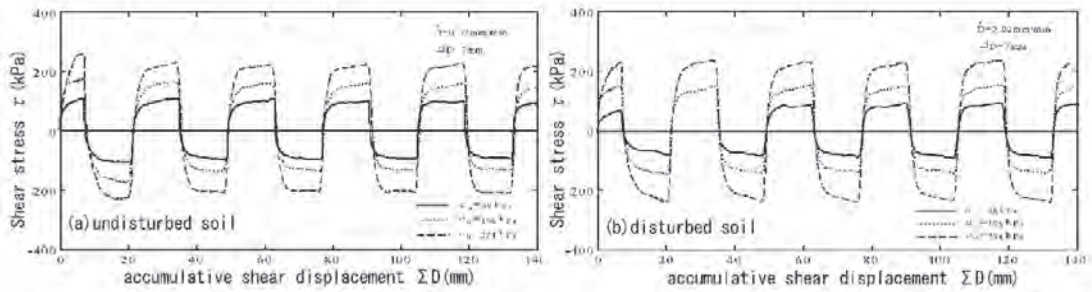


Figure 2.4.33 Device of Cyclic Shear Test Device.[*9]



(a) undisturbed soil (b) disturbed soil

Figure 2.4.34 Relationship of Shear Stress and Accumulative Shear Displacement [*9]

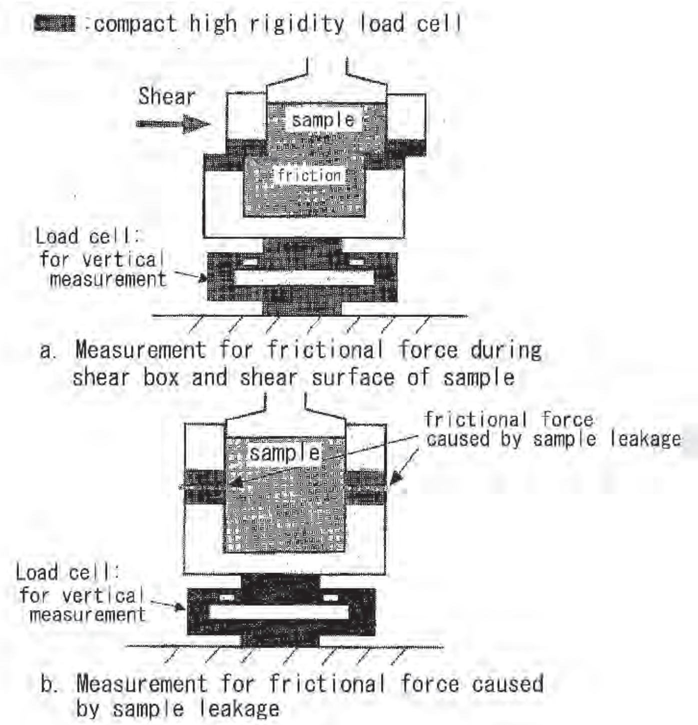


Figure 2.4.35 Measuring the Friction Force between two Shear Boxes [*10]

Following graph shows the method of determining the strength values for countermeasure design, using c-tanφ graph, peak strength, fully decreased strength and residual strength obtained from the cyclic shear test (Figure 2.4.35). Point A is the peak strength, Point B is the fully decreased strength and point C is the residual strength. Point D crossing between the line A, B, C and c-tanφ line shall be used for the stability analysis of the design.

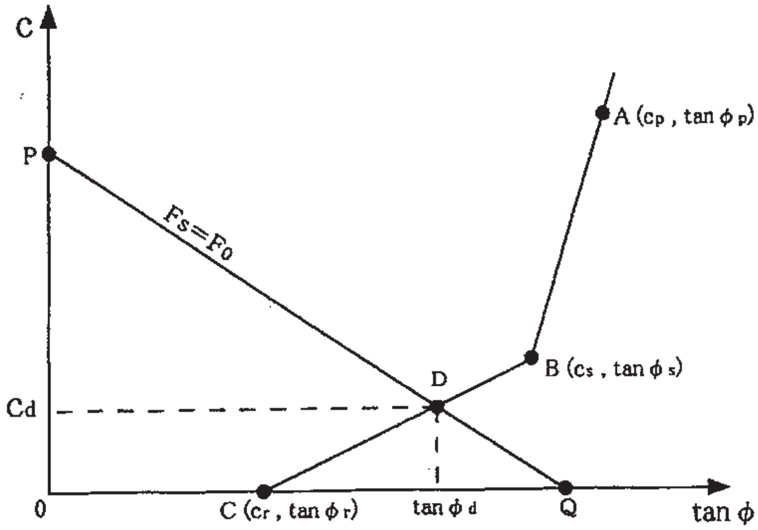


Figure 2.4.36 Determination of Strength Factor for Design using a c-tan ϕ diagram [*6]

Figure 2.4.36 shows a schematic figure of direct shear test for slip surface, which is used to measure the shear strength on the slip surface. The shear line obtained from the test shall be used for the analysis on the slip surface.

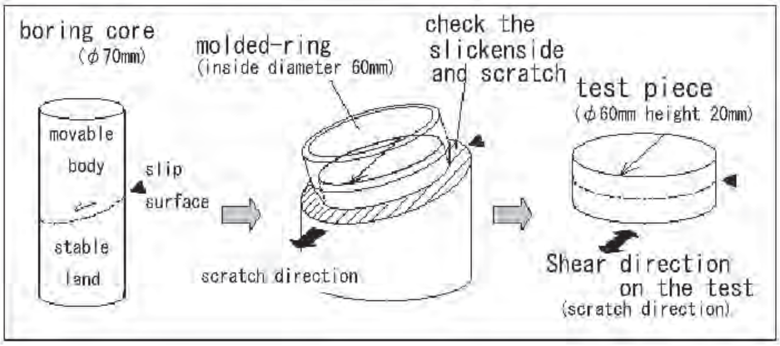


Figure 2.4.37 Way of making a test piece which interleaves slip surface [*6]

b. Ring Shear Test

The apparatus keeps the cross-sectional area of the shear surface constant during shear and shears the specimen continuously in one rotational direction for any magnitude of displacement. This allows clay particles to become oriented parallel to the direction of shear and a residual strength condition to develop.

The apparatus allows a remolded specimen to be over-consolidated and presheared prior to drained shearing. This simulates the field conditions that lead to a preexisting shear surface along which the drained residual strength can be mobilized.

The ring shear test is suited to the relatively rapid determination of drained residual shear strength because of the short drainage path through the thin specimen, and the capability of testing one specimen under different normal stresses to quickly obtain a shear strength envelope.

The test results are primarily applicable to assess the shear strength in slopes that contain a preexisting shear surface, such as old landslides, and sheared bedding planes, joints, or faults.

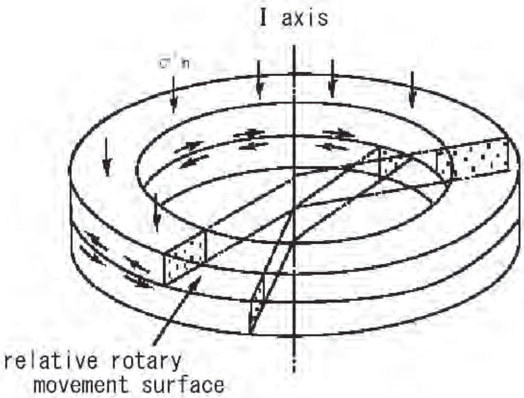


Figure 2.4.38 Schematic Diagram of Ring Shear Test [*6]

c. Tri-Axial Shear Test

The principle behind a tri-axial shear test is that the stress applied in the vertical direction (along the axis of the cylindrical sample) can be different from the stresses applied in the horizontal directions perpendicular to the sides of the cylinder, i.e. the confining pressure.

A solid is defined as a material that can support shear stress without moving. However, every solid has an upper limit to how much shear stress it can support. The tri-axial test is designed to measure that limit. The stress on the platens is increased until the material in the cylinder fails and forms sliding regions, known as shear bands. A motion where a material is deformed under shear stress is known as shearing. The geometry of the shearing in a tri-axial test typically causes the sample to become shorter while bulging out along the sides. The stress on the platen is then reduced and the water pressure pushes the sides back in, causing the sample to grow taller again. This cycle is usually repeated several times while collecting stress and strain data about the sample.

During the shearing, a granular material will typically have a net gain or loss of volume. If it had originally been in a dense state, then it typically gains volume, a characteristic known as Reynolds' dilatancy. If it had originally been in a very loose state, then contraction may occur before the shearing begins or in conjunction with the shearing.

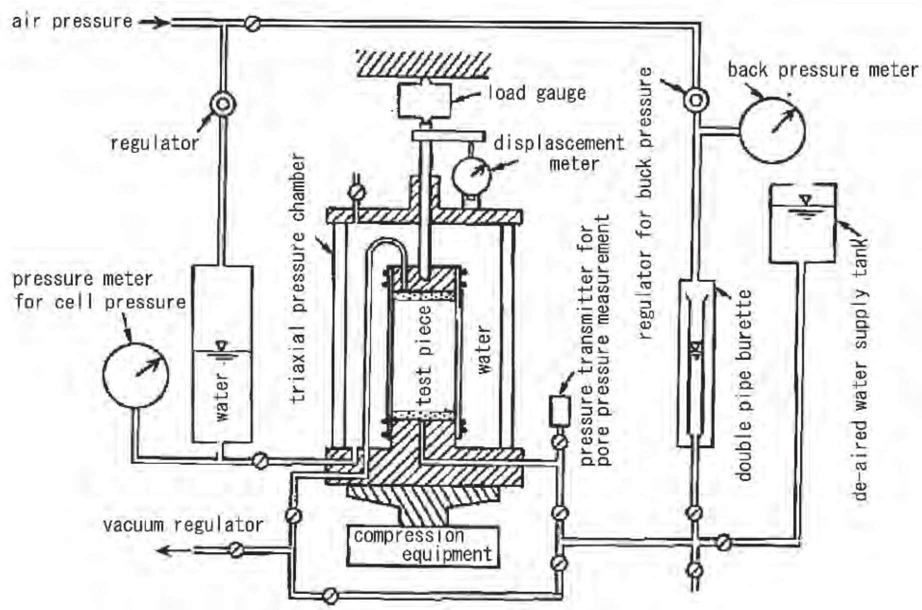


Figure 2.4.39 Device of Tri-Axial Shear Test *6

2.5 Analysis

The landslide analysis need to consider; natural factors, triggers for landslides, size and scale of landslides , shape and position of slip surfaces, groundwater condition in order to provide effective countermeasures. The cross-sections can be used to determine the safe ratios of the slopes by conducting the stability analysis.

Table 2.5.1 shows the outcomes of the surveys for producing the landslide maps and cross-sections.

Table 2.5.1 Outcomes for each Survey *1

Item of analysis		preliminary study	site investigation	mapping of landform	geological survey	slip surface survey	investigation for surface movement	investigation for ground water level	laboratory test for soil
map of micro-landform units of landslide									
	micro-landform units of landslide	○	○	○			○		
	land use / structure e.t.c.	○	○						
	feature of landslide topography		○	○					
	various result of investigation and observation				○	○	○	○	
	slip surface level contour line		○	○	○	○	○		
landslide cross section									
	geological cross section	○	○		○				
	groundwaster distribution		○					○	
	land use / structure e.t.c.	○	○						
	feature of Landslide cross section		○	○	○	○			
	various result of investigation and observation				○	○	○	○	
mechanism analysis of landslide		○	○	○	○	○	○	○	○

2.5.1 Identification of the Landslide Area

The landslide distribution map shall be created by interpretation of an aerial photograph and site survey. Characteristic of the landforms (e.g., rear hollow, stepwise landform, extension cracks and compression cracks, and sump water) shall be identified in order to segment land mass into blocks. The slide directions and conditions of active landslides can be estimated from the data such as precipitation, size of landslide block and quantity of soil mass. In addition, the survey results shall be used to predict the possible behaviors of landslide blocks. Figure 2.5.1 shows the example of landslide scale which was used to predict the landslide behavior from counter map. Figure 2.5.2 shows the example of segmentation of landslide body into several small blocks.

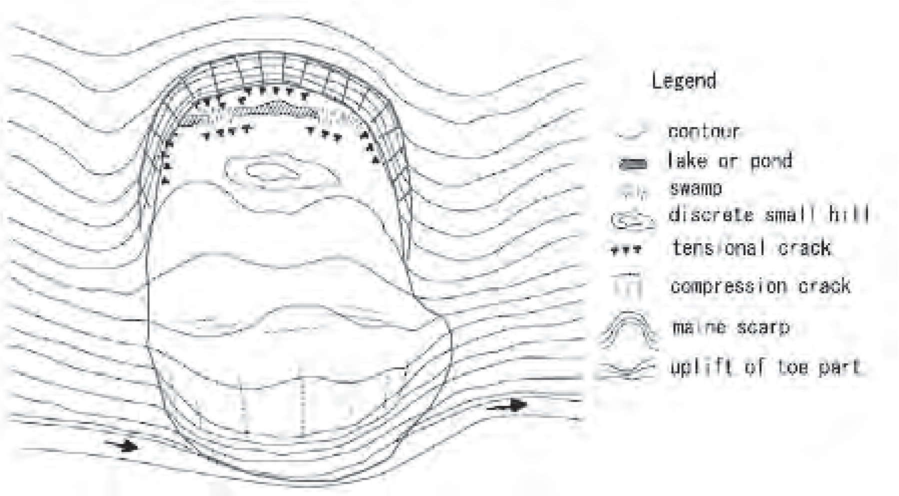


Figure 2.5.1 Example of deciding Landslide Area using Photographic Interpretation and Micro Topography [*1]

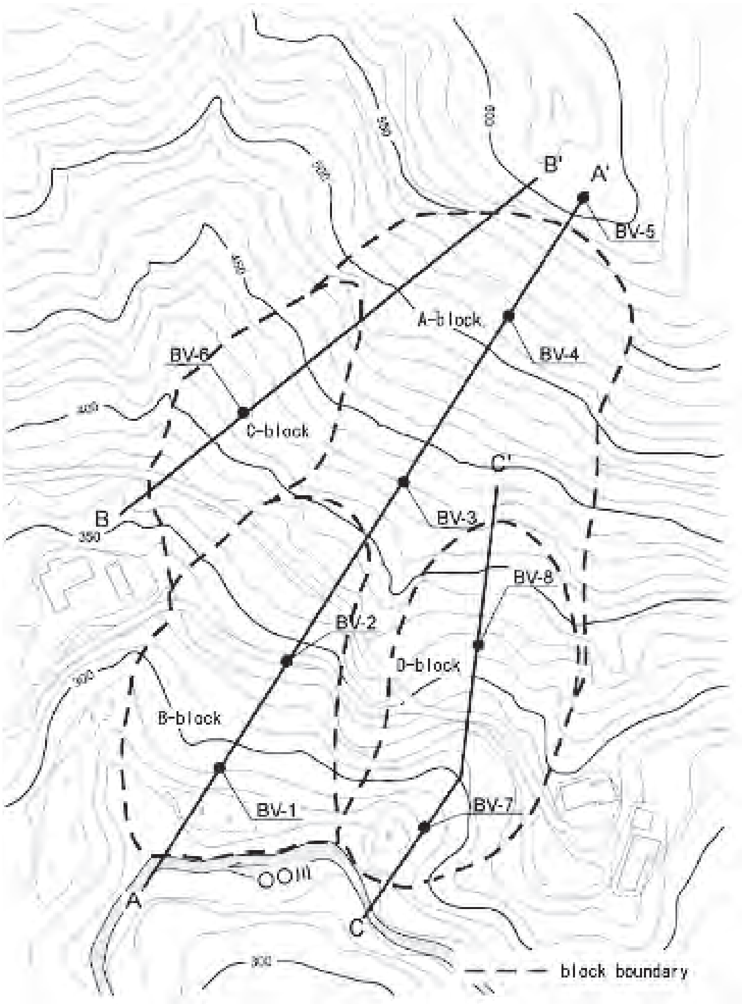


Figure 2.5.2 Geomorphologic Analysis of Landslide divided into one large block and three small blocks [*1]

2.5.2 Classification of landslide

Table 2.5.2 shows types of landslides with slip surfaces. Landslides are classified into several types by topographic and geological characteristics. The cross-section, the longitudinal profiles, depth of landslides can be estimated based on the classifications, and the survey lines can be identified (Figure. 2.5.3). The results can be used to provide effective plans for the geophysical explorations.

Table 2.5.2 Classification of Landslide [*2]

Type / Feature	Rock block slide	Weathered rock slide	Colluvium slide	Strongly-weathered rock slide
Planar shape	Horseshoe-shaped, Square-shaped	Horseshoe-shaped, Square-shaped	Horseshoe-shaped, Square-shaped, Bottleneck-shaped Valley-shaped	Bottleneck-shaped, Valley-shaped
Micro topography	Convex and ridge -shape	Convex and mono terrace -shape	Convex and uni-terrace shape	Concave and gentle slope-shape
Shape of slip surface	Chair like, Ship like shape	Chair like, Ship like shape	Stepwise, Laminar	Stepwise, Laminar
Ex-name	New born stage	Immature stage	Mature stage	Elder stage
Material (Head part)	Bedrock or Gentle-weathered rocks	Weathered rock (Many clacks)	Earth and sand including rocks	Boulder or Earth and sand including rocks
Material (Toe part)	Weathered rocks	Earth and sand including boulder	Earth and sand including rocks, Part-argillation	Clay, Clay including rocks
Movement velocity	Over 2cm/day	Around 1.0~2.0cm/day	0.5~1.0cm/day	Under 0.5cm/day
Movement continuity	Short and sudden event	Intermittent (Once from decades to centuries)	Intermittent (Once 5-20 years)	Intermittent (Once 1-5 years)
Figure of slip surface	Flat (Chair like shape)	Flat (Head and toe parts: a bit circular slips)	Circular slip and linear shape, Fluidized toe	Head part: Circular slip Most part: flow condition
Number of blocks	Normally, 1 block	Generating secondary-derived landslides on side and toe of landslide	Upper slope of landslide can be divided into 2-3 blocks.	Whole slope of landslide can be divided into many blocks. Their movement links each other.
Difficulty level of prediction	Quite difficult Needed detailed exploration and analyzing	Possible Using topographic maps (1/3,000~1/5,000) or aerial photographs	Possible Using topographic maps (1/5,000~1/10,000) or door-to-door investigation	Easy Site investigation
General slope shape	Unclear terrace, Convex slopes, Generating from saddleback	Clear scarp, A band of depression and terrace. Concave in macro point of view but generally convex	Main scarp, Pond, Swamp, Depression, Concave slopes. Monadnock at crown	Unclear terrace on upper slope, Uniform gentle slope, Valley shape
Main causes	Massive construction, Sunken slope, Earthquake, heavy rainfall	Torrential rainfall, Exceeding snow melting and washout, Earthquake, Mid-scale constructions	Snow melting, Typhoon, Torrential rainfall, construction	Heavy rainfall, Snow melting, Snow cover, Fluvi-erosion, Small-scale construction
Main geology and the structure	Effects of fault and fracture zone	A wide distribution of crystalline schist area, Neogene stratigraphy, Effects of fault and fracture zone	A wide distribution of crystalline schist area, Neogene stratigraphy	Distribution of Neogene stratigrap, fracture zone (Mikabu tectonic line)

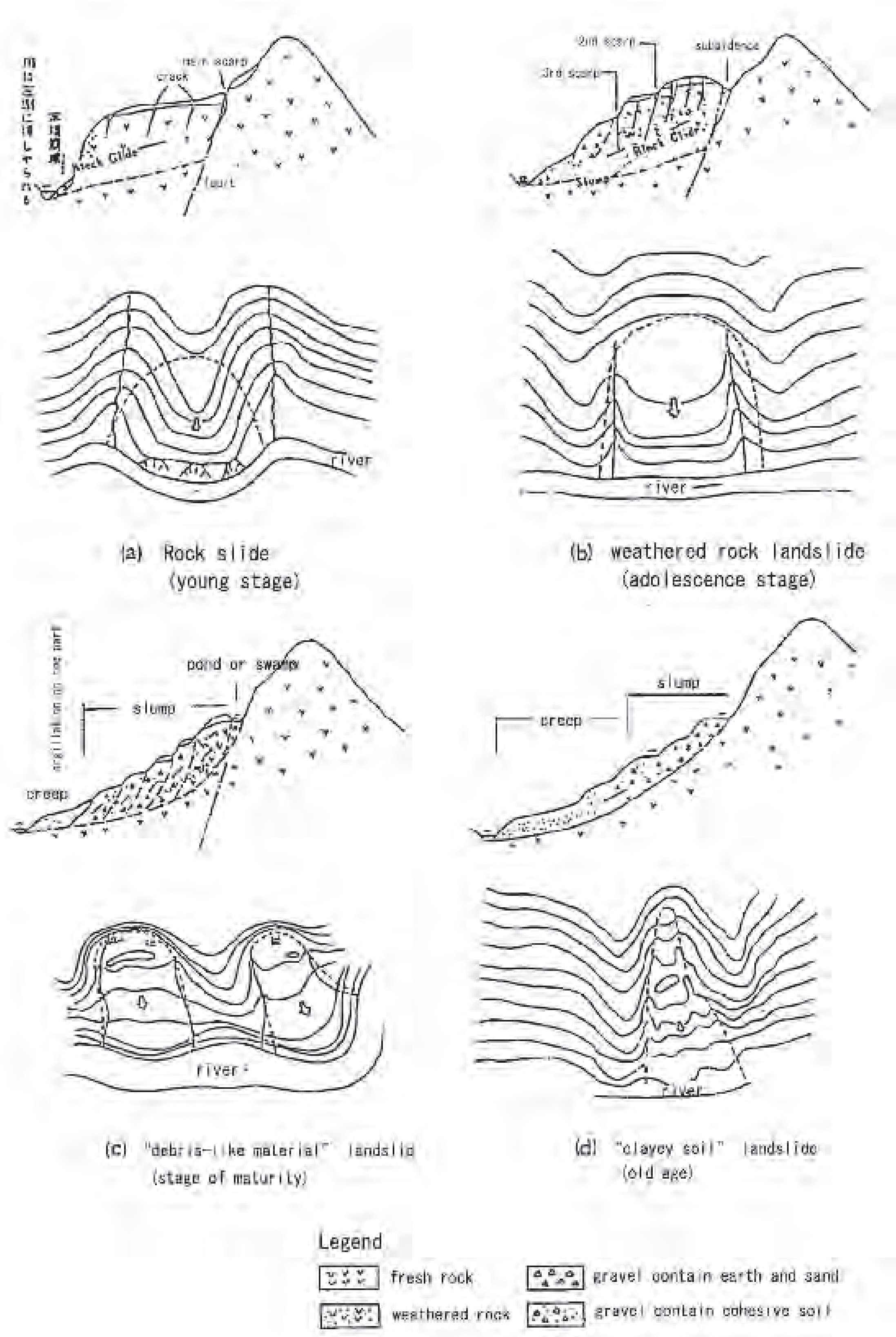


Figure 2.5.3 Schematic Diagram of Land Evolution [*2]

Figure 2.5.5 - Figure 2.5.6 show possible cross-sectional profiles based on the landslide topography shown in Figure2.5.4.

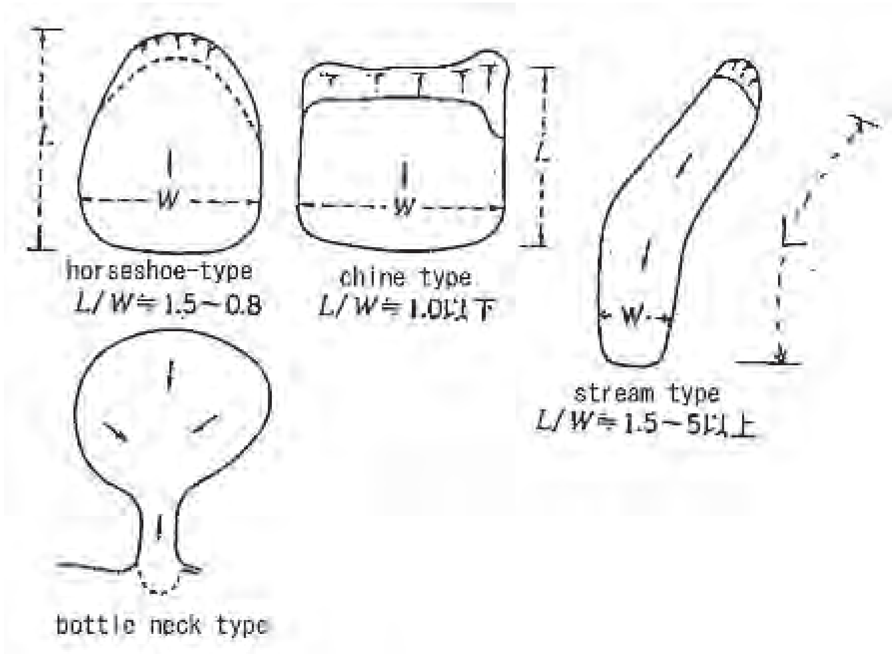


Figure 2.5.4 lane view of landslide area [*2]

i) The Horseshoe Shaped Type

The ratio of L/W varies from 0.8 to 1.5. About 40% of the landslides in Japan are categorized into this type. One of the characteristics of this shape is that the depth at the center is larger than the side length of the land mass. Followings illustrate the 3 types of the horse shaped type.

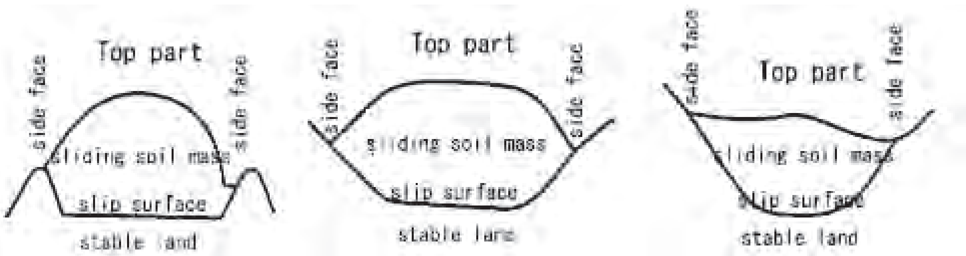


Figure 2.5.5 Head part lateral profile of horse shoe type landslide [*2]

ii) Rectangular shaped type

Ratio (L/W) of this type is less than 1.0. About 10 to 15% of the landslides in Japan are categorized into this type. Following Figure 2.6.5 illustrate the rectangular shape type.

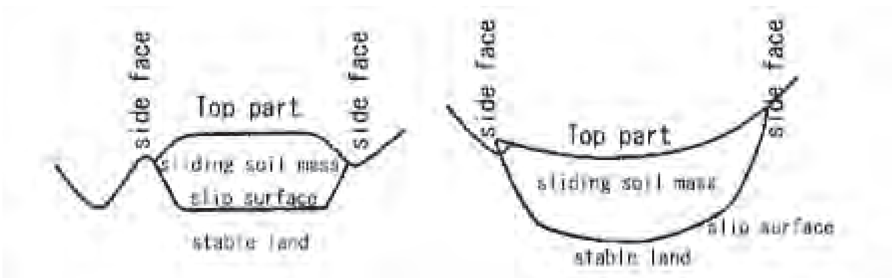


Figure 2.5.6 Head part lateral profile of Rectangular Shape type landslide [*2]

iii) Stream (U) shaped type: This shape can be often observed at the upper or the secondary landslide of horse shoe type or rectangular type. The cross sectional ratio (L / W) is from 1.5 up to 5.0. In general, this type of landslide takes for a long time in development since the initial landslide. The depth of the slip surface is shallow.

iv) Bottle Neck Shaped or Dipper Shaped Type: This shape is often observed at the middle of terrace slope, where a hard rock formation exists at the bottom. Normally the depth of the slip surface is shallow. The volcanic rocks with the soft layer exist at the middle do the slope. The soft layer expands due to weathering and finally forms this shape. The streams are developed at the center.

There are some other shapes at areas of clay and boundary of the geological formations which account for 1% of the landslides in Japan. If the ratio of the landslide shape (L/W) is larger, the landslides may be old. Initial landslide is normally 0.5 – 1.0, and it becomes larger, such as 1.- to 1.5 in the second or the third landslides.

2.5.3 Basic factor and inducing factor of landslide

i) Basic factors (Mechanical factor) affecting the landslides: In general, landslides occur at the landslide area which has a particular natural characteristic. Most of the landslides are caused by the natural factors. The basic factors include; topographical (affecting the water flows, geological (developing slip surfaces such as bedded structure, mud-clay layer, tuff etc., and thick loose formation at the unstable slope), geological structure (faults, anticline, syncline, etc.,) and the condition of groundwater, etc.

ii) Inducing factors: Floods during the rainy season, and other changes in the natural environment (wash out of the slope toe by rivers, formation or blockage of new waterways at surface and subsurface) of the area which is prone to the basic factors become triggers of landslides.

Human cases of the landslides include; construction of embankments at the upper slopes, cut of slopes at the toe, and submerging slopes underwater which cause subsurface blockages.

2.5.4 Identification of Slip Surface

Characteristics of a slip surface shall be identified by synthesizing the information acquired from monitoring drilling survey. The underground condition and movement of land mass can be estimated from monitoring by inclinometers and strain gauges, which enables to estimate the location of the slip surface.

Core samples from drilling shall be used to conduct the complete analysis on the slip surface, by observing the colors, density of cracks and fissures, condition of clays, and existence of slickensides.

Table 2.5.3 Vertical structure and condition of landslide [*1]

Surface	Velocity of landslide	Type of movement mass	Color of the materials	Permeability	Oxidation	Classification
	High	Rigid body	Brown	High	Oxidized	Landslide body
	Low	Fluid	Dark color	Low	Deoxidized	Slip surface
Underground	No movement	Stable materials	Original rock color	Low	Original condition	Base material

Followings shall be considered when observing the core samples in slip surface analysis;

1. Existence of soft clay layer
2. Base of the colluvial deposits
3. Boundary between weathered material and base rock
4. Mixture of accessory rocks and materials
5. Existence of fracture materials
6. Disturbance of base rock structures
7. Relation of the landslide shape and landslide type

The slip surface can be identified from results of monitoring and observation of core samples.

The monitoring and core samples can only provide the point information; therefore, it is important to expand the data to the plane areas from given geographical data.

Followings shall be considered for slip surfaces analysis;

i) Find the typical shape of the slip surface, and contour lines from the topographical maps.

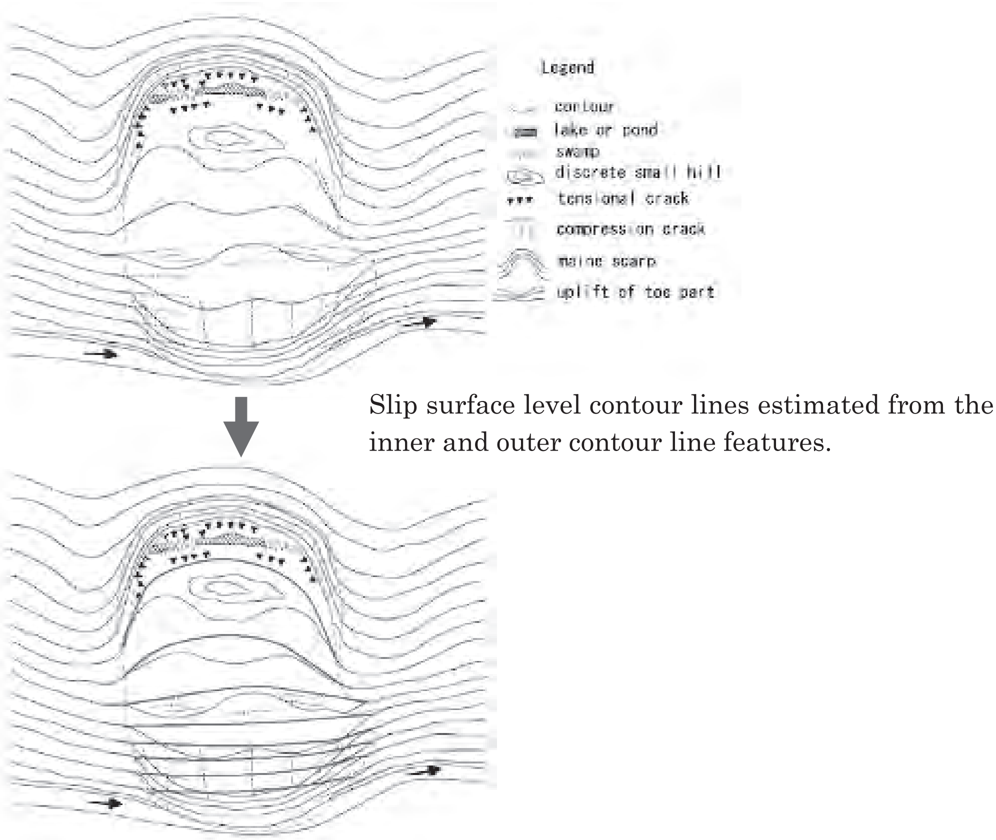


Figure 2.5.7 Estimation of slip surface level contour lines from topographic features [*1]

ii) The landslide cross section shall be used to estimate the shape, depth , and geology and geological structures of the slip surface.

2.5.5 Relationship between Groundwater and Rain Fall

The relationship between the characteristics of the groundwater (distribution, condition, direction of flow and quality) and the movement of the landslide can be examined from the groundwater level monitoring.

The correlation between rainfall and groundwater level shall be examined to provide information to identify the required operation and maintenance for the landslide controls.

2.5.6 Cross Sections of Landslide

Landslide cross sections shall be drawn over the geological cross sections along the traverse line towards the direction of the landslide movement. The data shall be taken from the geological survey and landslide anomaly information (such as position of crown and toe, angle of crown cliff and other information regarding the estimation of slip surface.)

The procedure is as follows;

i) Scale of the cross section shall be 1:200 or 1:500 (with the same ratio on vertical and horizontal cross section) along the traverse line. The sub cross section along the sub traverse line may be required for complex and large landslides.

ii) Any information obtained shall be marked on the cross sections. The information includes; variation of slope angle, cracks, steps, ponds, concaves, convexes, drilling points, points of measuring devices and equipment installation, dip and strike of surface soil and base rock, dividing line of colluvial deposit and base rock, soil, faults, fractures, estimated slip surface, groundwater level and the position of fracture.

iii) Other necessary cross sections may be required if there is any different landslide thickness at different vertical section.

iv) Add the surface topography and geological cross sections if available.

In general, the information obtained from the landslide surface survey and drilling survey only provides the point information. Therefore, it is necessary to estimate the surrounding conditions by expanding the obtained point information. Therefore, it is important to draw the cross sections for the further analysis.

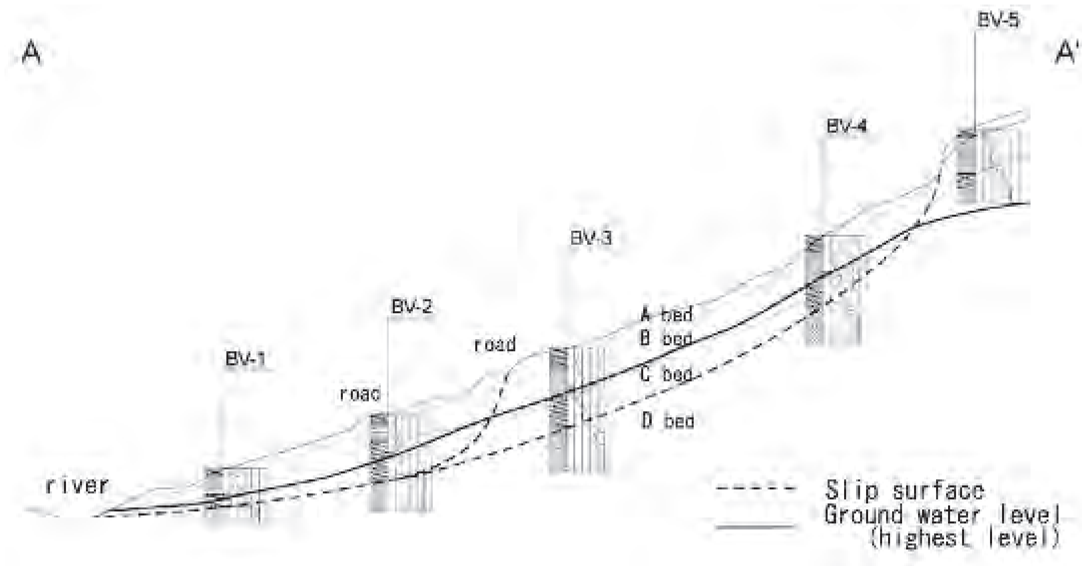


Figure 2.5.8 Landslide Cross Section [*1]

2.5.7 Others

The Figure 2.5.9 is the grid surface model that is developed from estimating the landslide slip surface. The periodical topographical surveys on each fixed point of the grid are conducted in order to estimate the landslide movement (see Figure 2.5.9).

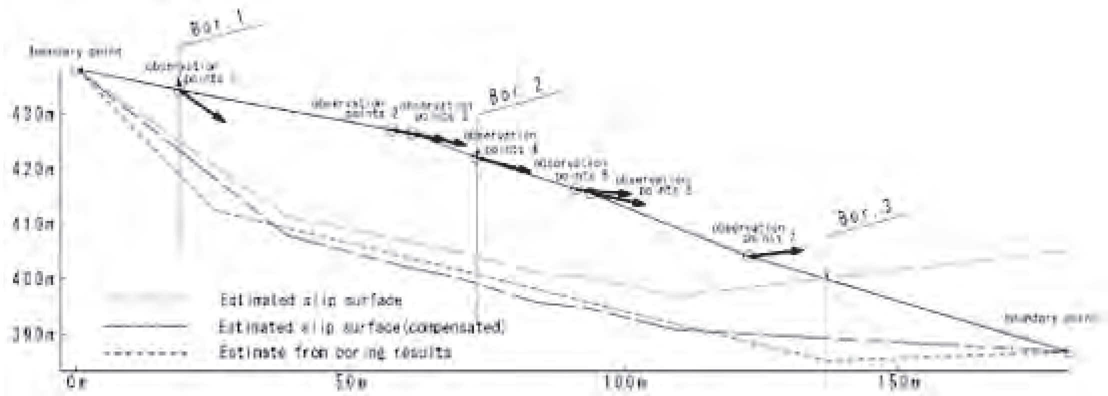


Figure 2.5.9 Analysis of Landslide Slip Surface *3

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3. Plan and Design of Countermeasures for Landslides

3.1 Plan for Prevention of Landslide

3.1.1 General

The landslide prevention plan shall include both technical and non-technical perspectives. The technical perspectives include the installation of the facilities to mitigate the landslide damages. The non-technical perspectives include the establishment of early warning systems. The landslide prevention plans shall consider the existing laws, natural environment, and the community development plans.

3.1.2 Identification of the Objects to be protected

The objects to be protected shall be selected based on the occurrences and mechanisms of the landslides. Followings are considered for the identifications of the objects to be protected;

1. Houses, roads, paddy and fields, public infrastructures and lives of people in the landslide area.
2. Houses, roads, paddy and fields, public infrastructures and lives of people below the landslide area.
3. Submerged areas in the upper stream of the dams created by landslides.
4. The flooded areas caused by landslides.

3.1.3 Determination of the Factor of Safety

The factor of safety (FS) shall be designed for each landslide block. The factor of safety (FS) shall be from 0.95 to 1.00 based on the landslide conditions. The factor of safety shall be 1.10 to 1.20 considering for the objects with high importance and for the degree and occurrence of landslides.

The attention should be paid to the presupposition that factor of safety is designated in the purpose of evaluating the amount of countermeasure works, and it is not designed for demonstrating the stability of the slope.

3.1.4 Establishment of Emergency Measure Frameworks

As for the precautious and evacuation measure, the installation of the monitoring instruments, such as rainfall meter, water level gauge, and extensometer, should be conducted in order that the monitoring results should be referred as the evacuation standard. Also, the effective communication system shall be established among the relevant organizations.

3.1.5 Considerations for the Environment

The surrounding natural environment shall be carefully examined in order to minimize the impacts on the environment.

3.2 Stability Analysis

3.2.1 General

In this chapter, the methods for the landslide stability analysis are explained. For the areas where there have never had landslides in the past, the initial conditions shall be identified by the investigations since there is no landslide data available. For steep sloped areas, it may be necessary to evaluate the existing conditions and determine the necessities of the countermeasures in advance. . Then the appropriate countermeasures can be designed and applied. For the zones where landslides have occurred previously, there already exists the sliding surfaces. In this case, the site activities shall be conducted, such as monitoring groundwater levels which could be a trigger for the landslides. Based on the monitoring results, the current situation of the landslide can be identified. If the factor of safety is less than 1.00, the landslides are considered to be active, and if the factor of safety is over 1.00, then the landslides are considered to be non-active. The factor of safety derived from the stability analysis shall reflect the actual conditions of the slopes.

In reality, the factor of safety changes over time, based on the natural conditions such as variations in groundwater levels. Following figure illustrates the variations in factor of safety. Groundwater level is called as a critical water level when a landslide starts to slide. The factor of safety at the time of landslides is considered as the only true safety factor for the landslides. The value is 1.0.

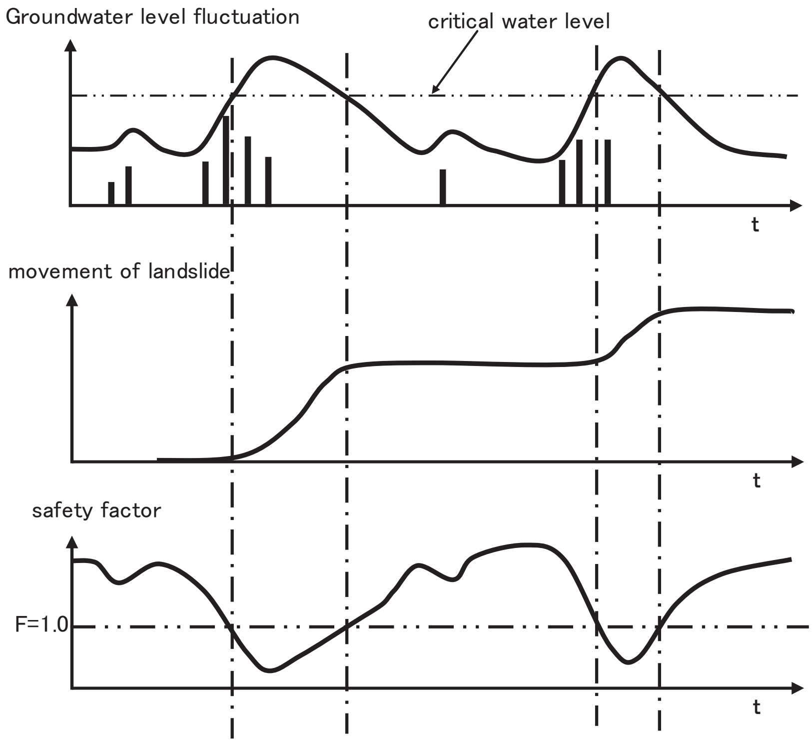
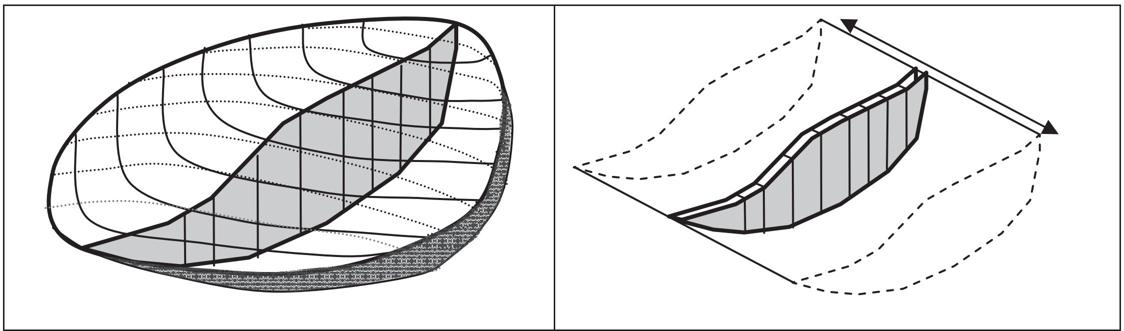


Figure 3.2.1 Changes in groundwater level triggering mass movement while also affecting values of safety factor over time*4

The main purpose of the landslide countermeasures shall increase the value of safety factor. When the factor of safety is less than 1.00, it means that the slope is unstable due to the presence of triggering factors. In order to increase the value of factor of safety, various countermeasures shall be examined and combined solutions may be suggested. And the safety factor shall be used to determine the design criteria, reflecting the slope stability, for implementing the appropriate countermeasures. It is very important to understand sliding process in response to groundwater fluctuation, soil strength parameters and groundwater distribution which are used to estimate the true factor of safety through back analysis approach.. As explained previously, value of safety factors fluctuate with various circumstances such as variations in groundwater level. The safety factor shall be determined taking into account the highest level of the groundwater, or the most active landslides during the monitoring period.

The Figure 3.2.2 (a) shows that the landslide sliding mass has three dimensional body. The . In stability analysis, only the two dimensions are used for the analysis, and the longitudinal section is assumed to extend to both sides infinitely as shown in Figure 3.2.2 (b). The 3-D stability analysis requires more drilling data from the entire landslide area, which require additional cost and time for survey. Therefore, the 2-D stability analysis assuming the longitudinal section shall be used.



(a) three-dimensional geometry of landslide movable body	(b) Analytical model of two usual dimension stability analysis

Figure 3.2.2 3D & 2D models of a sliding mass [*4]

3.2.2 Procedure of Stability Analysis

Following is the procedure for the stability analysis.

1) Monitor the condition of the slope deformation for a designated time period
2) Monitor the level of groundwater
3) Estimate the factor of safety
4) Select a method for the stability analysis
5) Estimate the shear strength for soils on the sliding surface
6) Estimate the effectiveness of the selected countermeasures

Following sections explain more details of the procedures;

3.2.3 Analysis on the Sliding Mechanism

a. Understanding the degree of land mass displacement

Change in groundwater levels due to rainfall shall be estimated in order to evaluate the existing safety factors. Table 3.1.1 provides sample data of deformation monitored by different sensors.

If there are no monitoring sensors installed at the area of landslides, the existing cracks and fissions can be used as an indicator to estimate the land deformations.

b. Understanding the land mass displacement in response to rainfall and groundwater fluctuation

Land mass displacement is caused by the triggering factors such as rainfalls or variations in groundwater levels; therefore, it is important to understand the relationship between the displacement and the triggering factors, and identify the direct cause of the landslides. The relationship can be plotted on a graph, showing the change in groundwater levels and landslide deformation over a time. The accumulated mass displacement or sliding velocity with the variations in groundwater levels can also compared in chart. The maximum, minimum, and critical groundwater levels can be plotted at each location of the drilling hole along the longitudinal section for stability analysis.

If the monitoring results indicate that the rainfall and/or the change in groundwater level are not the cause of the land mass movement, then the lowest groundwater level at each drilling hole shall be used for the stability analysis.

3.2.4 Factor of Safety and Groundwater Level

The safety factor is an indicator for the land mass movement. As noted above, the groundwater levels shall be collected at each drilling hole located along the longitudinal lines. All the levels, including the highest, the lowest, and the critical level, shall be plotted and connected on a graph for the analysis. Figure 3.2.3 shows the plotted groundwater levels.

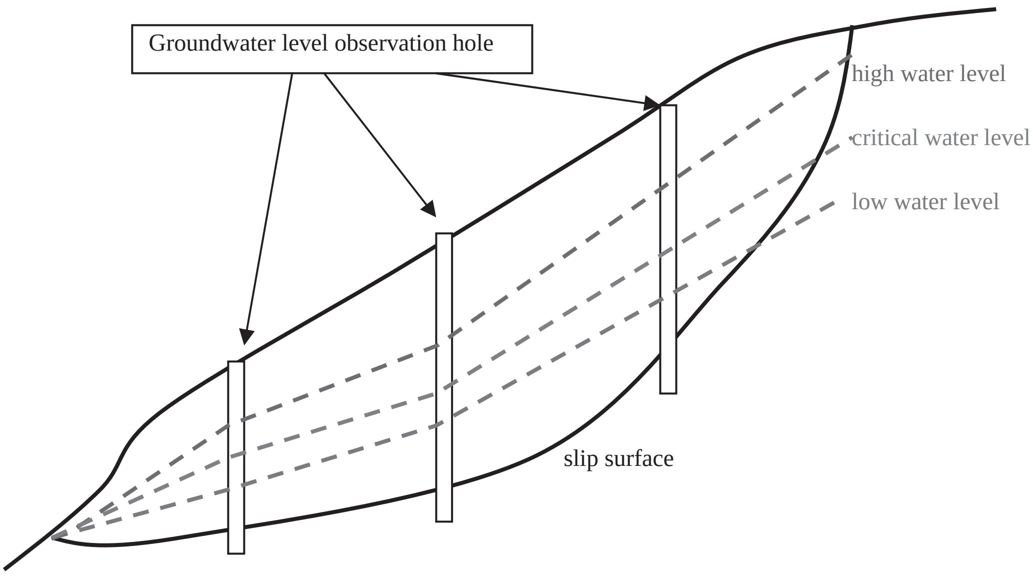


Figure 3.2.3 Schematic diagram showing groundwater level distribution in the longitudinal section for stability analysis [*4]

3.2.5 Selection of Stability Analysis Method

There are several methods for the slope stability analysis, such as; "Fellenius method", "Bishop method", "Spencer method", "Janbu method", and "Morgenstern & Price method". The Table 3.1.1 lists the characteristics of each analysis method.

In Japan, the modified Fellenious Method and simple Junbu Methods are the two methods used for the countermeasure evaluation because of its simplicity. Those methods are explained below.

Table 3.2.1 Landslide slope stability methods and selected factors *4

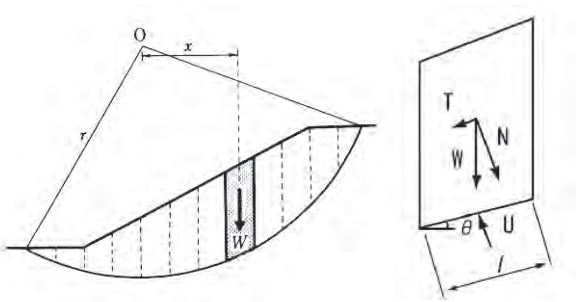
name of method	selecting factor of stability analysis method						feature
	grand water condition		acceptable slip bsurface figure		type of landslide		
	confind	free	rotational	other	rock slide	other	
Fellenius method	○		○			○	this formula basically give small exact solution of stability factor. (sometime large)
Modified Fellenius method		○	○			○	using free grondwater, but not accept a seepage flow
Bishop method	○		○			○	this formula give almost exact solution of stability factor.
simple Bishop method	○	△	○				
Jambu method	○	△	△	○		○	this formula give almost exact solution of stability factor. On the other hands, this method propose other fomula for submerged slope, and for rotaitional slide.
SHIN-Jambu metod	○			○	○		Based on Janbu method, modified for rock slide phenomenon analysis.
Spencer method	○		(1)	(2)	△	○	this formula is good for exact solution of stability factor analysis, but sometime this formula has multiple solution depend on way of putting parameter.
Morgenstern & Price method	○			○		○	

○ : well accept △ ,(1),(2): has other fomula " ": not so good result

Fellenius method is most popular way of stability analysis in Japan because 1) the calculation is very simple, 2) the calculated value could be safer side for countermeasure. However, Kinoshita and Enokida (2000) argued that the possibility which the calculation result differs from precise solution more than 1%, up to 27%. Therefore, it is preferable to confirm the result by re-calculating with several methods.

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

a. Modified Fellenius Method (Sweden Method or Simple Method)



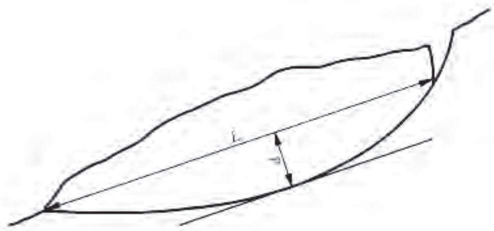
The Fellenius method focuses on the balance of the moment between soil weight and the shear resistance acting on the slip surface. The Wcosα shall be 0; however, if the angle of inclination of the slip surface is large, then the the Wcosα-ul may become negative Actually shear stress occurs in the slip surface, Since the shear stress occurs at the slip surface, the safety factor becomes small. The modified Fellenium method corrects the low value of the safety factor by using the effective soil weight, W'=W-ub instead of using the soil weight of W.

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

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

b. Simple Janbu Method

The Janbu method is a method which uses the balance of horizontal stress and vertical stress in each slice. Then the total stress in the entire soil mass shall be balanced equal to zero. It is applied to tabular-shape slides controlled by the soil weight and the shear resistance on the bedrock, and to complex slides in which are mixed circular slides on the scarp zone and the end zone and tabular-shape slides on the middle zone in the slip surface.



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

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

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

f_0: correction coefficient,

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

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

Figure 3.2.4 Modified Fellenius Method and Simple Janbu Method.

3.2.6 Choosing Soil Strength Parameters

a. Determination of the Factor of Safety

The Safety factor, "Fs" is the ratio of resistance force against the landslide soil mass to the sliding force which occurs at the starts of landslides along the slip surface. The Fs is1 when the resistance force and the sliding force are balanced. The Fs is larger than 1 when the slope is stable, and theFs is less than 1 when the slope is unstable.

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

Since the Fs =1 at the time when the land mass starts sliding, the Fs can be determined within 0.95 < Fs < 1 for the active state. The factor of safety can be determined based on the slope condition, described in Table 3.2.2 of "the Disaster Notebook" prepared by Japan Construction Engineer's Association (2010).

Table 3.2.2 Definition of Safety Factor for landslide

Safety factor	Landslide condition
F_s =0.95	Moving Condition
F_s =0.98	Moving by other factors such as rainfalls
F_s =1.00	Stable Condition

Japan Construction Engineer's Association (2010)

b. Selecting Parameters

The parameters for landslide stability analysis include;

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

The pore water pressure can be derived from the critical pore water pressure which occurs at the time of sliding. The cohesion and the shear strength angle,c' and φ', can be obtained from the shear test.. The landslide mass and the wet unit weight γ t can be calculated using those parameters. The unidentified parameters are the pore water pressure u (particularly the critical pore water pressure), cohesion c' and shear resistance angle φ'. Because landslides frequently occur in the rainy season, cohesion c' is considered to be relatively small. Samples as soil mass of slip surface are obtained when drainage well is dug or when the slip surface is exposed to the ground surface.

Critical pore water pressure when the land mass starts sliding in the rainy season is necessary parameter because it is indispensable for ensuring stability analysis accuracy and determining landslide countermeasures.

c. Wet UnitWweight, γ t

In general, the value for the wet unit weight of soil mass for the stability analysis in Japan is γt=18kN/m3. Wet unit weight of Loamy layer from volcanic ash and clay layer are smaller than 18kN/m3, and colluvial deposit from hard rock and weathered rock are larger than γt=18kN/m3.The wet unit weight of moving soil mass is shown Table 3.2.3. The unit weight shall be measured on site as much as possible.

Table 3.2.3 Designing value of soil parameter in Japan *3

Classification		Soil state		Wet unit weight [kN/m^3]
Embankment	Gravel and Sand with Gravel	Compacted		20
	Sand	Compacted	Wide grain size	20
			Sorted	19
	Sandy Soil	Compacted		19
	Cohesive Soil	Compacted		18
	Volcanic ash	Compacted		14
Natural Ground	Gravel	Dense or wide grain size		20
		Not dense or sorted		18
	Sand with Gravel	Dense		21
		Not dense		19
	Sand	Dense or wide grain size		20
		Not dense or sorted		18
	Sandy Soil	Dense		19
		Not dense		17
	Cohesive Soil	Hard (yield under strong pressure of a finger)		18
		A little soft (penetrate under pressure of a finger)		17
		Soft (penetrate under pressure of a finger easily)		16
	Clay and Silt	Hard (yield under strong pressure of a finger)		17
		A little soft (penetrate under pressure of a finger)		16
		Soft (penetrate under pressure of a finger easily)		14
	Volcanic ash			14

d. Cohesion, c, and Soil Strength Constant, φ'

When the soil strength parameters (c and φ) are obtained from the stability analysis, the calculated factor of safety sometimes differs from the actual values obtained from the monitoring of the landslide. In general, the reverse calculation of stability analysis shall be used to determine one of the strength parameter (c or φ) by using the current factor of safety, and determine the actual values for the rest of the parameters as the last step.

Generally, the value φ is affected by groundwater drainage works, and the value c is affected by earth removal works, . Therefore,, for groundwater drainage work, the φ value shall be obtained from an appropriate soil shear test, and the c value shall be obtained using the reverse calculation for implementing the ground drainage works.

And the c value shall be obtained from soil shear test, and the φ value shall be obtained from reverse calculation for implementing the earth removal works.

Figure 3.2.5 shows an example using reverse calculation when the current factor of safety is set as 0.98.

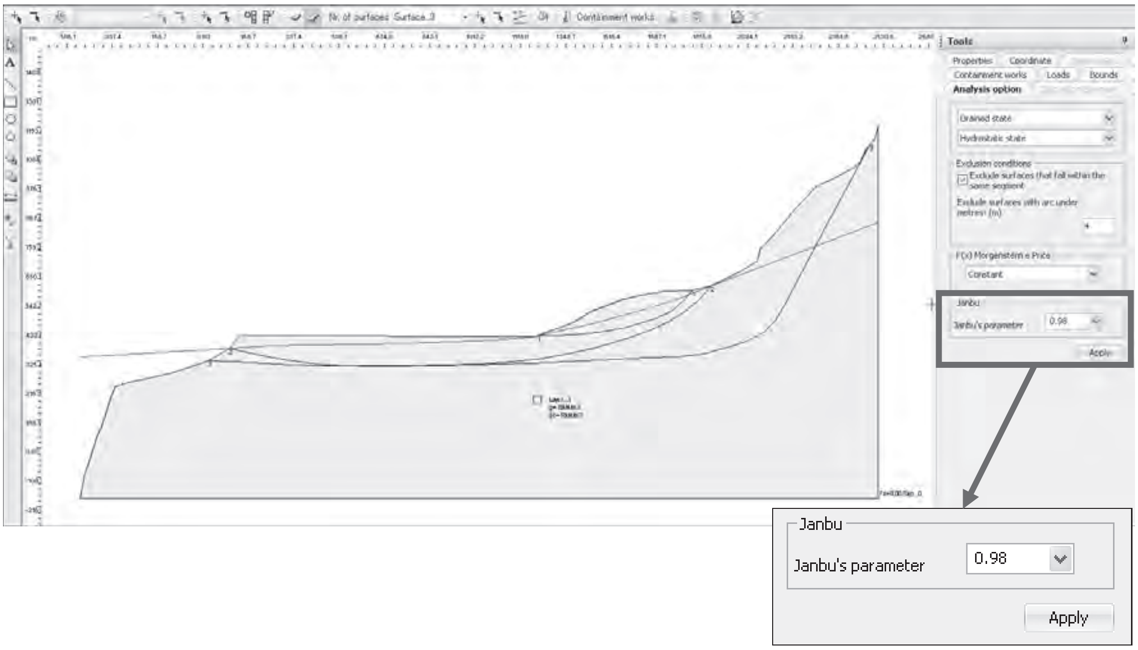


Figure 3.2.5 An example of back calculation of the stability analysis (1) [*4]

Figure 3.2.6 is the result of estimating the values c and φ using reverse calculation software. The horizontal axis is the cohesion "c" and the vertical axis is the friction angle φ. Using the curve plotted on the graph, any figures for the c or φ can be obtained.

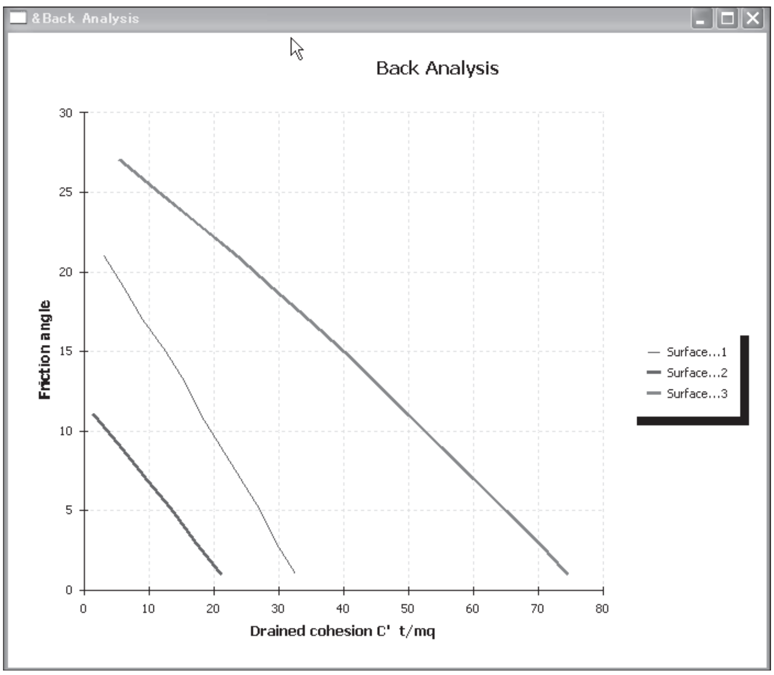


Figure 3.2.6 An example of back calculation of the stability analysis (2) [*4]

Figure 3.2.7 shows relationships between the residual friction angle (φr') and plasticity index (IP) of clayey soil taken from the sliding zone. The data are collected from various landslide affected areas in Japan. When the soil shear test cannot be conducted, the empirical values for the similar geological conditions can be selected for the stability analysis.

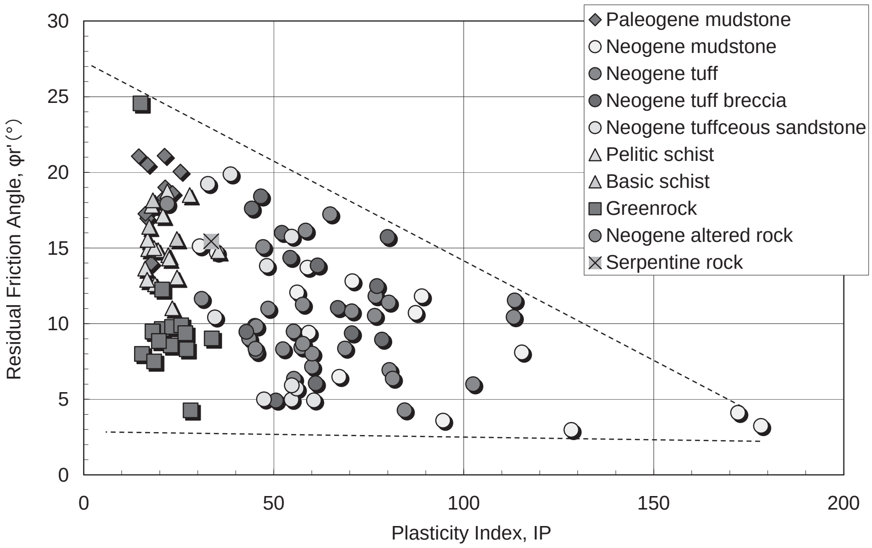


Figure 3.2.7 Relationship between residual friction angle φ r' and plasticity index in JAPAN [*1]

3.2.7 3Evaluation of the countermeasures

a. Evaluation the effectiveness of earth removal work and buttress fill work

The earth removal works and/or the buttress fill works for the countermeasures shall be evaluated by stability analysis, along the longitudinal line with the improved topography (Figure 3.2.8 and Figure 3.2.9). The safety factor is an indicator for the effectiveness of the countermeasures. If the countermeasure is not appropriate, value of the safety factor become negative or zero.

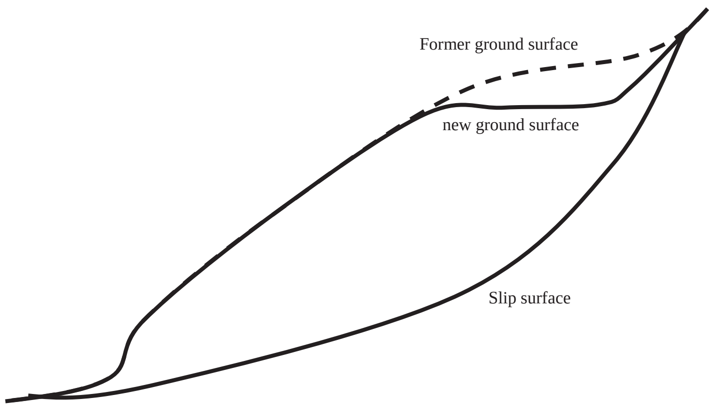


Figure 3.2.8 Topographic change after earth removal work [*4]

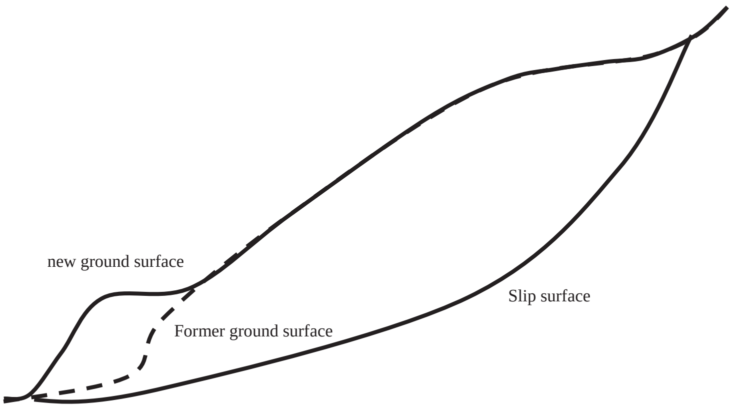


Figure 3.2.9 Topographic change after buttress fill work *4

b. Evaluating the effectiveness of groundwater drainage work

The effectiveness of the groundwater drainage works shall be evaluated by observing the change in groundwater level. The numerical simulations such as FEM (Finite Element Method) or FDM (Finite Difference Method) can be used to estimate the decrease in groundwater level.. The hydrologic equations for pipe drains can be used to provide a rough estimation for the effectiveness.

The safety factor shall be derived from the stability analysis, reflecting the change in groundwater levels by implementing the countermeasures. The increment of the factor of safety is the result of decrease in groundwater level, and can be the indicator for the effect of the groundwater drainage work.

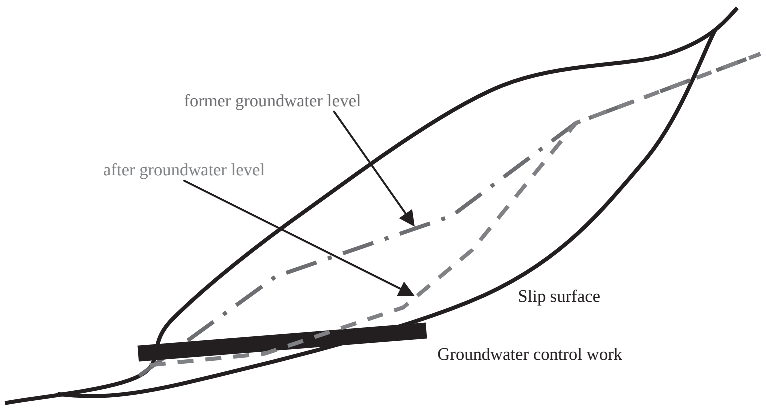


Figure 3.2.10 Changes in groundwater level by groundwater drainage work *4

3.3 Introduction to Countermeasures for the Landslide

Landslide countermeasure shall be planned considering the scale and mechanisms of the damages,, the importance of the infrastructures and houses to be protected, and balance of benefit and cost for the countermeasures to be implemented.

The landslide countermeasures include; control measures and restraint measures. The control measures indirectly influence the landslide risks by removing the affecting factors. The restraint measures directly influence the landslide risks.

Followings shall be considered for selecting the countermeasures;

1. In principle, the control works shall be prioritized to the restraint works.
2. Where the landslides are active, the control measure shall be implemented with a priority. Once settled, then the restraint measure shall be introduced.
3. The total cost including the maintenance shall be considered.

Following flowchart illustrates an example of selecting the countermeasures and calculating the factor of safety for the road construction work.

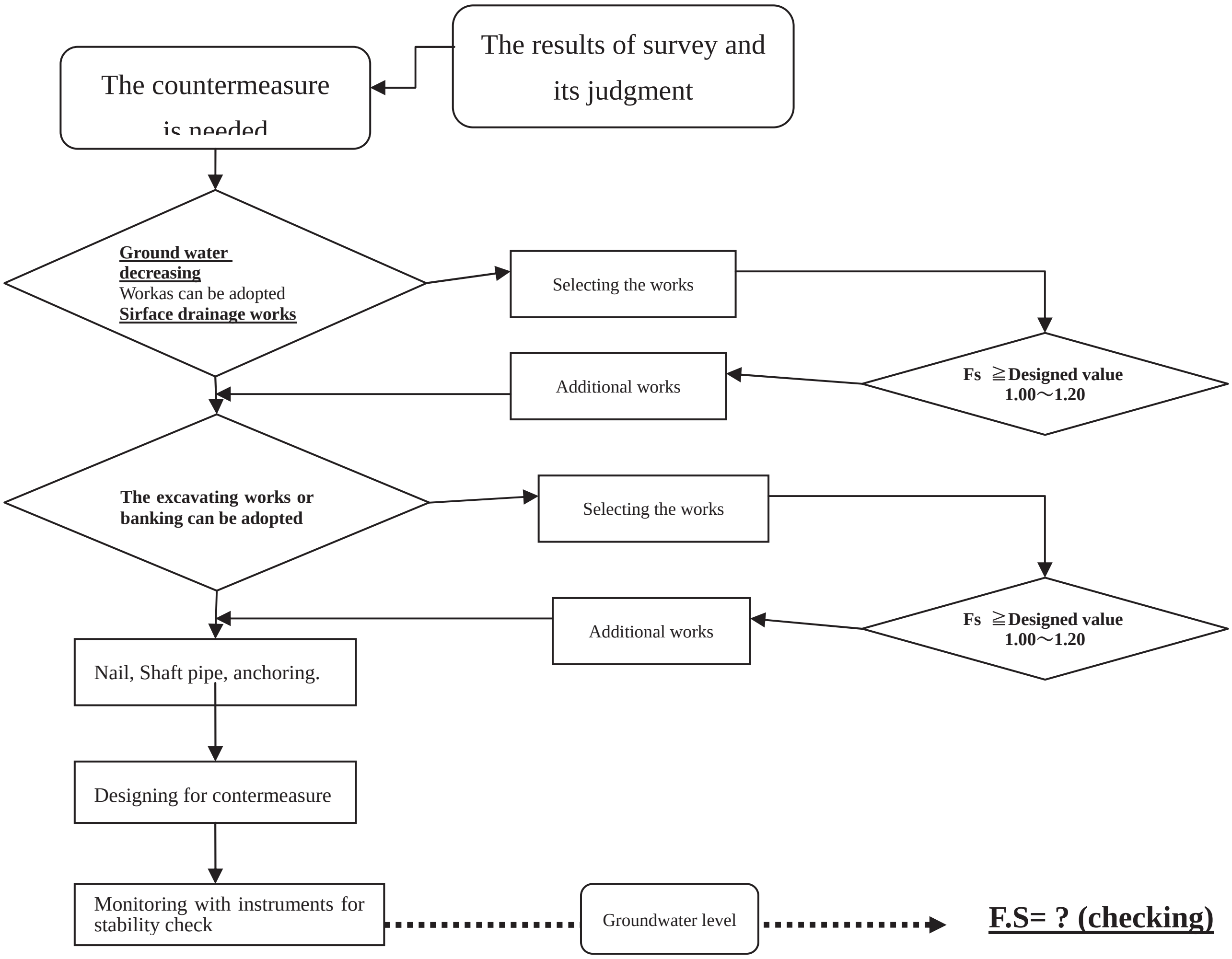


Figure 3.3.1 The work flow chart of the landslide countermeasure in the road construction works in Japan

Landslide countermeasure is divided into control works and restraint works. The control works target at the environmental factors, such as groundwater level and weight of the soil mass, which affect the slope stability. Example of the control works include; to prevent the surface water penetrating into the soils, or to decrease the groundwater level. The restraint works include; installation of the structures such as piles, shafts, and anchors so as to add more resistance to the current landslide stability.

Types of landslide countermeasures are shown in Figure 3.3.2 and Figure 3.3.3.

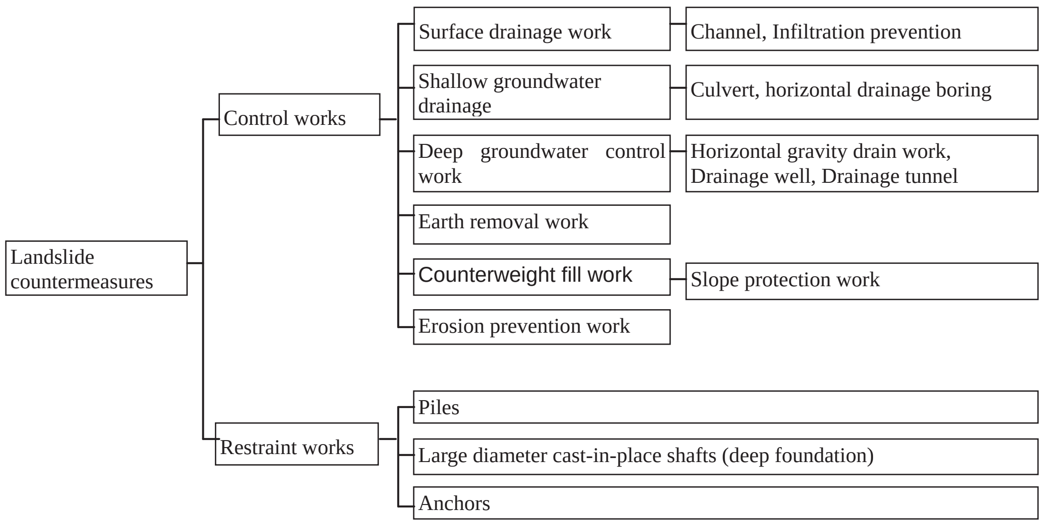


Figure 3.3.2 Landslide countermeasures [*2]

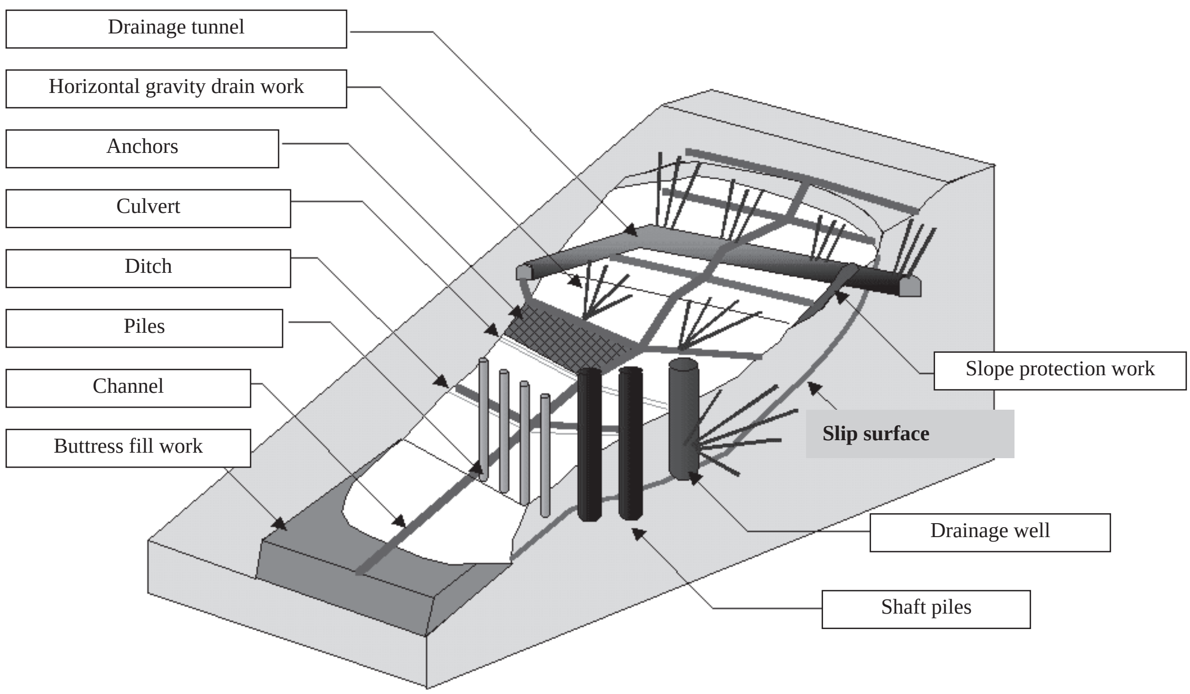


Figure 3.3.3 Schematic figure of landslide countermeasure works [*2]

1. The Surface drainage work can be used to control the landslide by preventing the infiltrations from rainfalls and surface water flowing from internal and external landslide areas.
2. Shallow groundwater control works can control the ground water supply near the slip surface by draining away ground water in the shallow areas.
3. Deep groundwater drainage works can reduce the pore water pressure near the slip surfaces by draining away ground water distributed in deep areas.
4. Earth removal work can be generally implemented in the upper zone of the landslide area in order to reduce the sliding force. Buttress fill work is generally implemented in the toe zone of the landslide area in order to increase the sliding resistances.
5. Erosion restraint works are used to prevent erosion and collapse which may cause a landslide.
6. Installation of piles into the stable bedrocks can directly increase the resistance the shear resistance and bending resistance.
7. Shaft piles, large diameter cast-in-place shafts for deep foundation, are vertical shaft drilled into the stable bedrock and filled with reinforced concrete.
8. Anchors increase the resistance to landslide sliding using the extension strength of the steel and the adhesion of anchors installed in the stable bedrock.

The following describes more details for each countermeasure work

3.4 Landslide Control Works

Landslide control work is to stabilize unstable slope through modifying the balance between the sliding-driving force and sliding-resisting strength by means of landslide topographic change and groundwater drainage. The following provides explanation for each control work in details.

3.4.1 Surface Drainage

a. Purpose

Surface drainage work can drain out the surface rain water and prevent the infiltration into the ground. The shallow groundwater drainage can drain the groundwater and it can decrease the water pressures acting on the slip surface.

b. Description

Structure of the surface drainage works shall be easy to be modified in order to follow the shape of the land deformation.. It also shall be easy to be maintained and repaired. The surface drainage structure may be combined with the culvert if necessary. The groundwater drainage structures include; infiltration prevention work and drainage channel.

The Infiltration prevention works are considered to be the most effective if location of the installation is carefully selected in a fissure zone where high permeability can be achieved. It is also effective in a marshland where there is a possible groundwater supplying source. But it is difficult to install this type of structure for an entire landslide area.

The Drainage channel is used to drain out surface water which is collected at the concave and low part of the slope. It requires digging of water path to prevent infiltration into the landslide body with minimum excavation.

The cross section shall be wide and shallow for purpose of easy access and maintenance. Furthermore, geometry of the cross section shall be determined based on the estimated flow volume. In addition, the cross section shall be designed considering the decrease in cross sectional areas due to the debris accumulation and channel deformation. The structures such as corrugate or corrugate flume are applicable.

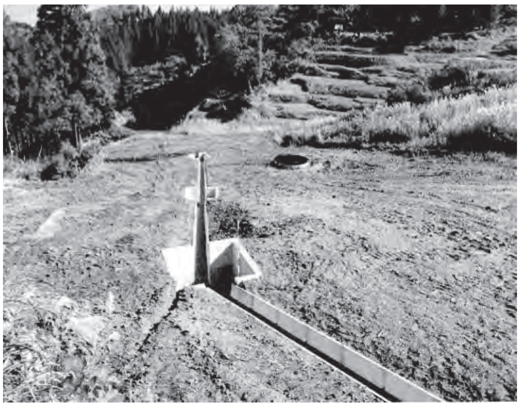


Figure 3.4.1 Bench flume water path

Figure 3.4.2 Corrugate water path

3.4.2 Shallow Groundwater Drainage

a. Purpose

The Shallow groundwater drainage is used to drain out the groundwater which is located less than 15 m in depth.

b. Details

Types of shallow groundwater drainage include; underground culvert, surface culvert, and horizontal drainage boring hole.

c. Underground culvert

The underground culvert consists of a continuous columnar gabion (gravels with very high permeability) placed on water-proof sheet, filled with the filtering materials such as gravels and sands, acting as an artificial drainage for the shallow ground. Top of the drainage shall be filled with locally available soils. The structure shall prevent any leakages, and it shall be easy to be modified for the ground deformation or cloggings.

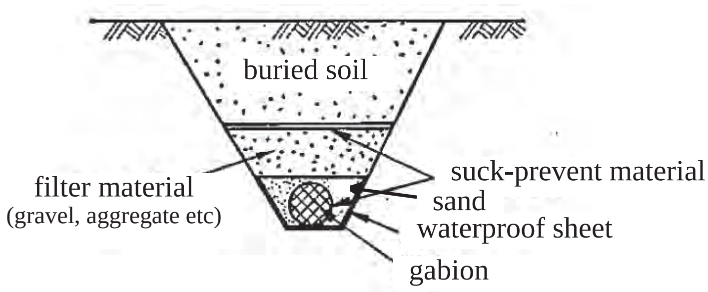


Figure 3.4.3 Culvert *3

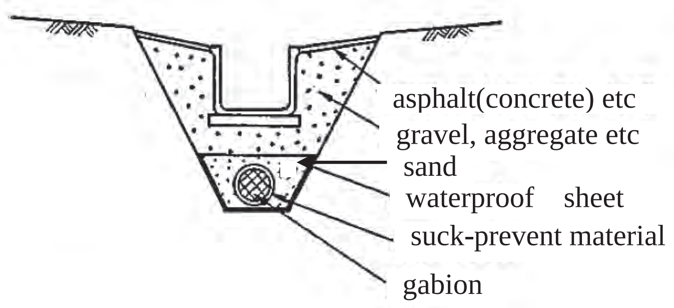


Figure 3.4.4 Surface culvert *3

d. Surface culvert

The Surface culvert consists of a combination of gabion and surface drainage work. The Gabion receives water from the surface drainage path for effective collection and drainage of water.

e. Horizontal drainage work

The horizontal drainage work can decrease the pore-water pressure which is acting on the slip surface. Drilling with a diameter of 66 to 86 mm shall be made horizontally, and a perforated pipe shall be installed for collecting water. Generally, vinyl chloride pipe and iron pipe are the materials used for the perforated pipe. Locations and number of boreholes to be installed shall be determined in order to achieve the effective performance. Locations of aquifers and groundwater shall be identified by detailed investigation on topography, geology and groundwater.

Figure 3.4.5 Horizontal drainage work

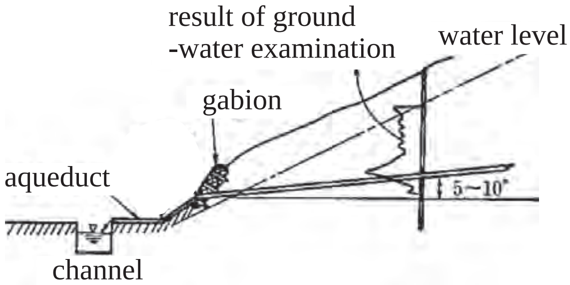


Figure 3.4.6 Horizontal drainage work [*4]

3.4.3 Deep Groundwater Drainage

a. Purpose

The groundwater drainage work can drain out the groundwater located at a depth of 15 m or deeper in the landslide areas.

b. Details

The deep groundwater drainage work includes; horizontal drainage boring holes, water collecting wells, and drainage tunnels.

c. Horizontal drainage work

The horizontal drainage work works can decrease the pore-water pressure which are acting on the slip surface, and as a result, reduce the water content in the sliding mass. The horizontal hole shall be drilled and then a perforated pipe shall be installed for collecting water. For deep groundwater, a diameter of 200 to 300 mm shall be used for drilling and perforated pipe. Generally, Vinyl chloride and iron are used for the pipe materials. Locations and number of boreholes to be installed shall be determined in order to achieve the effective performance. Locations of aquifers and groundwater shall be identified by detailed

d. Drainage well

The Drainage well is used to drain the deep groundwater by drilling a vertical well with water collecting structures This structure is used where the culvert by itself cannot drain the water due to the depth. The well with the structure of water collection shall be installed to the depth below the target groundwater flow. The following illustrates the drainage well. The casing shall be made of lining plate or reinforced concrete.

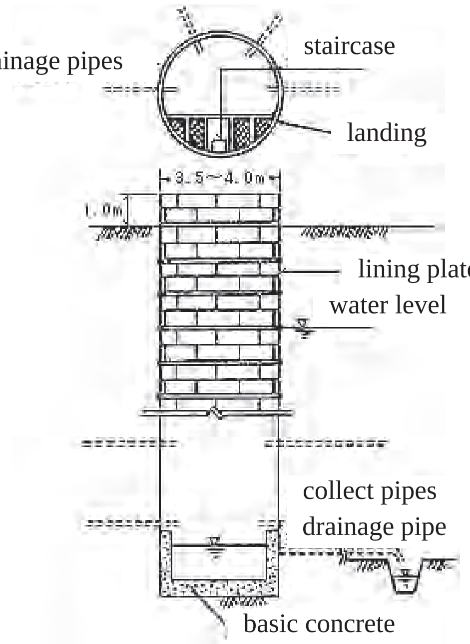


Figure 3.4.7 Cross section of a drainage well *4

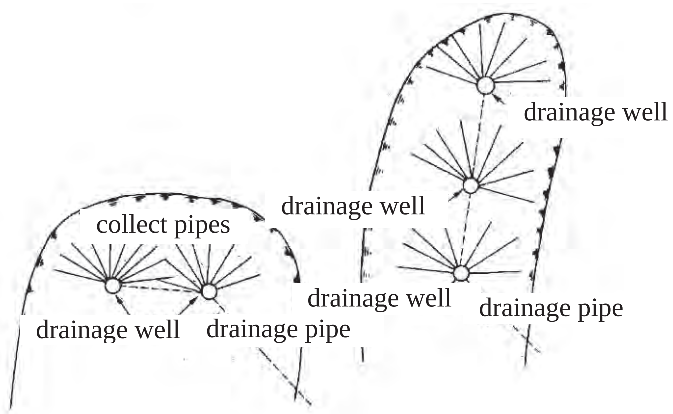


Figure 3.4.8 Sample arrangement of drainage wells *4

Followings are the considerations for the drainage wells;

- Diameter: 3.5m - 5.0m;
- Materials: lining plate or reinforced concrete;
- Dimensions: maximum length ＝80m, inner diameter of drainage pipe: 80 - 100mm;
- Collecting structure: standard length is 50m. The inner diameter of collecting pipe is more than 40mm, strainer treated stiff polyvinyl chloride pipe (PVC pipe);
- Locations and number of layers of collecting structures: multiple layers shall be investigated for each aquifer.

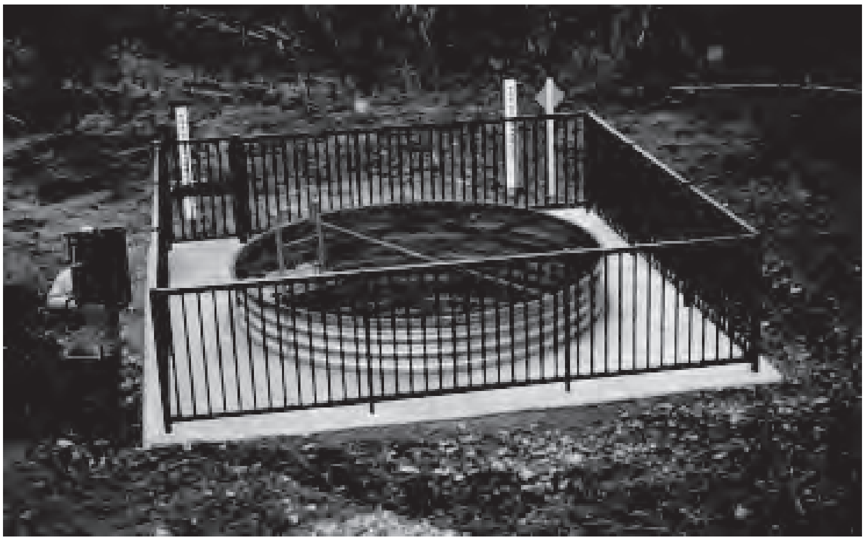


Figure 3.4.9 View of a drainage well at the surface [*5]

e. Drainage tunnel work

The Drainage tunnel work can drain out the deep groundwater through water collecting pipes. The pipes are attached to a drainage tunnel and extended upward, passing the slip surface where target groundwater is located. This structure shall be used in the areas where a large landslide is expected, with a thick moving layers or high sliding velocity. The drainage tunnel shall be installed in the stable bedrock located below the slip surface.

Slope of the tunnel shall be less than 1.5% in order for the water to keep flowing. The lining shall be placed on the tunnel roofs and walls for better maintenance purpose.

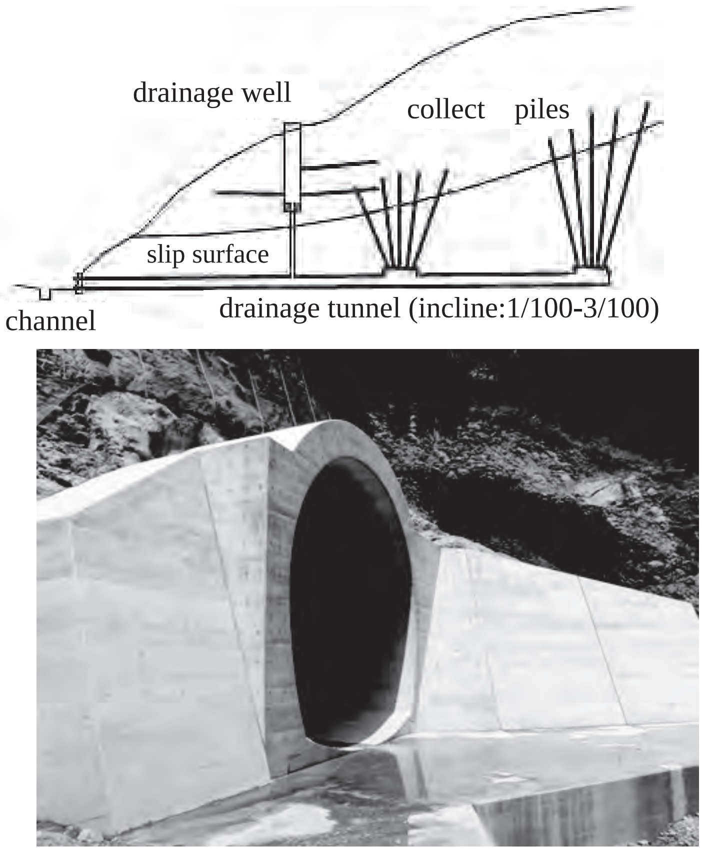


Figure 3.4.10 Drainage tunnel work [*4]

3.4.4 Earth Removal and Buttress Fill

a. Purpose

The earth removal work and buttress fill work can increase the factor of safety by modifying the balance between slide-driving forces and resisting strength by changing the topographical features

b. Details

1) Earth removal work

The Earth removal work literally removes earth at the head of slope in order to reduce the driving force and stabilize the sliding slope. The slope gradient and the height of the sliding mass shall be determined based on the geological conditions. For cut slopes in soft rock, generally, the slope gradient is designed as 1:0.5 to 1:1.2, and the general beam width is 1.0 - 2.0 m for every 7m height. For the sandy soils with 5 - 10m high cutting slopes, the slope gradient is about 1:1.0 to 1:1.5, and the general beam width is 1.0 - 2.0m for every 5m height.

After the earth removal works, surface drainage work in the slope and drainage water path at the general beam shall be designed for the cutting slope for water collecting and water drainage. The topographic conditions shall be considered in the design. Moreover, it is very important to protect the cut slopes from erosion and weathering by providing surface protecting structures such as vegetation.

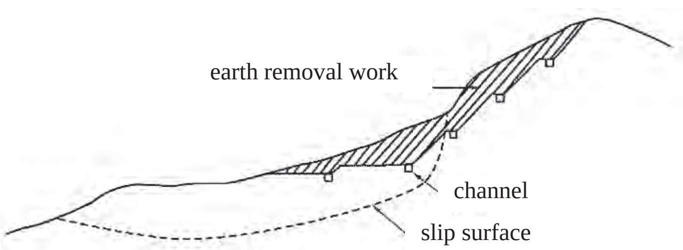


Figure 3.4.11 Earth removal work and cutting slope surface [*3]

2) Buttress fill work

The Buttress fill work can stabilize the landslide by adding additional weight at the toe part of a slope, and increase the resisting force. However, in some cases, the toe part of slope could be disturbed and becomes weaker due to the bottom failure of the buttress fill works. The filling work could become a trigger for another landslides, since it loads additional weights on top of the slope. Therefore, stability of the ground foundation shall be carefully evaluated for design of buttress fill works. If the buttress fill work prevents the groundwater flow at the slope toe, it may increase the groundwater levels, and as a result, becomes the slope unstable. Therefore, the groundwater drainage shall be secured. Height and slope gradient of a buttress fill work shall be determined according to the property of the filling materials and conditions of the ground foundation. In most cases, the slope gradient is 1:1.8 to 1.20. Rainfalls on the slope surface of the buttress fill work could become a trigger for collapse and erosion; therefore, surface protection work such as vegetation shall be considered.

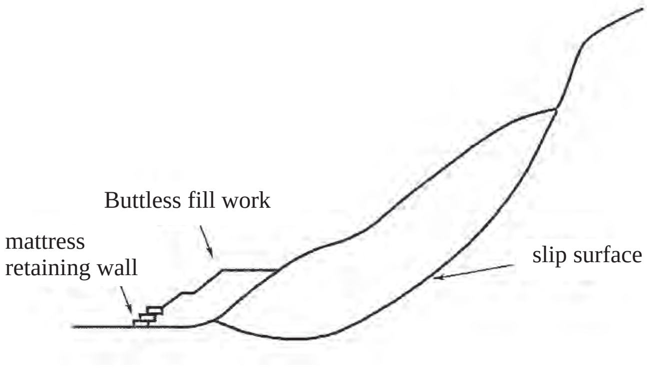


Figure 3.4.12 Earth removal work and cutting slope surface [*3]

3.5 Retaining Works

The Restraint work can increase the resisting force. The followings explain the detailed methods.

3.5.1 Pile Work

a. Purpose

The pile work includes the installation of penetration pipes through the moving layer to the stable ground. The safety factor can be increased by the pile shear resistance and the resisting force…

Purpose of pile work is to install a pile which penetrates the moving layer to the stable ground in a landslide. The factor of safety of a landslide can be increased by use of the pile shear resistance and the resisting forces which accompany to the pile bending deformation.

b. Details

The steel piles with the diameter of 250 to 1000 mm and reinforced concrete piles are installed crossing the landslide areas with the even intervals in the perpendicular directions. Pile locations shall be determined based on followings;

1. Pile bottoms shall be installed in the stable ground;
2. Piles shall be located along the centerline and at the lower elevation of the slope
3. Piles shall be installed at the bottom of land mass where the ground reaction force can be fully utilized.
4. The piles shall be installed at the areas where thick sliding mass and the compression stress exist,
5. Passive failure shall not be observed in the area of installation
6. The low land area shall have a large ground reaction to the piles.

Bending stress and shear stress shall be examined for the pile design. The pile intervals shall be identified by dividing the required restraint force by the allowable shear strength of a single pile.

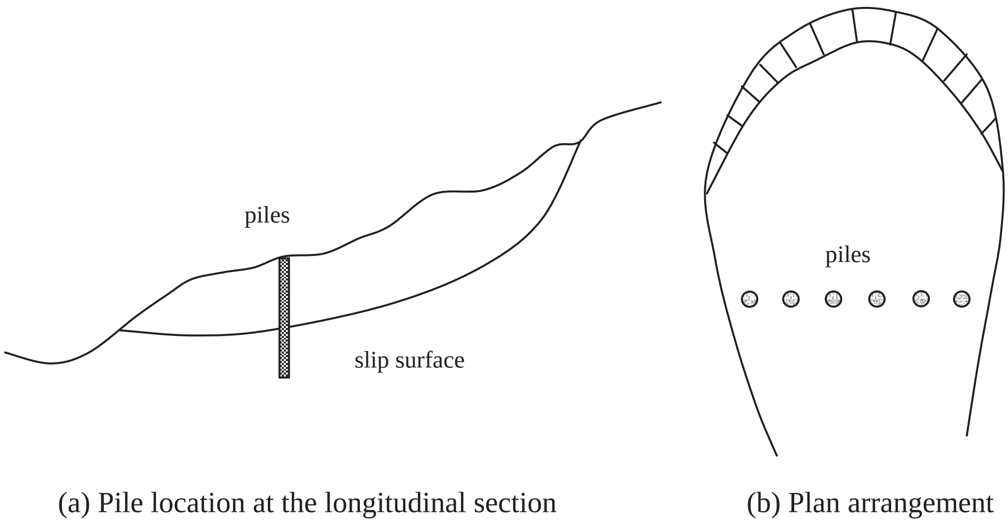


Figure 3.5.1 Pile work

Figure 3.5.2 Pile work

3.5.2 Shaft Work

a. Purpose

The shaft work is used to stabilize the slope movement by placing a reinforced concrete pile (shaft) with a large-size diameter, down to the stable ground. The factor of safety can then be increased by increased shear resistance.

b. Details

A rounded vertical pit with large-diameter (3 - 5m in diameter) is excavated to a depth below the slip surface (the side wall of the pit shall be protected from collapsing during the excavation). Then vertical reinforcing steel bars are installed in the pit. Finally, concrete is poured in the pit, and a large-diameter reinforced-concrete column (shaft) is constructed. The shaft work is used in the areas where there is a high possibility of sliding. The pile works by itself cannot satisfy the designated factor of safety. The method is also suitable at the areas where the steel pipes are not available.

The interval of the shaft work can be determined by dividing the necessary restraint force for a designated factor of safety by the shear strength of a single shaft. The shafts shall not be pukked up by the force produced by the soil mass movement.

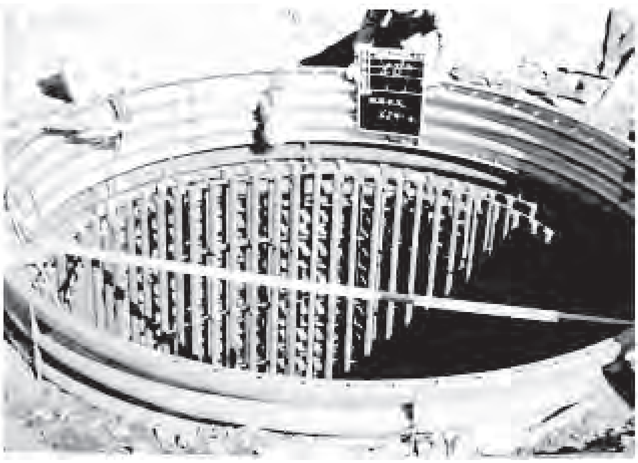


Figure 3.5.3 Shaft Work [*5]

3.5.3 Anchor Work

a. Purpose

The ideas of the Anchor work for the landslide is similar to the ground anchor works in the civil engineering work. The factor of safety can be increased by using the tension load in the anchor materials.

b. Details

The high strength steels are used as a tension agent for the anchor body to be fixed at the stable ground, which enable the anchor to withstand the ground movement.

The anchor works can be used in the case when the slope gradient is high (steep) and pile work or shaft work cannot receive enough ground reactions, and in the urgent case when the prompt stabilization effect is needed.

The treated anchors, such as double coated anchors against corrosion, shall be used for the anchor structure.

The loading plate should be strong enough to sustain the tension force from the anchor.

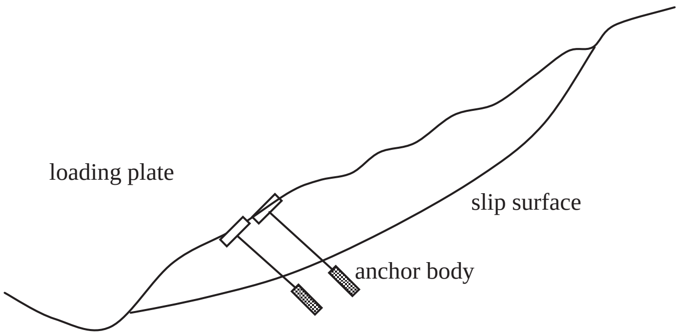


Figure 3.5.4 Anchor Work

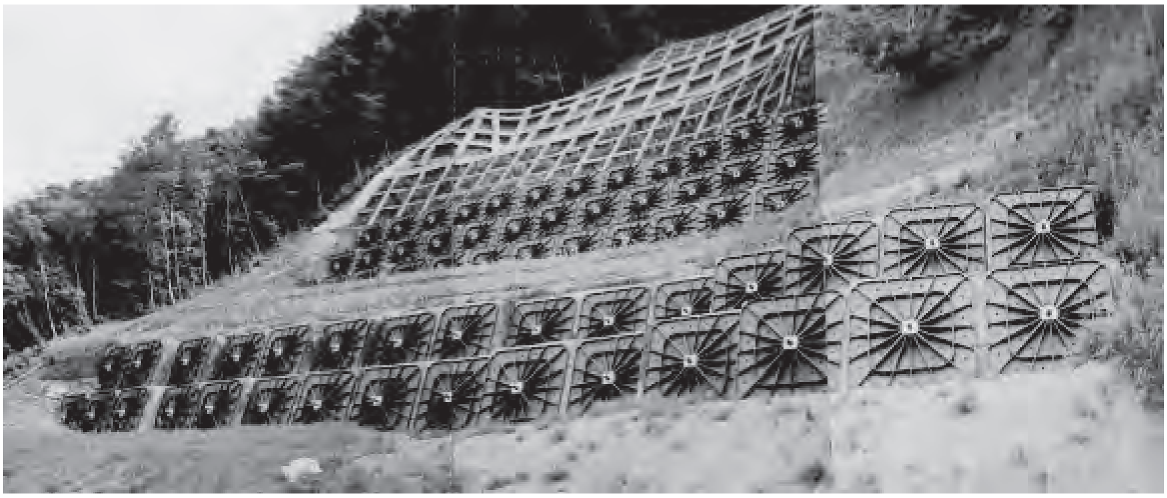


Figure 3.5.5 Anchor Work [*5]

References

*1 Japan Road Association : The flow chart for landslide countermeasure in the road construction works, page 405 Figure11-23, The guideline for stabilization of the cut or excavated slope in the road construction (2009)

*2 Kokusai Kogyo and Japan Conservation Engineers(2012) : The Project for Developing Countermeasures against Landslide in the Abay River Gorge-Final Report

*3 Ministry of Land, Infrastructure and Transport and Public Works Research Institute of Japan (2008): Detailed explanation for Landslide Prevention Technical Guidelines

*4 Landslide Association web site (http://www.jisuberi-kyokai.or.jp/)

*5 Japan Conservation Engineers web site

4. Emergency Measures

4.1 Measures for Emergency Situation

4.1.1 General

If any unusual conditions are detected in the landslide areas, following actions shall be required;

1. Identify the magnitude and direction of the landslide
2. Measure the distance of the land mass displacement
3. Identify the direct and indirect causes of the movement
4. Predict the risk or possibility of landslides
5. Estimate the development of the land mass movement, by field survey
6. Estimate the hazardous areas
7. Install the monitoring tools accordingly, and construct the networking system for evacuation

Item 6 and 7 shall be implemented as soon as possible since it affects the human lives.

4.1.2 Surveys during a emergency situation

Item 1 and 2 in the above section shall be implemented during a site survey.

The item 1 shall be conducted in larger zones that include the areas where the landslide was observed. The surveys include; topography, geology, and distortions observed on the buildings and seepage of water on the ground surface nearby the areas.

The item 2 shall include the installation of the monitoring tools based on the site requirements. The extensometer (Figure 4.1.1) shall be installed across the crack or fissure created by the landslide movement. This measuring tool is preferable during an emergency situation because of the simple method of measuring the land mass displacement. The opening spaces shall be measured and recorded.

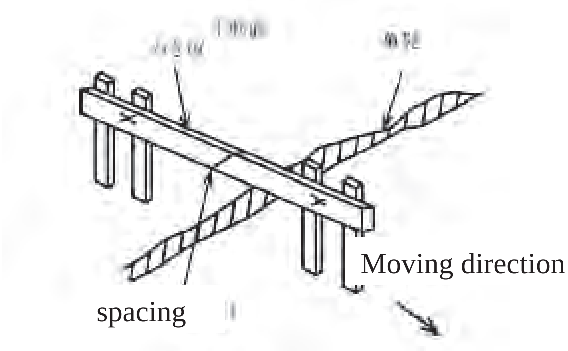


Figure 4.1.1 Nail & plate

4.1.3 Prediction of the Land Mass Movement

Direct and indirect causes and further land mass movement shall be estimated.

Topography, geological structures, rainfall history and human activities such as earth cuttings or construction of embankment are shall be evaluated for estimating the direct and indirect causes of the landslides.

The surface abnormally shall be carefully examined in order to identify the further land mass movement. If the soil plasticity in the area is high, it may take a longer time for the crack development Figure4.1.2 shows the typical landslide movement.

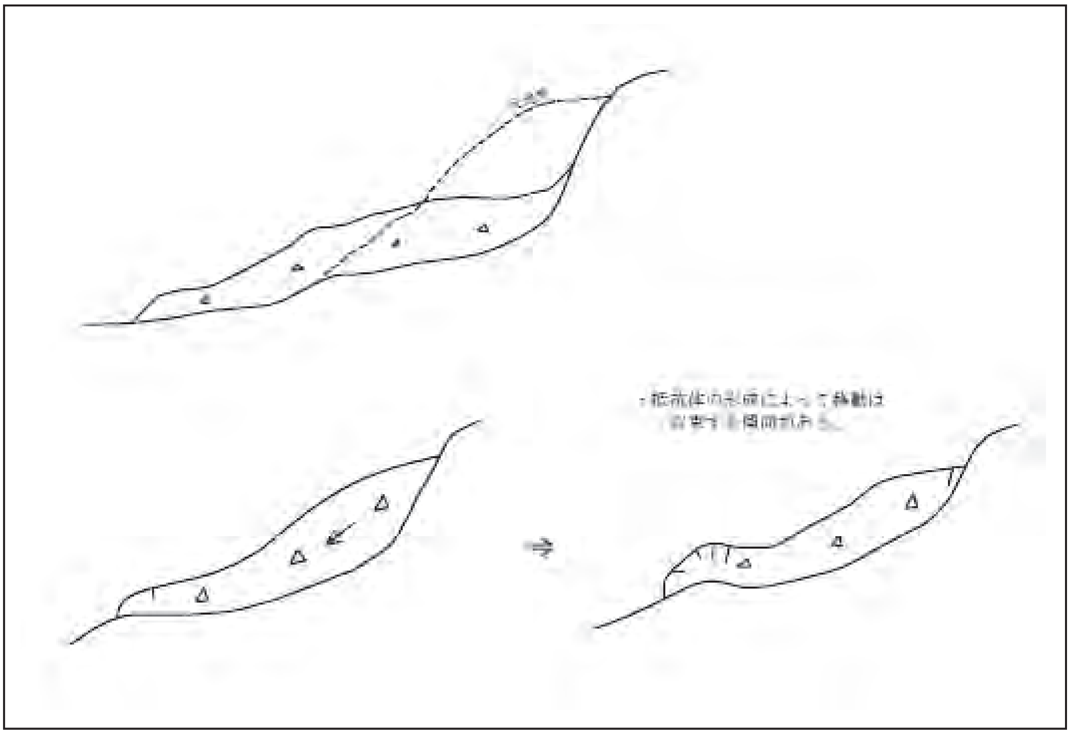


Figure 4.1.2 The Typica Landslide Movement

The several experiences in Japan indicate that the extent of the landslides can be estimated as approximately 2 times the length and 2 times the width (2L x 2W). (Figure4.1.3). Condition of the landslide extent depends largely on the topography of the peripheral area. Landslide may create a natural dam if there exist rivers in the areas.

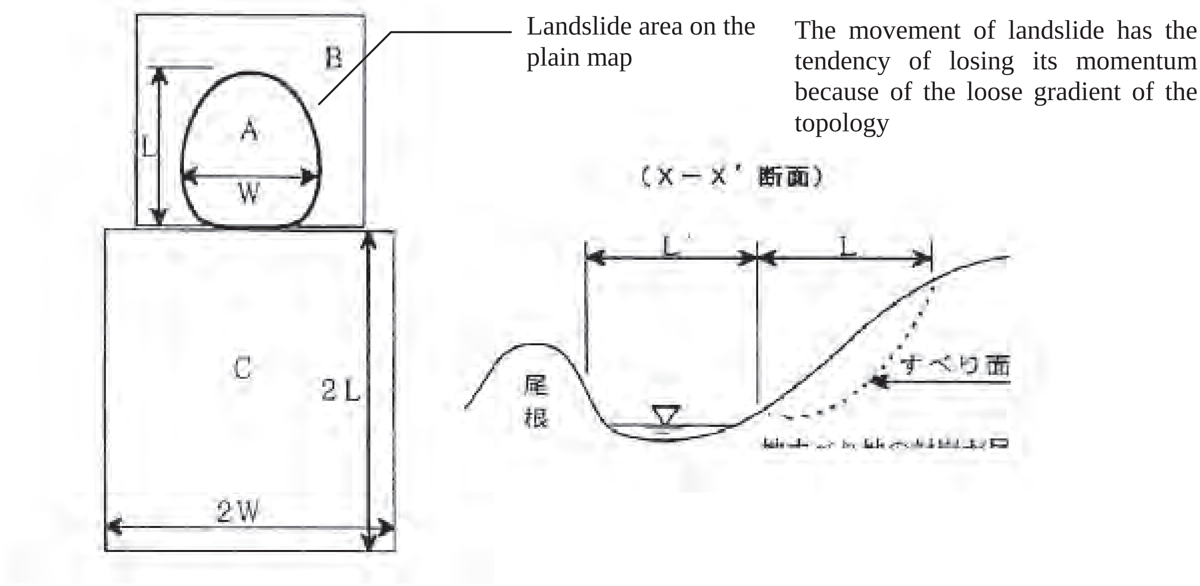


Figure 4.1.3 The assumed extent (one example)

4.1.4 Measures for Emergency Situation

Measures for emergency situation shall be derived from the data taken from the monitoring tools such as extensometer. Table 4.2.1 and 4.2.2 in next section explain the criteria and standard for the emergency situations.

4.2 Early Warnings

The early-warning systems shall be installed in order to protect the human lives.

The factors to be considered for installations of the early warning systems can be divided into two groups; 1) Causes by the environmental factors such as anomalies caused by the landslides, and 2) Causes by the inducing factors such as heavy rainfalls and earthquakes.

Followings shall be verified for evaluating the landslides;

1. Location of landslide
2. Time of occurrence
3. Volume and velocity of the landslide
4. Direction of the land mass movement
5. Possibility of further landslide

Monitoring can provide information for the necessary precautions for the land mass movement, by identifying the areas and times of the potential landslides. The proper monitoring and evacuation systems can prevent further damages and casualties caused by landslides.

Observation of rainfall patterns can provide the indirect precursory information, directing the community evacuations prior to the landslide disasters.

a. Observation of Anomalies and Deformation

The movement of landslide is slower than that of the typical slope failures, therefore, the effective field observation shall be conducted for providing the reliable warnings to the local people. Type of anomalies and deformation differ depending on the slope condition and landslide type. Type of anomalies and deformation are shown below.

1) Crack Appearances

Tension cracks tend to appear on the top or the upper part of the slopes.. Direction of the landslide movement can be estimated to be orthogonal to the tension cracks. The Lateral cracks appear on the side of the moving mass and the direction of the landslide movement is parallel to the lateral cracks. The compression cracks and pressure mounds tend to appear on the toe (end) of the landslide. The outline of the landslide area can be delineated by connecting those cracks. The Cracks can also be seen on the surface of asphalt road and concrete structures.

(NBRO)

Figure 4.2.1 Appearance of new crack at Mahawewa

2) Gully Erosion and Piping

The gully erosion occurs by surface stream which exist on the slope of soft and weathered material. As the gully become deeper, the slope between deep gullies becomes more unstable. The piping phenomena occur on the slope of soft and weathered material by spring water. As the amount of spring water increase, the piping hole become larger and the slope become unstable.

3) Heaving of the slope

The slope heaves sometimes due to the land mass movement. The heaving of the slope can be observed on the solid materials such as concrete retaining walls, masonry structures and gabion. The heaving of the slope usually accompanies tension zone or depression behind heaved slope.

(JICA Consultant Team)

Figure 4.2.2 Heaving of Embankment at Permadulla

4) Muddy spring water and stream water

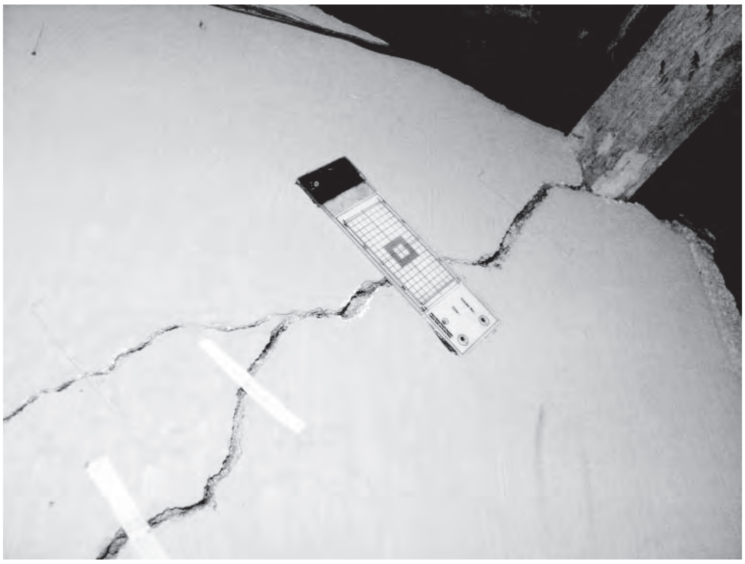
If the spring water and stream water in the area become muddy water, it may be an indication of landslide. The causes of muddy water are by increase of stream water, erosion of the surface materials and change of the stream route. Those conditions are caused by the land mass movement.

b. Monitoring Devices

In this section, methods of predicting the landslides and the general warning system for each predicted landslide level are introduced.

The warning levels shall be established depending on the site conditions. The risk assessment shall be updated as necessary.

For early warning and evacuation, the extensometer is useful to identify the activity of landslide, and to warn the local people. Any monitoring equipment to measure the movement as an extensometer can be applicable, for example, a simple wooden extensometer and a ruler to measure the crack on the walls can be used. The extensometer can also measure the crack on the road surface.



(Photo by NBRO)

Figure 4.2.3 Ruler to measure the crack on the wall

1) Extensometer

The warning standard practiced in Japan is shown below. Once the movement level exceeds 1mm/day or 10mm/month, the situation becomes very serious, and the evacuations shall be made. If the movement level is between 0.2mm/day to 10mm/day or between 2mm/month to 10mm/month, the situation becomes serious and the movement shall be observed.

For the short time movement which exceeds 2mm/hour, entry to the landslide area shall be restrained.

Table 4.2.1 Warning standard by Extensometer (Modified from *6)

Movement Level	Movement per day (㎜)	Movement per month (㎜)	Tendency of accumulation	Decision level of landslide	Activity level
Emergency Level	Over 1	Over 10	Very conspicuous	Definite	Very active level (Surface and deep slide)
Defined Level	0.1 to 1	2 to 10	Conspicuous	Semi-definite	Active or slow slide level (Clayey and colluvial deposit slide)
Quasi-defined Level	0.02 to 0.1	0.5 to 2	A little conspicuous	Potential	A little active level (continuous monitoring)
Potential Level	Less than 0.02	Less than 0.5	Small	Anomaly level	Partial deformation level

Table 4.2.2 Warning standard by pipe strain gauge(Modified from *6)

Movement Level	Daily movement (μ)	Monthly movement (μ/month)	Movement Feature		Geological or Geotechnical possibility of slip surface	Decision level of landslide	Activity level
			Trend	Feature			
Defined Level	over 10^2	over 5×10^3	prominence	superfetation	Exist	Defined sliding surface	Very active level (Rock and colluvial deposit slide)
Quasi-defined Level	over 10^2	over 10^3	semi -prominence	superfetation	Exist	Quasi-defined sliding surface	Active or slow slide level (Creep type slide)
Potential Level	under 10^2	over 10^2	a little moved	superfetation intermittence disturbing recursion	Exist	Potential sliding surface	Difficult to decide the existence of slip surface (continuous monitoring)
anomaly movement	under 10^2	over 10^3	nothing	intermittence disturbing recursion	Not exist	Another factor movement	No slip surface exist

2) Rain Gauge

Though influence of rain fall to landslide activity is considered important, the relationship between landslide activity and rainfall characteristics are difficult to analyze. The mechanism of rain water infiltration into the soil differs by topography, vegetation and land use, soil and geology, and pattern of rain fall. Regarding the evaluation of rain fall, followings shall be examined;

Hourly rain fall,
Half day rain fall,
Daily rain fall,
2 or 3 days rainfall,
Weekly rain fall,
Two weeks rainfall,
And monthly rain fall etc.

The factor of water content in the soil is one of the main factors for landslide evaluation. Once the amount of water in the soil exceeds the limit of saturation, overflows of surface water and underground water occur. Ground water condition is one of the important factors for the landslides.

The Mahawewa landslide activated from late December 2010 to middle of February, reference rain fall for warning and evacuation for the landslide can be examined from the data. Rain fall in short period, such as one day or one week rain fall did not affect the land mass movement, but the accumulation of one to two months rain fall affected the land mass movement.

c. Rainfall Accumulation

Rainfall and rise of ground water level are some of the indirect causes of landslide. The ground water level can be observed by specific observation well, and amount of rain fall can be observed by simple equipment. There are several ways of evaluating the accumulated rain fall based on warning and evacuation criteria.

The effective rainfall is considered as an index of water content in the ground which is closely related to the fluctuation of the ground water level. Several methods are proposed for the calculation of effective rainfall, for example;

1. The method based on accumulation of daily rainfall with weight
2. The method based on the daily rainfall with weighted average
3. The method based on accumulation of hourly rainfall with weight

The first and the third methods are popular for calculating the effective rainfall. Equation of the first method is explained as below,

Daily effective rain fall E_0 is expressed as;

$$E_0=\alpha \cdot R_0+\alpha^2 \cdot R_1+\alpha^3 \cdot R_{2n}+\cdots\cdots+\alpha^{n+1} \cdot R_n$$

R_0 : rainfall on the day, R_n : rainfall of n days before, α :coefficient of decrease($0<\alpha<1$)

The "n" shall be selected so as to "$\alpha^{n+1} \fallingdotseq 0$"

The "coefficient of decrease" represents the rate of decrease of effect, same as a half-life period "M". The relationship between "coefficient of decrease" and "a half-life period M" is as below.

$M=\log 0.5/\log\alpha$ or $\alpha=(0.5)1/M$

4.2.2 Warning Signs

It is important to inform the dangers to the people in the hazardous areas with possible landslides, debris flows and falling rocks in advance. Especially during rainy seasons, the warning signs can raise the awareness and keep the people out of the hazardous areas.

(JICA Consultant Team)

Figure 4.2.4 Examples of Road Side Signs

References

*1 T. Yamasaki, T.Mayumi and E.Yoshida(2000): Ring shear characteristics of high purity clay minerals －Correlation with natural slip surface clay－, Journal of The Japan Landslide Society, Vol.37, No.2, pp.30-39

*2 A.Fujiwara(1979) : Analysis and Prevent-Plan of Landslides, Rikoh Pub. Co., Tokyo

*3 Japan Road Association (2001) : Highway Earthworks Series Manual Slop Protection

*4 Kokusai Kogyo and JICA(2012) : Landslide Investigation Manual

*5 Japan Association for Slope Disaster Management and Japan Construction Training Center (1995): Textbook of landslide prevention technical training

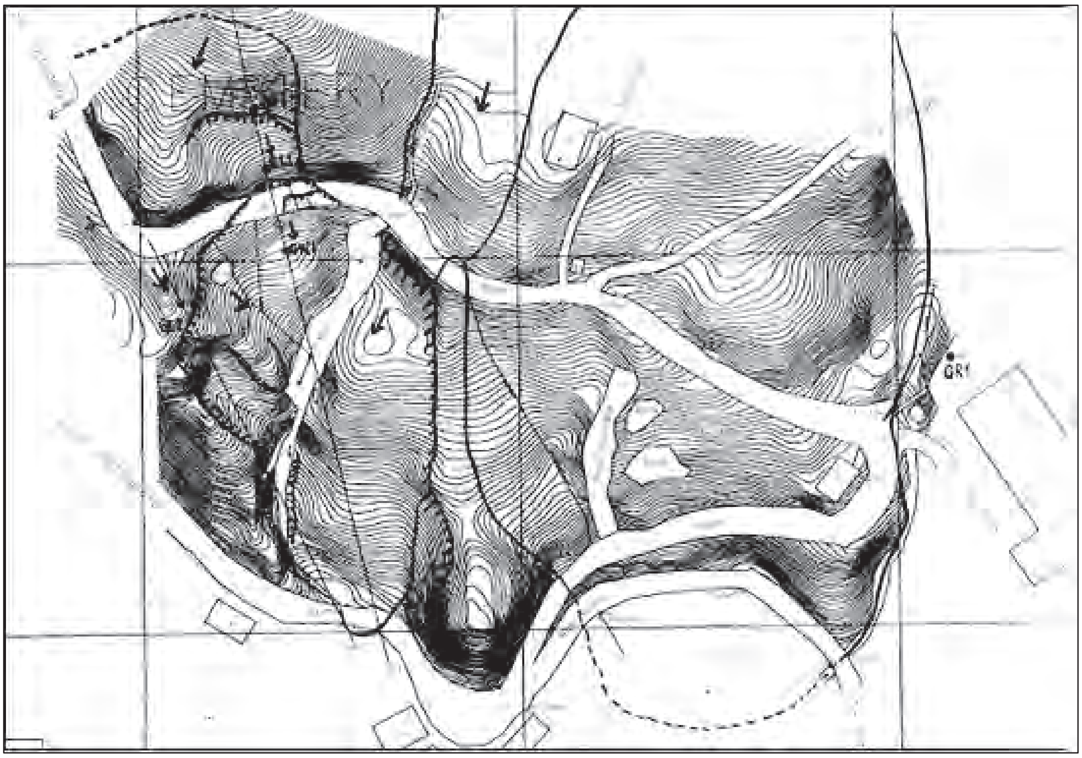
*6 Ministry of Land, Infrastructure and Transport and Public Works Research Institute of Japan (2008): Technical guide and instruction of landslide prevention

5. Example of Landslide Survey and Countermeasures (Result of Activities by DiMCEP)

5.1 Survey Results

5.1.1 Aerial Photo Interpretation

The Aerial photo interpretation can provide visual information for scoping the project site in a wide area. The aerial photos of Galaboda are shown below;



(NBRO and JICA Consultant Team)

Figure 5.1.1 Aerial Photo of Galaboda Area

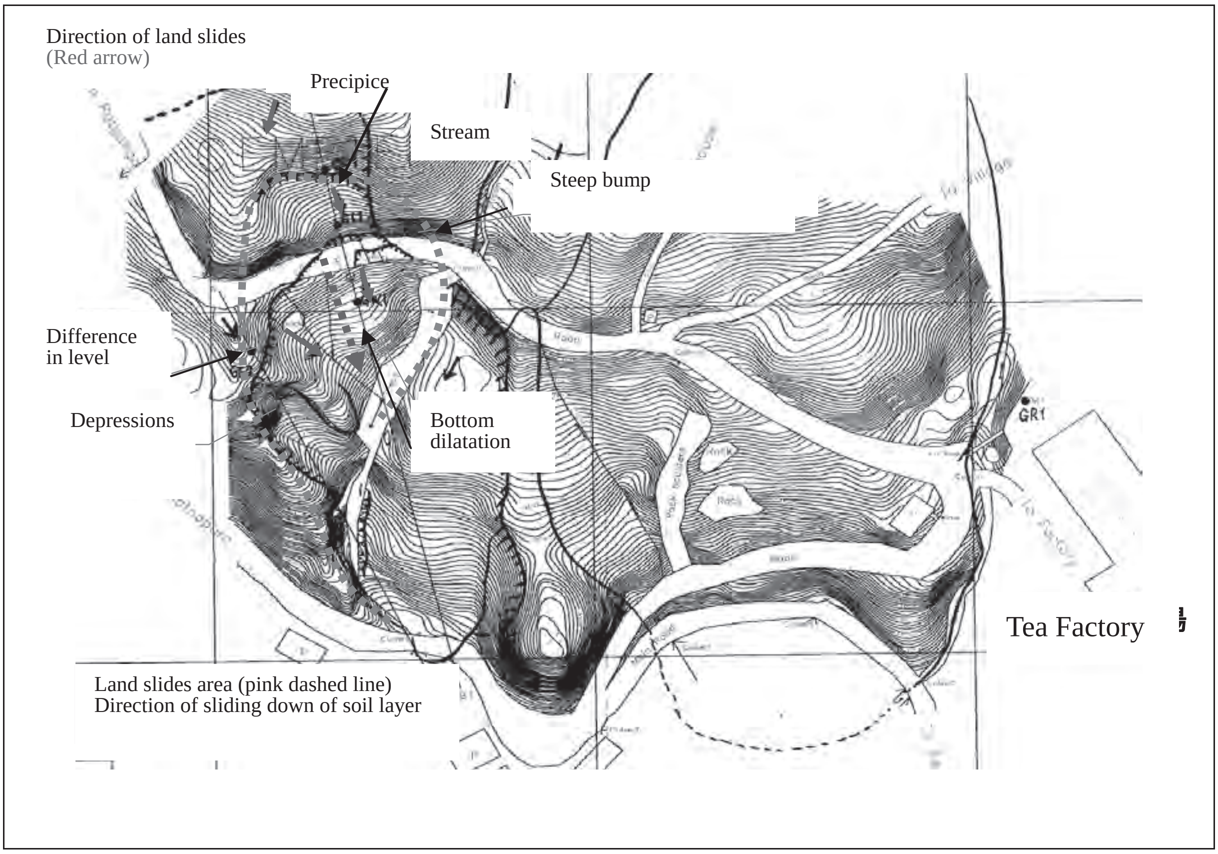
Table 5.1.1 Geomorphic Elements and Landslide Morphology Identified using Aerial Photo

Result of photographic interpretation			Landslide morphology	
Landforms	Area selected	Reason for selection	Geomorphologic element	Landslide features
1.Steep cliff	Upside of road	Horses shoe/dense contour	Sliding cliff	Head of slip clump/tensile phenomenon
2.Steep bump	Nigh of road	Dense contour	Colluvial	Instability soil/impact of construction?
3.Difference in level	Near the pressure ridge	Dense contour/strike	Lateral cliff	Difference between initial land form and landslide block
4.Dilatation	Under the road	Different shape of contour	Bottom dilatation	Dilatation of bottom of slip clump
5.Depressions	Under the pressure ridge	Colluvial phenomenon	Small colluvial	Secondary colluvial phenomenon

(NBRO and JICA Consultant Team)

5.1.2 Site Investigation

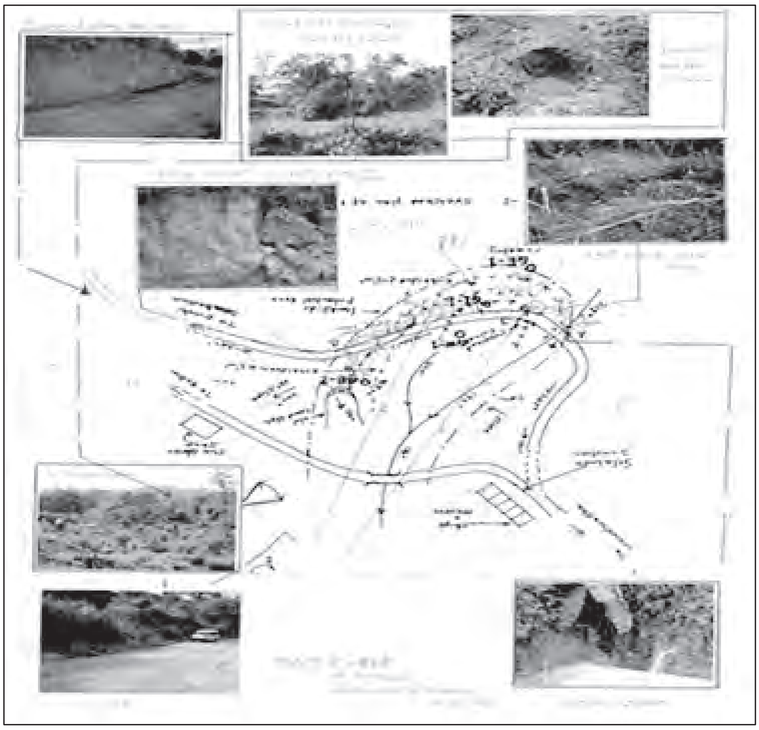
Site investigation follows after the aerial photo interpretation. The site investigations include the identification of any features peculiar to the landslides, such as precipices and cracks on road surfaces which cannot be identified by the aerial interpretations. Following illustrate the results obtained from the site investigations.



(NBRO and JICA Consultant Team)

Figure 5.1.2 Results from the Site Investigation at Galaboda

Once the site is selected for the investigation, topographical survey shall be performed, producing the topographical map with a scale of 1/200 to 1/500. In addition, the cross section of the land mass shall be produced along the direction of the movement. Number of cross section shall depend on the size of the moving mass. The topography survey shall cover the whole landslide areas. In Galaboda project, two cross sections were produced. Photographs and any findings from the surveys are noted on the map.



(NBRO and JICA Consultant Team)

Figure 5.1.3 Field Map Sample

Figure 5.1.4 and Figure 5.1.5 are the photographs taken from the site investigations.

(JICA Consultant Team)

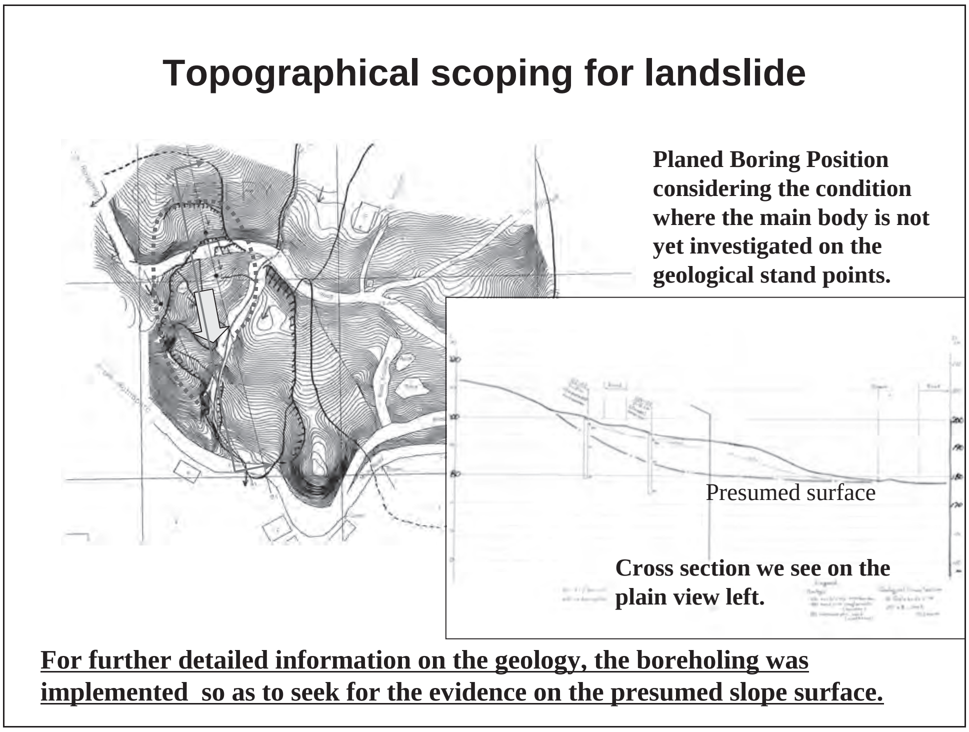
Figure 5.1.4 Cracks on the road（Left）and sliding cliff（Right）

(JICA Consultant Team)

Figure 5.1.5 Failure of earth cut face（Left）and weathering（Right）

5.1.3 Drilling Survey

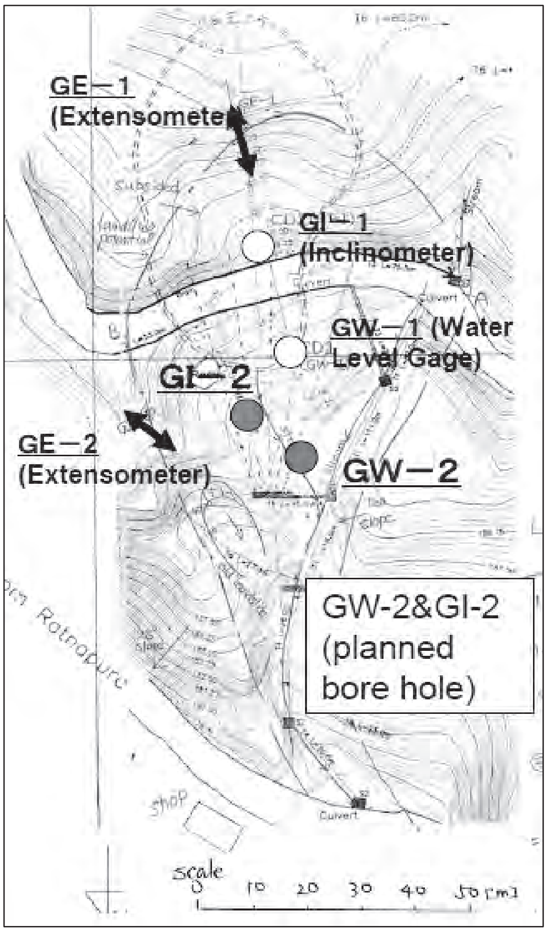
The cross section in the direction of the land mass movement shall be obtained based on the site surveys. The drilling surveys shall be conducted along the cross section of landslides. The blue line in Figure 5.1.6 indicates the cross section.



(NBRO and JICA Consultant Team)

Figure 5.1.6 Determination of the Cross Sections

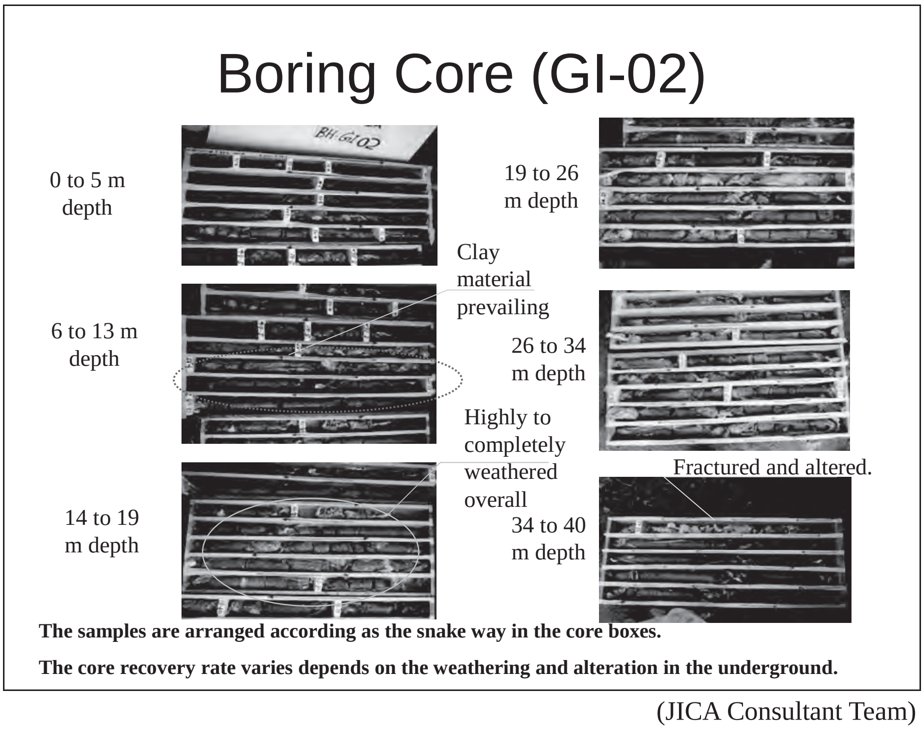
Location and number of boreholes shall be determined based on scale of landslide, geographical features, and monitoring activities. Figure 5.1.7 illustrates the installations of monitoring tools in Galaboda site. The cores shall be collected from the drilling surveys. Changes in the ground water level shall also be carefully recorded during the survey.



(NBRO and JICA Consultant Team)

Figure 5.1.7 Locations of drilling survey

The results of the drilling surveys are shown as below;

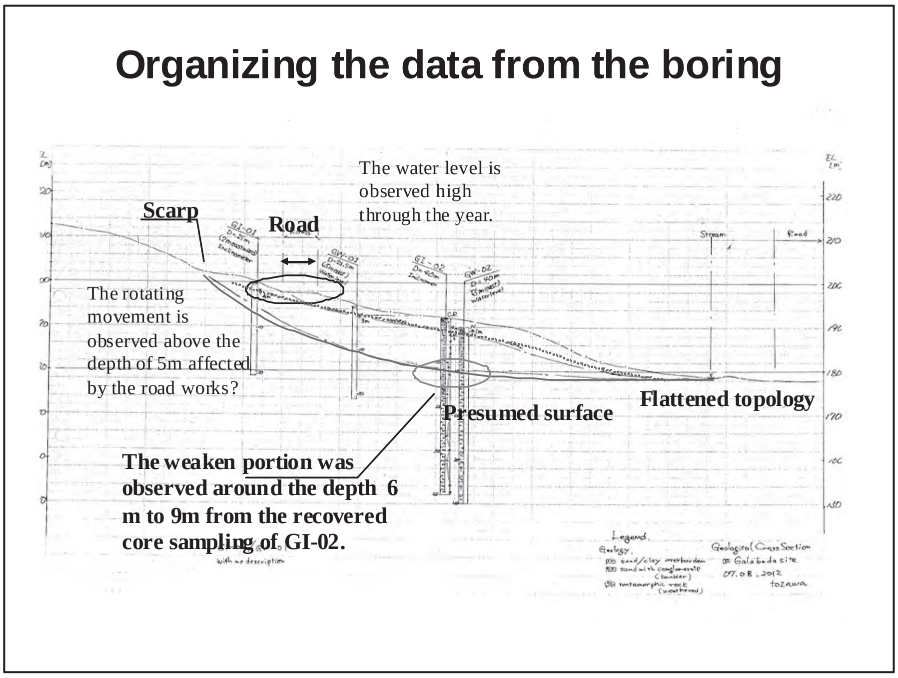


(JICA Consultant Team)

Figure 5.1.8 Drilling core (GI-02)

a. Estimation of slip surface

A core sample (GI-02) obtained from the drilling survey shows that there is a clay layer at the depth of 6m-9m. The clay layer is considered as unfavorable soil composition, and it may be the slip surface. The figure 5.1.9 illustrates the landslide block at the slip surface, depth of 9 m.



(JICA Consultant Team)

Figure 5.1.9 Cross section of the Landslide Block

b. Groundwater Level

The groundwater level was found at approximately 2m below the ground surface at the time of drilling. It is very important to measure the groundwater level continuously when conducting the stability analysis. Monitoring of changes in groundwater levels can provide information for identifying the types of groundwater such as deep or shallow groundwater. Unfortunately, in this investigation, the groundwater level was monitored only sporadically. According to the result, double layers of unconfined and confined groundwater are discovered. (Figure 5.1.10). From July to August in 2012 the result shows that the declining curves are different by locations (GW-01/02), which means that the steep declining was caused by the unconfined groundwater layer for its rapid run-off in the upper layer, and the gradual declining curve was caused by the influence from the confined groundwater layer for its constant water head. The depth of each bore hole is consistent with the facts above mentioned. The depth of GW-01 is approximately 20 m and GW-02 is approximately 40m.

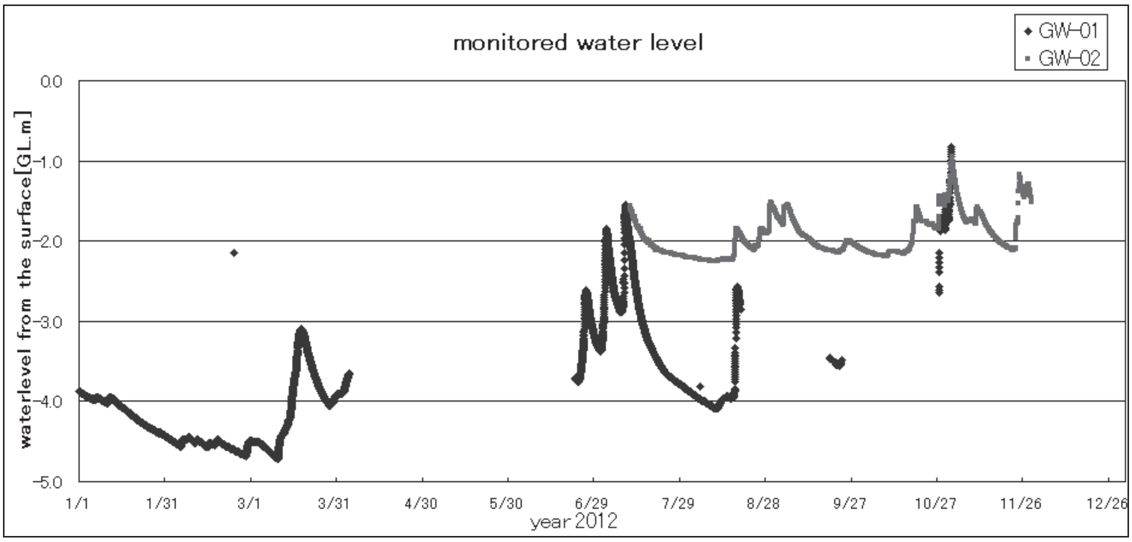
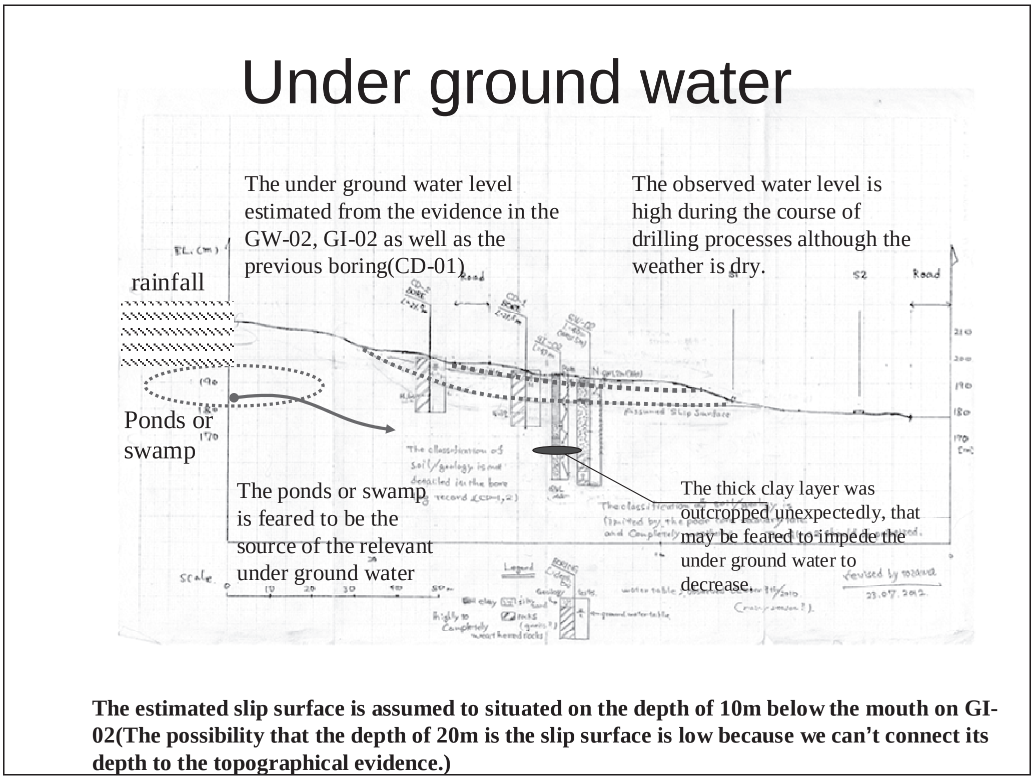


Figure 5.1.10 Trends of Groundwater Level



(JICA Consultant Team)

Figure 5.1.11 Hydrogeology Profile

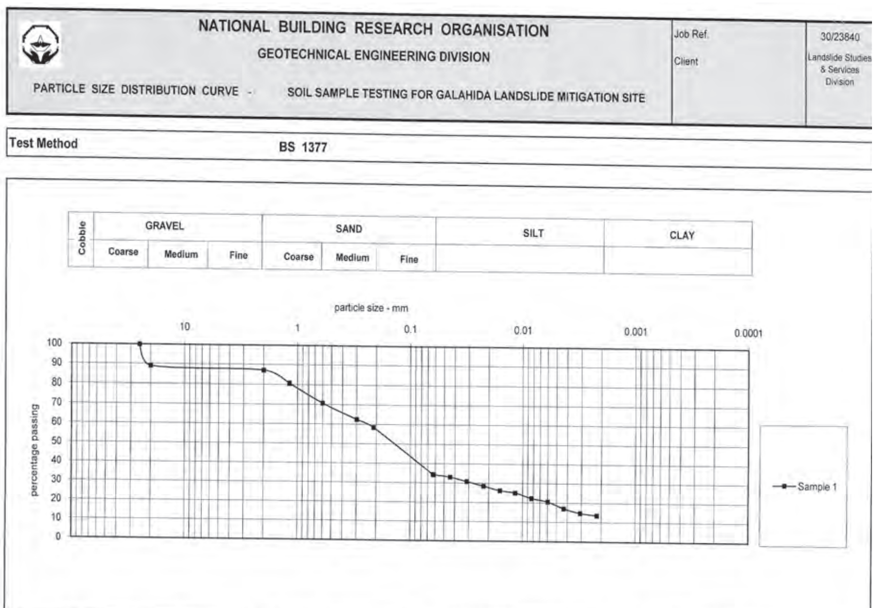
c. **Soil Properties**

According to the field survey including the core sampling, and evaluation of the soil properties at the Galaboda landslide areas, soils are found to be uniformly distributed. And the soil property of Galaboda is characterized as a mixture of fine grained soil (cohesive soil) and coarse grained soil (sandy soil). A piping phenomenon, where groundwater flows out of a hollow waterway, was identified on a nearby cut slope, where the typical properties of the landslide blocks are identified (Figure 5.1.12).

(JICA Consultant Team)

Figure 5.1.12 Surface Outflow near the Landslide Area

To evaluate the soil property, the grain distribution was obtained by the in-house test (Figure 5.1.13)



Location	Sample No	Classification	Liquid Limits	Plastic Limits	Plasticity Index	Cobble (%)	Gravel (%)	Sand (%)	Silt & Clay (%)	Clay (%)	Cu	Cc	Remarks
Galaboda landslide mitigation site	Sample 01		28	20	8		13	53	34	14			

DATE : 04/08/2012 TESTED BY : WKS CHECKED BY : KSH CERTIFIED BY: JU

(Implemented by NBRO)

Figure 5.1.13 Grain Size distribution

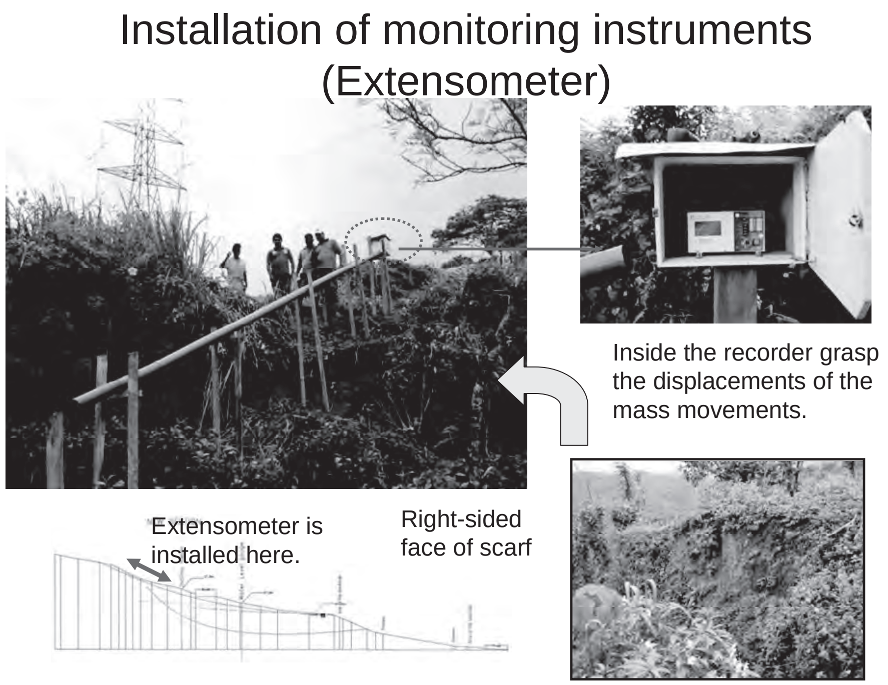
5.1.4 Monitoring using Instruments

Following table lists the types of instruments used to monitor and provide information regarding the landslide behaviors. Figure 5.1.14 and Figure 5.1.15 provide directions where to install the instruments.

Table 5.1.2 Types of Monitoring Instruments

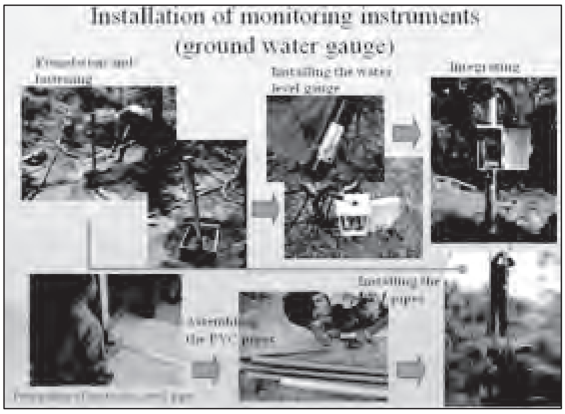
Name	Type	Purpose	Data to be Obtained
GR	Rainfall gauge	Hourly rainfall	Short-term rainfall/time series
GE-01	Extensometer	Crack of soil surface/behavior of open crack	Displacement information at initiation of landslide
GE-02	Extensometer	Same as above	Same as above
GI-02	Inclinometer	Inclination of each ambit of drill hole	The inclination at each ambit (depth interval) is measured during the action of inserting the meter. A landslide action (horizontal displacement) can be measured quantitatively, as the total of the inclination from the bottom to the top of the drill hole.
GI-02	Inclinometer	Same as above	Same as above
GW-01	Water level gauge	Water level of the drill hole	The groundwater level in a landslide block is measured, and the value is used in effective stress evaluation, which is an component of slope stability analysis.
GW-02	Water level gauge	Same as above	Same as above

(JICA Consultant Team)



(NBRO and JICA Consultant Team)

Figure 5.1.14 Extensometer in Galaboda



(JICA Consultant Team)

Figure 5.1.15　Installation of Groundwater Level Gauge（Left）and Inclinometer（Right）

Table 5.1.3　　Data Analysis and Interpretation

Observation type	Phenomenon	Understanding/interpretation	Remarks
Rainfall	Heavy rain from Apr. to May, and also in Nov.	Is heavy rain frequent at the change of season, from rainy to dry?　If yes, is this a seasonal factor causing landslide hazards?	
	The precipitation varies by year.		
Groundwater Level	Min. W.L　ＧＬ-4～5ｍ	This value is used for stability analysis	Some data missing
	Max. W.L　ＧＬ-1ｍ	This value becomes the standard for groundwater rise control when constructing groundwater drainage works as countermeasures.	
	After one or two weeks, rainfall becomes groundwater.	This is a time factor for landslide risk.	
	Correlation between groundwater and rainfall is not high.	There is a possibility that another supply of groundwater is coming in from the upper part of the landslide area.	
Inclination	A collapse near the road bank (GL-4m) is observed.	The stability of cuts and banks should be put to question.　This observation from instruments agree with field observations made during the site investigation.	Changing the location and positioning of instruments should be considered.
Expansion	Observed the size of expansion.	The instrument is usually set in the direction in which expansion can be recorded.	

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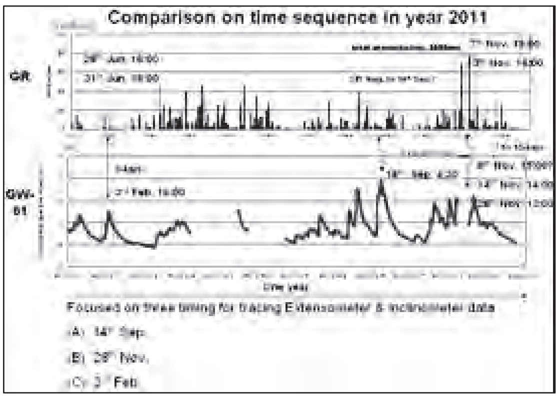
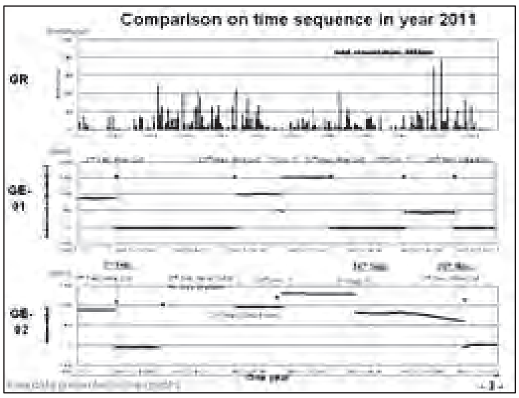
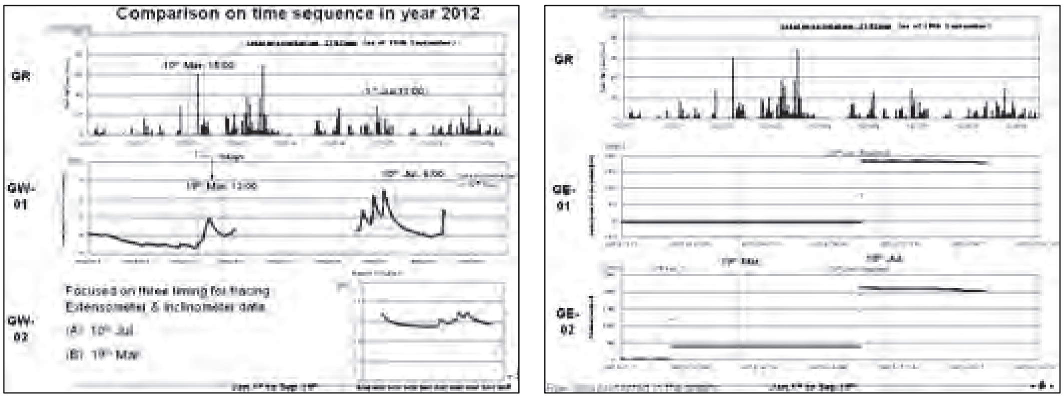




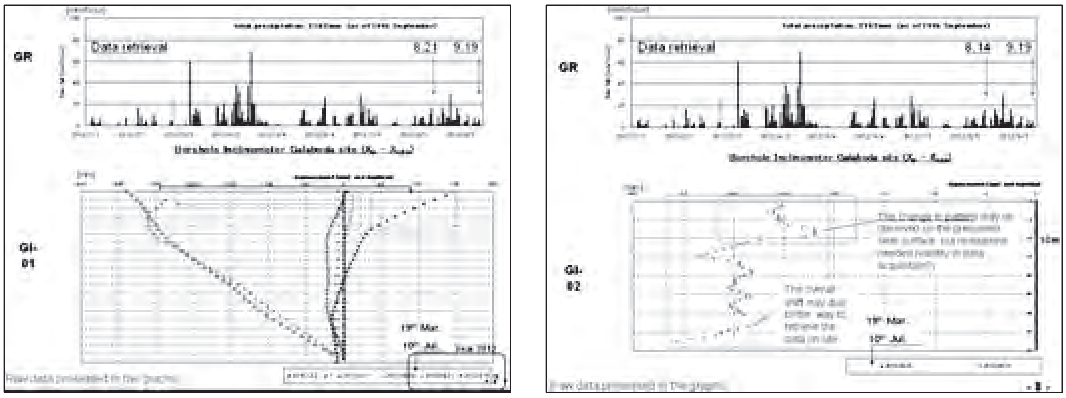
(NBRO and JICA Consultant Team)

Figure 5.1.16　Rainfall and Groundwater Level (Left), Rainfall and Extensometer (Right)



(NBRO and JICA Consultant Team)

Figure 5.1.17 Rainfall and Groundwater Level (Left), Rainfall and Extensometer (Right)



(NBRO and JICA Consultant Team)

Figure 5.1.18 Inclinometer GI-01 (Left), Inclinometer GI-02 (Right)）

a. Relationship between rainfall and groundwater

After heavy rainfalls, such as rainfall of over 60 mm/hour, the groundwater level rise for the maximum of GL-1.5 m. with a time lag of one or two weeks. However, according to the various data, the rise in groundwater level is caused not due to the rainfall. The groundwater level is raised due to the flow from the outside of the landslide areas, or possibly from the artesian groundwater, or deep groundwater.

b. Inclinometer Data

The inclinometer GI-01 shows that there is a horizontal displacement above the GL-04m level. This displacement was caused due to the road repair works conducted nearby the instrument. The inclinometer GI-02 shows the difference in the cross section between the upper and lower depth from the GL-10m in the borehole.

c. Extensometer Data

There are no clear tendencies in extension observed; however, there is a tendency of shrinkage (5 mm at GE-01 and 11 mm at GE-02). At the GE-01, it may be assumed that the upper landslide block influence the downward landslide block by pushing soil from the upper part; however, possible instrumental or positioning errors shall be carefully verified.

d. Interpretation

Even though there is no indication of land mass movement at this moment, some slides may be caused by the road construction nearby the areas. For a long-term solution, the effective countermeasures shall be implemented by lowering the groundwater level and improve the resistance of the land mass. The data obtained from the GI-02 indicates that the slope stability analysis shall be carried out with the safety factor of 1.0 when the groundwater level at the GW-01 reaches to GL-1.5m as a reference point. Some kind of countermeasures shall be necessary in order to increase the safety factor of 1.10 to 1.20, from the current safety factor of 1.0.

e. Soil Constants

The soil constants, such as the true cohesion (C) and the angle of internal friction (φ) can be determined by backward calculation, or core sampling and soil tests.

f. Reliability of Data

Quality of the data obtained from the instruments, especially the data from the rain gauge, are not enough to evaluate due to the lack of data points. Crucial water level gauge measurements during rainfall were discontinuous and thus the relationship between the osmosis of surface runoff and groundwater level rise could not be clearly understood. In the future, acquisition of continuous data without any missed data points is a priority

5.2 Plan and Design of Countermeasures

5.2.1 Facilities to be Protected

Followings shall be considered for evaluating the countermeasures;

a. Facilities to be protected

The facilities which may be affected by the landslide shall be identified, considering the magnitude of the potential landslides. In Galaboda, a tea plantation, six houses, and a road to a famous temple are identified as facilities to be protected.

b. Setting the Factor of Safety

There are several factors of safety considered during the analysis process. Firs, the safety factor was determined to be 1.00 when the groundwater level is at GL-1.5m, as a reference point. Using the safety factor of 1.0, the soil parameters such as c and φ are estimated by the stability analysis for the current condition. Then in accordance to the guidelines for the landslides, the safety factor was set in a range of 1.1 to 1.2, as a target safety factor. In Galaboda case, the planned safety factor was set to 1.1, and the countermeasures shall satisfy this value at the construction planning stage.

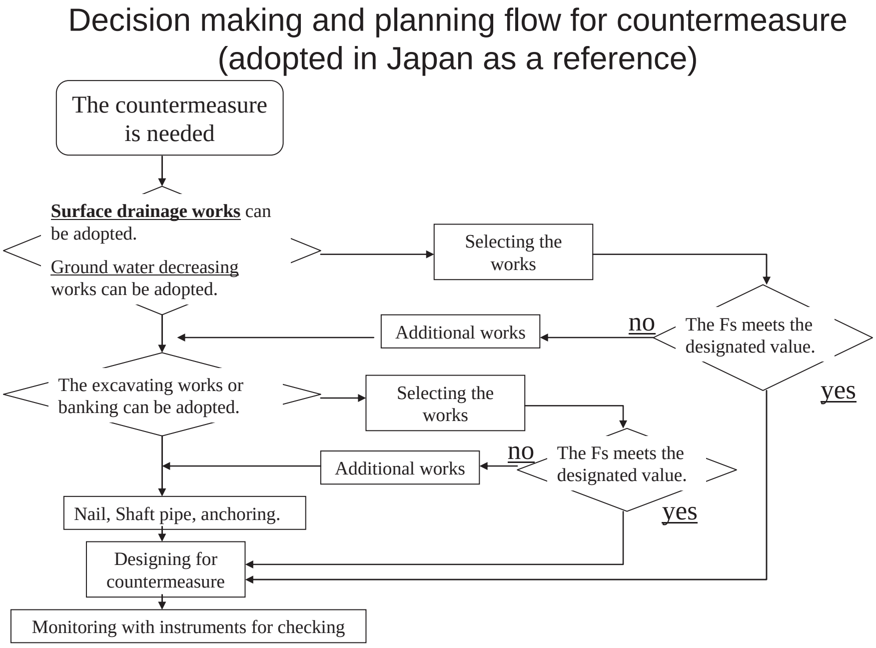
c. Considerations for the Environment

The countermeasures for the landslides shall be planned considering the environment, which includes the changes in water levels of the wells used by the residents, as well as protecting the scenic views. Therefore, the investigation shall include the verification of the existing conditions. In Galaboda, one well is used by one household, and downstream river water is used by another household, and both need to be verified for further project implementation.

5.2.2 Safety Factors

a. Stability Analysis for Existing Slope

The workflow for planning of countermeasures is shown in Figure 5.2.1. When planning the countermeasures, the soil constants (unit volume weight: γ, true cohesion: C, angle of internal friction: φ) shall be identified. Generally, there are two methods for finding the soil constants; soil tests of the samples obtained from the drilling survey, and inverse calculation to estimate the hypothetical safety factor. In Galaboda, the inverse calculation method was used for identifying the soil constants, and the factor of safety was calculated as 1.0. See "Section 3.2.6 Choosing Soil Strength Parameters" for detailed procedures and "Figure 5.2.1" for illustrating the stability analysis at Galaboda.



(The Guideline for Stability of Earth Cut Slope along the Road, p405)

Figure 5.2.1 Workflow for the Countermeasures Planning

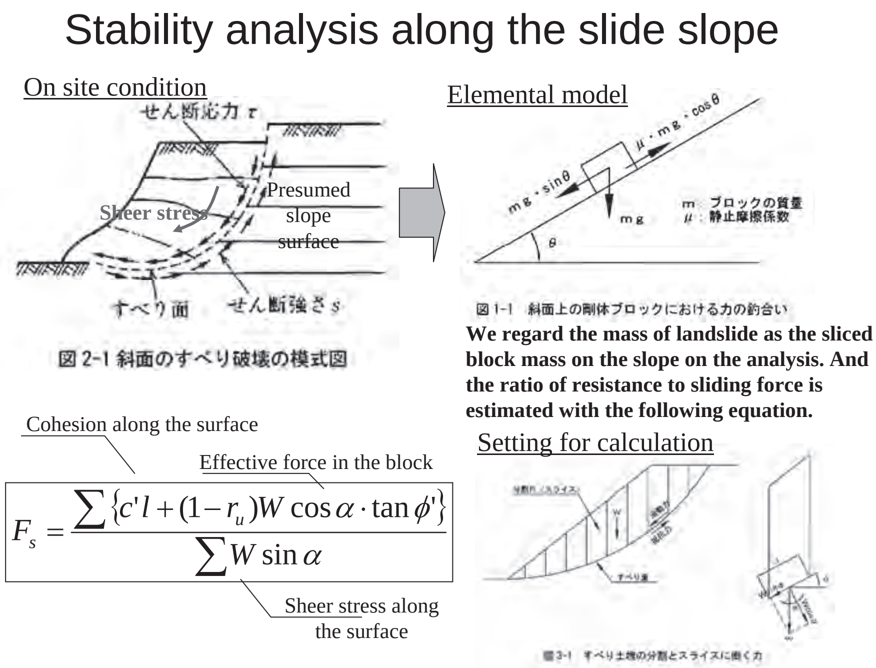


Figure 5.2.2 Slope Stability Analysis

b. Soil Constants

Soil Constants for Galaboda are shown as follows.

Bulk Density γ=18kN/m^3

True Cohesion C=11kN/m^2

Angle of Internal Friction φ=10°

c. Pore Water Pressure

The pore water pressure at the slip surface can be measured by the groundwater level gauge; however, measurement using the pore pressure meter is more desirable. l. The groundwater level gauge can measure the groundwater level, which can be used for the stability analysis. In Galaboda, GL-1 m was identified as the maximum groundwater level at GI-02.

5.3 Considerations for the Countermeasures

5.3.1 Surface Drainage Works

Purpose of the surface drainage works is to prevent infiltration of flows from rainfalls, springs ponds, channels, etc. In Galaboda, there is an infiltration of surface water from rainfall, affecting the land mass stability. Therefore in the landslide area, the priority is given to the construction of channel works along the roads (mountain side), preventing the surface water from infiltrating into the ground.

a. Runoff Calculation

The parameters which are required for the channel design can be calculated by estimating the rainfall discharge through channel. The catchment area (Figure 5.3.1) was estimated by field surveys (Figure 5.3.2). The design rainfall amount was estimated using the past rainfall data. The formula for the rational runoff and the parameters for Galaboda are shown below;

Rational formula $Qp=f=f\times(1/3.6)\times r\times A$

Qp: Peak Discharge (m^3/s)

f: Coefficient of Runoff (0.7)

r: Average Rainfall Rate (mm/hr) (Estimate 150 mm/hr)

A: Discharge Area (km^2) (Total Area 8300m2≒$0.0083km^2$)

$Qp=0.7\times(1/3.6)\times150\times0.0083\fallingdotseq0.25\ m^3/s$

The Manning formula shall be used to estimate the discharge for the design drainage canal.

The drainage canal was calculated using a half-circle shaped, 30cm diameter, concrete canal.

Because the calculation of the hydraulic depth based on the condition where the surface water flows in the half-circled shape is complex, some analogy was employed to calculate the hydraulic depth on the supposition where the surface water flows in the rectangular water way with its width 30cm and its height H [m].

Manning Formula $Q=Vul1=(1/n)\ R\ (2/3)\times I(1/2)\times A1$

Q: Capacity of Flow (m3/s)

V: Velocity (m2/s)

n: Coefficient of Roughness (0.017)

R: Hydraulic Mean Depth (m) (0.015)

I: Gradient (1/20)

H: Hydraulic depth in the water way (m)

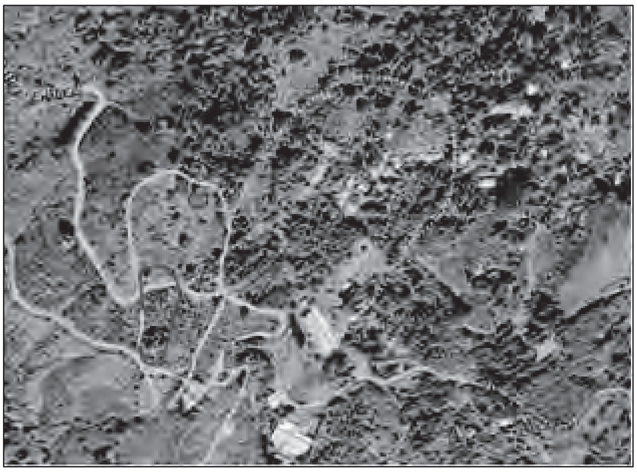
A: Flow Section (m2) depends on the H

$$V=(1/n)\ \times R(2/3)\ \times I(1/2)=(1/0.017)\ \times H(2/3)\times(1/20)(1/2)$$

$$Q=A\times V=\{H\times(2H+0.3)\}\ \times V=0.25m3/s$$

H is roughly equal to 0.05m, so it is estimated that the planned concrete shall contain the 150mm/h rainfall flow in the Galaboda.

The estimated discharge area is shown in the Figure 5.3.1.



(JICA Consultant Team)

Figure 5.3.1 Discharge Areas

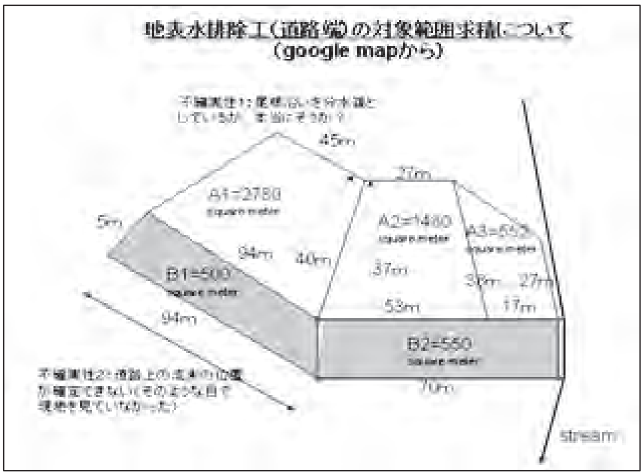


Figure 5.3.2 Calculation of Catchment Area

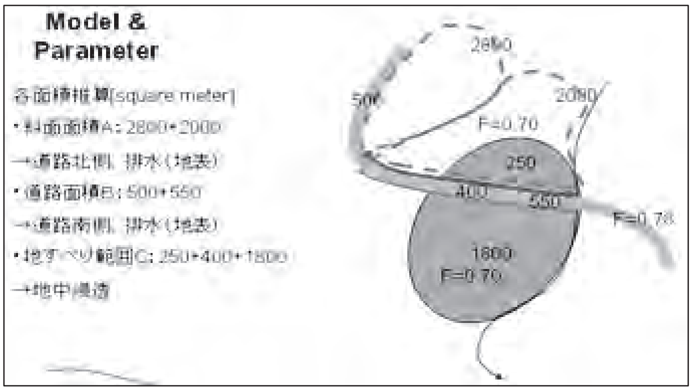
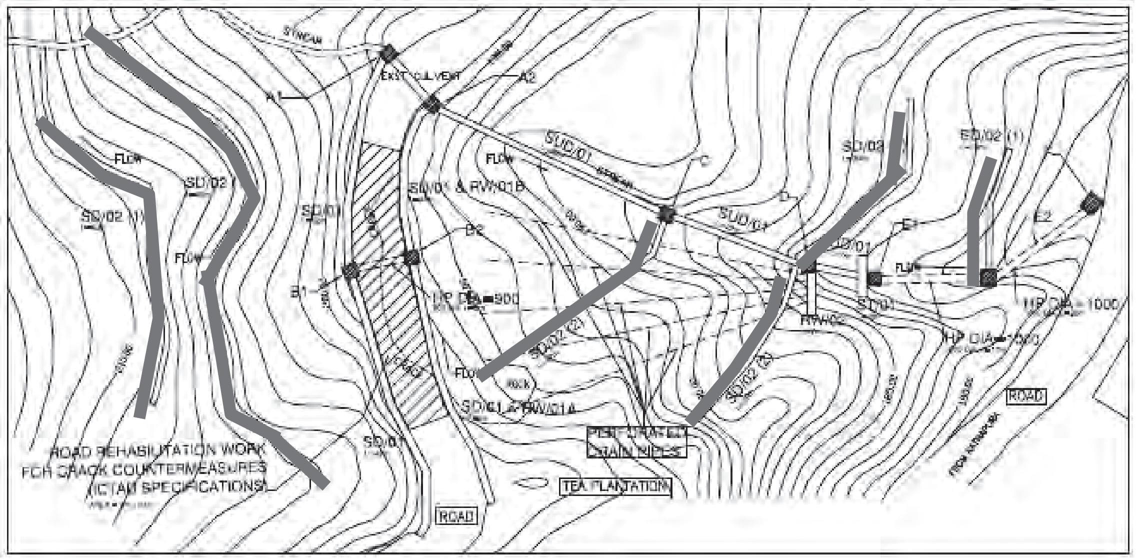


Figure 5.3.3 Discharge Model

b. Layout Plan for the Surface Drainage

The layout plan for the surface drainage is shown in the following plan.



(NBRO and JICA Consultant Team)

Figure 5.3.4 Layout Plan for the Surface Drainage

5.3.2 Groundwater Drainage Works

a. Outline of Horizontal Drilling Works

The horizontal drilling works shall be implemented at the shallow groundwater areas. The drillings shall be conducted in a fan shape opening towards the inside of the land mass, with the end spacing between the drilled holes be 5 to 10 m. The water collected through the horizontally installed pipes shall be drained out from the landslide areas to the catch pits or drainage channels. The drillings shall be implemented at the stable soil layer in order to prevent collapsing. Slope of the drilling, or angle of elevation, shall be from 5 to 10 degrees, which enables the gravitational flow of water. And the diameter of the drilling hole shall be 66 mm or larger, which enable the water drain. The drilling length shall reach to the aquifer, or extends from 5 to 10 m over the slip surface. After drilling, perforated pipes, such as hard vinyl chloride pipes or steel pipes with strainers or slits, shall be inserted into the drilling holes.

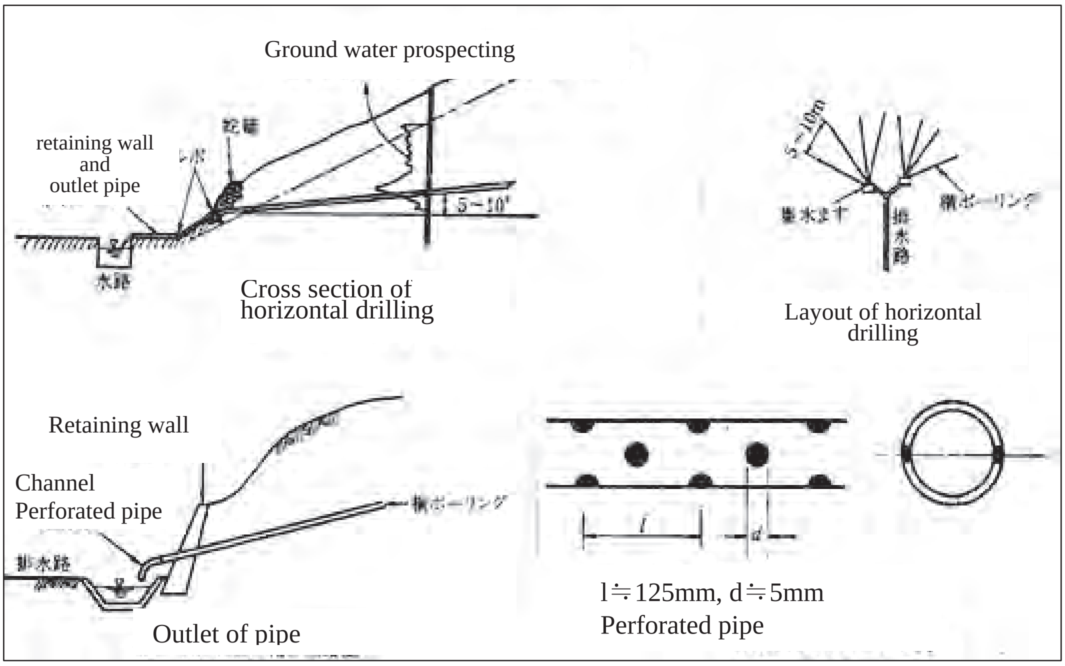


Figure 5.3.5 Diagram of Horizontal Drilling

Figure 5.3.6 Outlet of Horizontal Drilling

b. Installation of Horizontal Drilling

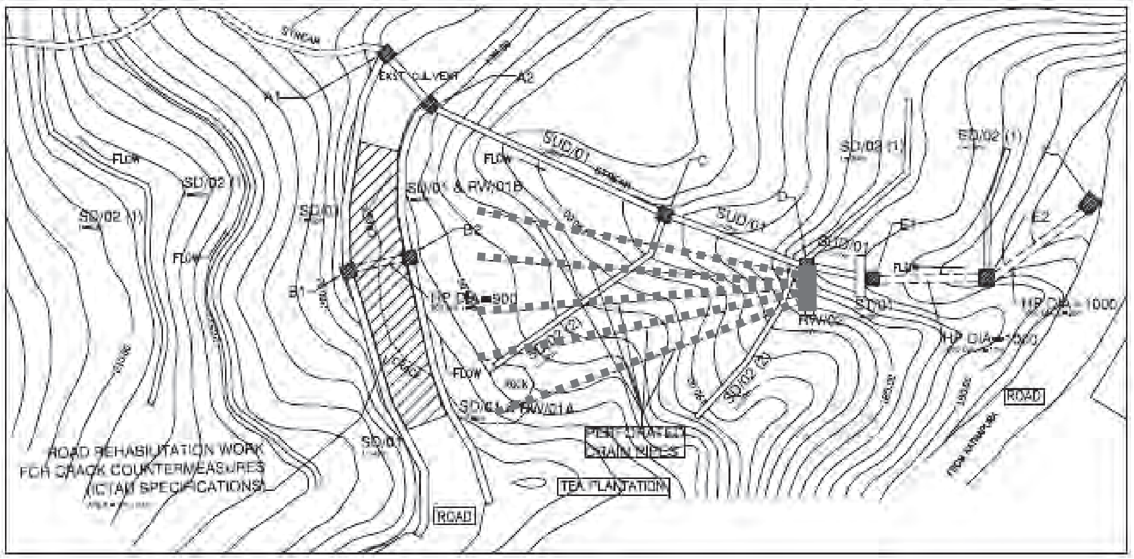


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Figure 5.3.7 Installation of Horizontal Drilling

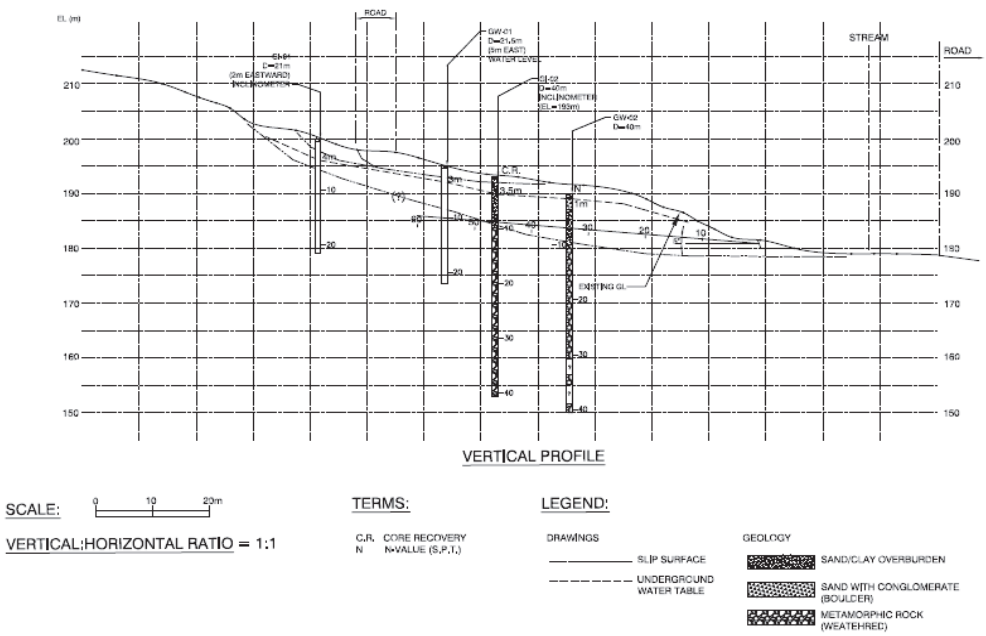

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Figure 5.3.8 Horizontal Drilling Profile

5.3.3 Open and Closed Channel Works

The water collected from the slope is drained as surface water to a mountain stream. The closed drainage, or culvert, shall be constructed for the groundwater drainage on the slope of mountains. Following shows the closed drainage plan.

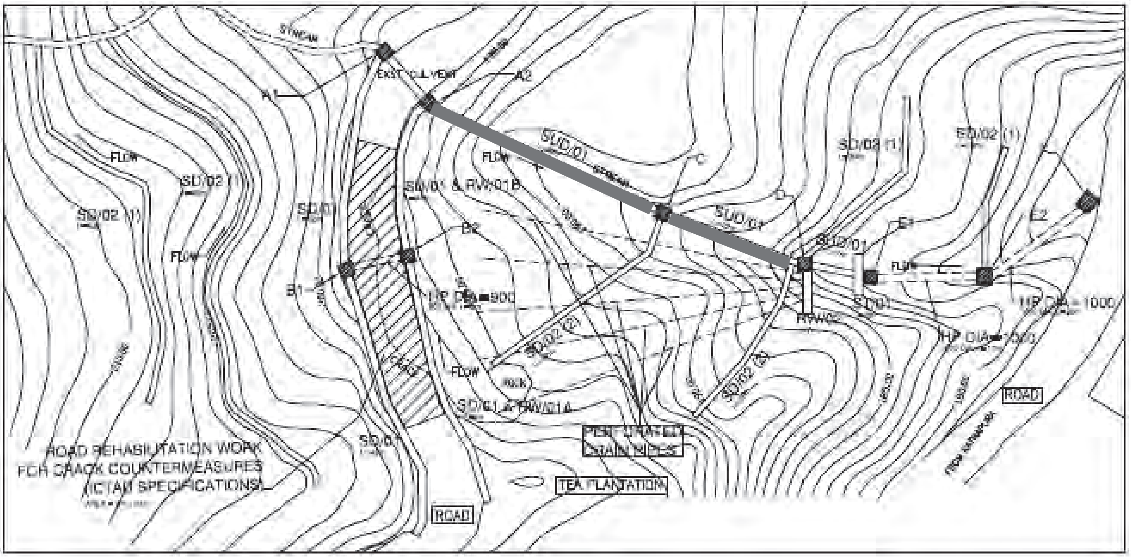

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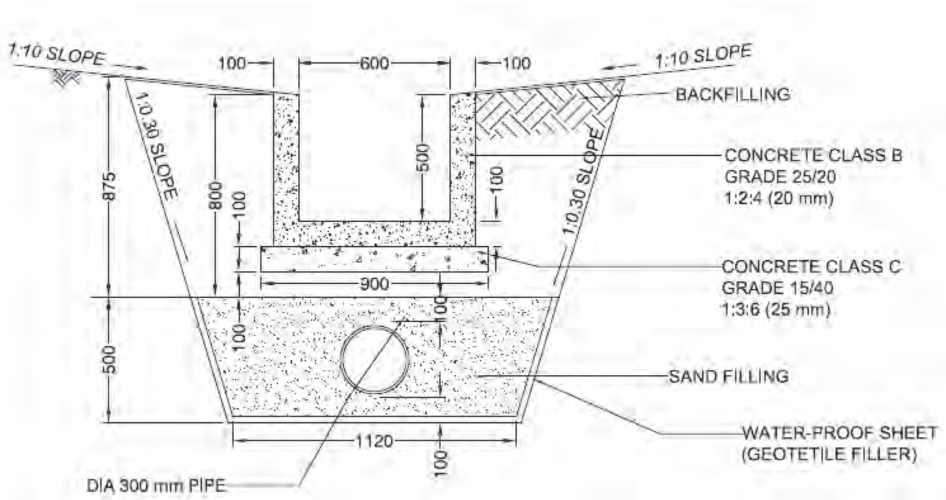
Figure 5.3.9 Plan of Open and Closed Drainage



(NBRO and JICA Consultant Team)

Figure 5.3.10 Open and Closed Drainage Works

5.4 Schedule of Implementation

The construction schedule is shown below. Constructions for the surface and groundwater drainage works can be implemented at the same time.

Table 5.4.1　　Construction Schedule

Item	1st Month	2nd Month	3rd Month	4th Month
Preparation	15days			
Temporary Road Work	15days			
Horizontal Boring		60 ～ 75days		
Drainage Work	70 ～85 days			
Crearance Work				15days

(NBRO and JICA Consultant Team)

A horizontal drilling machine is used for the groundwater drainage works. Generally, there are two types of drilling machines used in groundwater drainage works, the "Horizontal Drilling Machine" and "Rotary Percussion Drilling Machine." Following Table 5.4.2 lists the characteristics of two drilling machines.

Table 5.4.2　　Drilling Machines

Item	Horizontal Drilling Machine	Rotary Percussion Drilling Machine
Weight	2.5 tons	2.0 tons
Drilling Diameter	φ 66～300mm	φ 96～170mm
Power	30 kW	60 kW
Drilling Method	Rotary	Rotary and percussion
Concept	Standard use	Special use
Advantages	Coring function, Large diameter	High Speed of　Drilling
Disadvantages	Slow drilling speed	No coring function, noise
Drilling Length (Example)	≒40ｍ（Constant Soil Property）	≒50ｍ（Constant Soil Property）

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Horizontal drilling Machine

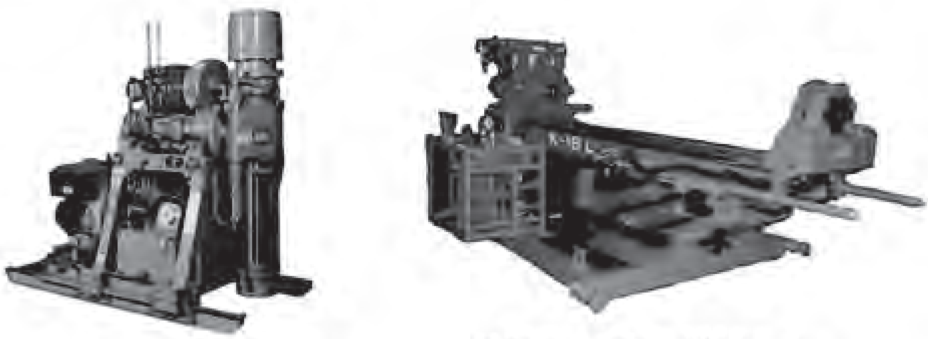

Figure 5.4.1　 Horizontal Drilling Machine

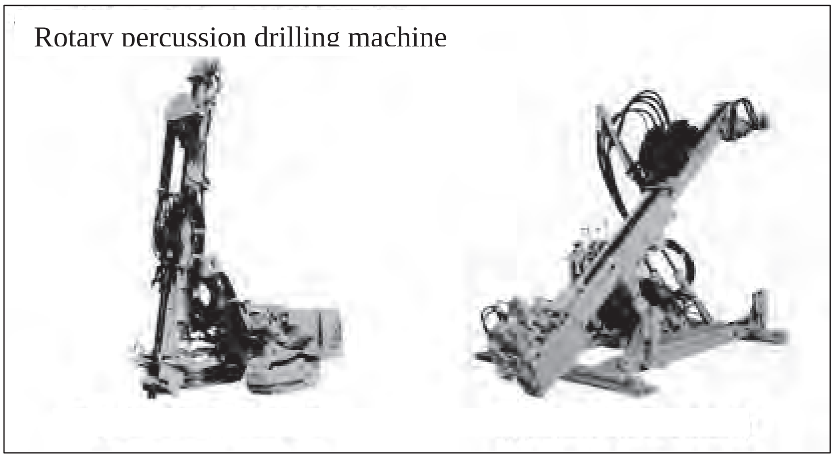

Figure 5.4.2 Rotary Percussion Drilling Machine

The types of drilling machine shall be chosen in accordance with the type of stratum. In Galaboda, use of the "rotary percussion system" is more suitable because it can correspond with various strata types, from clay, silt, and sand, including soft rock, hard rock, and cobbled stone.

Perforated pipes shall be inserted in the drilling hole to collect the groundwater from the aquifer. Hard vinyl chloride pipe is generally used for the material of the perforated pipe. Steel pipes shall be selected based on the site conditions, for example, the walls of the drilling holes are easy to collapse. The types of perforation include the circular holes (strainer) and the rectangle holes (slit), which shall be selected based on the site requirements. The diameter of the circular hole is about 5mm. Width of the slit is about 2 mm, and the length is about 10 cm.

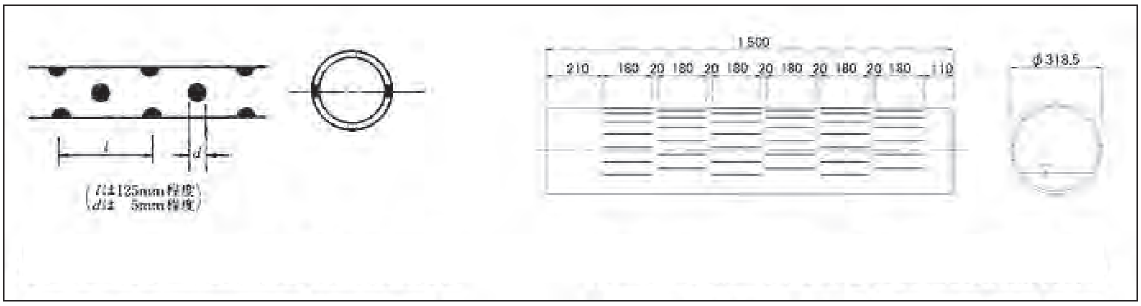

Figure 5.4.3 Types of perforated pipes

Followings shall be considered for establishing the construction schedules.

- The stakeholders or any concerned persons shall be involved in the meetings prior to the construction. For Galaboda, the stakeholders such as owners of tea factories, representatives from road constructions and telephone poles shall be participated.

- The areas below the landslide shall be secured for storing of the construction materials and equipment and treatment of turbid water. The road B391 located at the lower part of the landslide areas was selected for the laydown areas. The stream water shall be temporarily diverted during the construction. The turbid water due to the construction works shall be treated when discharge.

- Other considerations

The construction works may affect the groundwater levels of the local wells. Pay special attention to the groundwater conditions especially if the wells are used by the locals.

5.5 Evaluation of the Effectiveness

After the implementation, the effectiveness of the countermeasures shall be evaluated, verifying if the slope stability is improved. The groundwater drainage works shall be evaluated. The data required for the evaluation are; daily rainfall, daily water level, daily extensometer readings. Each data shall be compared year by year from one year before the construction starts until one year after the construction.

This manual does not include the actual post-construction analysis; however, the data shall be taken before and after the construction work for monitoring and evaluation.

5.6 Operation and Maintenance

Maintenance of the physical works means the maintenance of the effective countermeasures, and thus it is an extremely important process.

5.6.1 Drainage Works (Surface water and Groundwater)

The open channel works can be easily damaged, such as cracks, sediment blockages, and joint damages. The closed drainages also have problems with water clogging by slime built-up, sediment accumulation, and plants overgrowth.

At Galaboda, the main concern is that the drainage pipe can be easily blocked up by slime.

The slime is generated by oxidation-reduction reaction. The iron bacteria and microbes form the slime in an oxidized environment. At Galaboda, the soil contains laterite with rich iron. The slime starts accumulating in two to three years after construction and it builds up in three to four years, and after all, it blocks the drainage pipe (see figure below). As a countermeasure, the pipes must be flushed and dredged periodically using the correct equipment (Figure 5.6.2).

Figure 5.6.1 Clogged Drainage Pipes

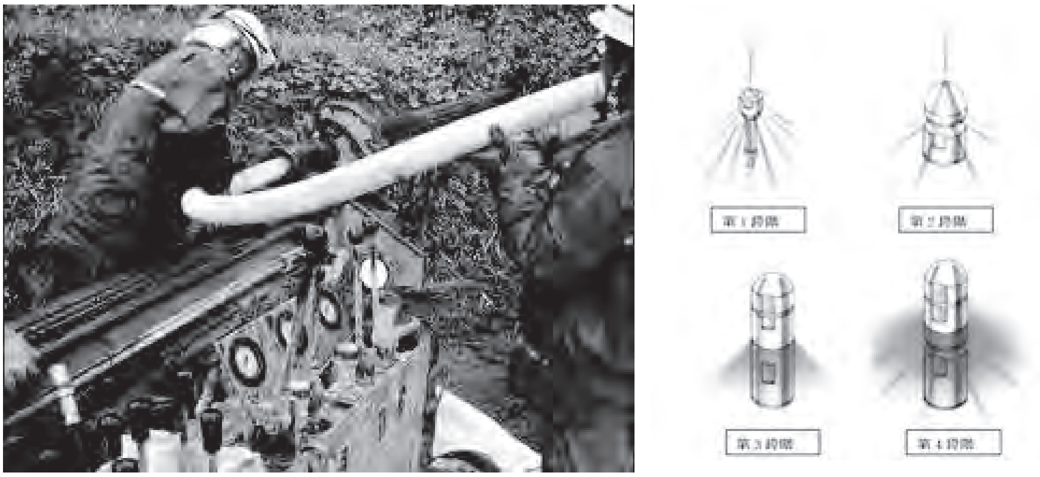

Figure 5.6.2 Flushing of Drainage Pipe

Another method to prevent the blockage is shown in Figure 5.6.3. This method extends the pipe outlets, which limits the contact of groundwater with air, and it eventually prevents the water oxidation and growth of iron bacteria and microbes.

Figure 5.6.3 Pipe Outlets which prevent Water Clogging

5.6.2 Maintenance of Sensors

At Galaboda, algae accretion was observed at the areas where the water level gauges are installed. The algae have negative impacts on observations data with the gauge. The algae control agents can be used for control of algae growth; however, it requires careful considerations since the algae control agents may affect the groundwater quality in the areas. The better solution is to increase the frequency of the maintenance, which take out the gauge for readings, and the algae attached can be removed.

5.7 Emergency Measures (Early Warning Systems)

a. Effective Warning and Evacuation System

The roles of each organization, including local community people, for implementing the effective early warning system are proposed as follows.

Table 5.7.1 Roles of Relevant Organizations

Organization	Actions to be Taken
Community People	- Monitor daily rainfall amount, and inform NBRO if it exceeds the criteria - Inform NBRO for necessary actions, if precursory phenomenon or damage is found - Inform GN, DS or GA/DDMCU for necessary actions, if precursory phenomenon or damage is found - Receive warning message, evacuation instruction / order, or advise from GN, DS, GA/DDMCU, or NBRO - Take necessary actions
Tea Factory (Galaboda) / School (Mahawewa)	- Monitor daily rainfall amount, and inform NBRO if it exceeds the criteria - Inform NBRO for necessary actions, if precursory phenomenon or damage is found - Inform GN, DS or GA/DDMCU for necessary actions, if precursory phenomenon or damage is found - Receive warning message, evacuation instruction / order, or advise from GN, DS, GA/DDMCU, or NBRO - Take necessary actions
NBRO (Ratnapura / Nuwara Eliya Office)	- Receive information from Community People, Tea Factory or School - Receive information from GN, DS or DDMCU - Inform NBRO Head Office - Conduct field survey - Download data from monitoring equipments and analyze data - Discuss with NBRO Head Office and advise necessary action to Community people, Tea Factory, School, GN, DS or DDMCU
NBRO Head Office	- Receive information form NBRO Ratnapura / Nuwara Eliya Office. - Discuss with NBRO Ratnapura / Nuwara Eliya Office, issue warning if necessary, and disseminate it to DMC
GN	- Receive information from Community People, Tea Factory or School, and inform it to DS and NBRO Ratnpaura / Nuwara Eliya Office - Receive advise from NBRO Ratnapura / Nuwara Eliya Office - Receive warning message from DS, and disseminate it to Community People - Issue evacuation instruction / order if necessary or advise necessary action to Community People
DS	- Receive information from GN, Community People, Tea Factory or School, and inform it to GA / DDMCU and NBRO Ratnpaura / Nuwara Eliya Office - Receive advise from NBRO Ratnapura / Nuwara Eliya Office - Receive warning message from GA / DDMCU, and disseminate it to GN - Issue evacuation instruction / order if necessary or advise necessary action to GN
GA/DDMCU	- Receive information from DS, Community People, Tea Factory or School, and inform it to DMC and NBRO Ratnpaura / Nuwara Eliya Office - Receive advise from NBRO Ratnapura / Nuwara Eliya Office - Receive warning message from DMC, and disseminate it to DS - Issue evacuation instruction / order if necessary or advise necessary action to DS

(NBRO and JICA Consultant Team)

When the NBRO receives information from local level organizations or local community people, the NBRO investigates the anomalies and deformation as described in the previous section. Based on the investigation, the NBRO forecasts the landslide movement and determine if the early warning shall be issued. The NBRO also provides the advice to the local level organizations regarding the evacuation instruction and order.

For the Mahawewa landslide, the local community people living on the upper part of the landslide shall receive the warning for the collapse of the houses and slope failures prior to the occurrences. The community people in the middle part and lower part of the landslide shall receive the warning of hazards by the landslide mass and liquidation. For the schools located on the lower slope, if some anomalies are observed on the slope behind the school, the school shall receive the warnings in order to prevent the tragedy.

b. Warning Criteria

At present, it is difficult to determine the specific warning criteria due to the lack of information. Therefore, this section provides the Here, two examples to show how to analyze the data for deciding the warning criteria are shown. Monitoring activities have to be continued to accumulate the data for deciding accurate warning criteria.

1) Trial analysis of warning standard on Mahawewa site

On Mahaweha site, the landside occurred on the 8th December and continued up to January next year (Figure 5.7.1). The land mass movement was recorded by the extensometer on 8th December. The daily rainfall and accumulative rainfall were 60 mm and 400 mm during the time respectively (Figure 5.7.2). These monitoring data can provide information for evaluating the warning standard at Mahaweha site.

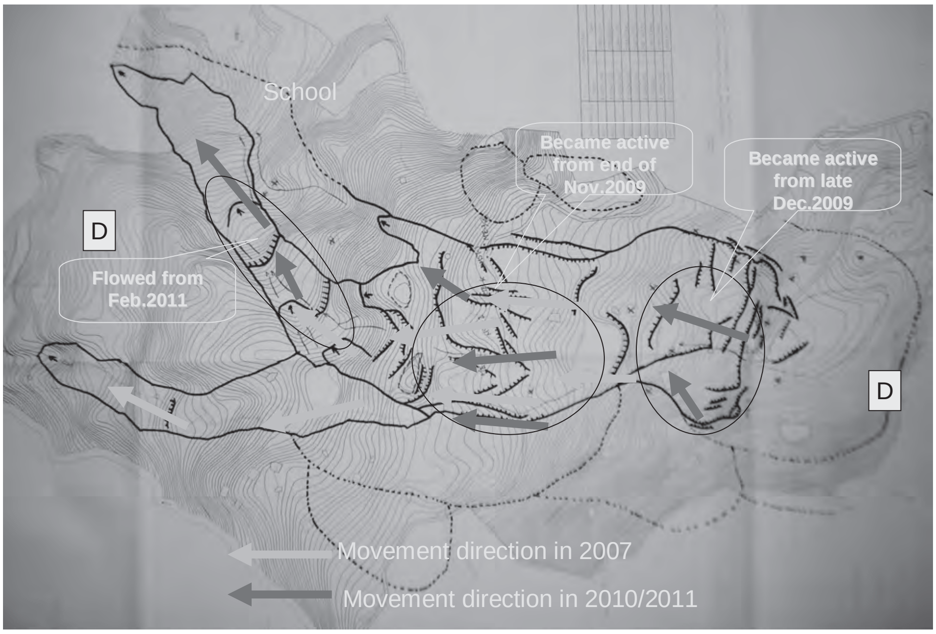

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Figure 5.7.1 Movement of Mahawawa Landslide,

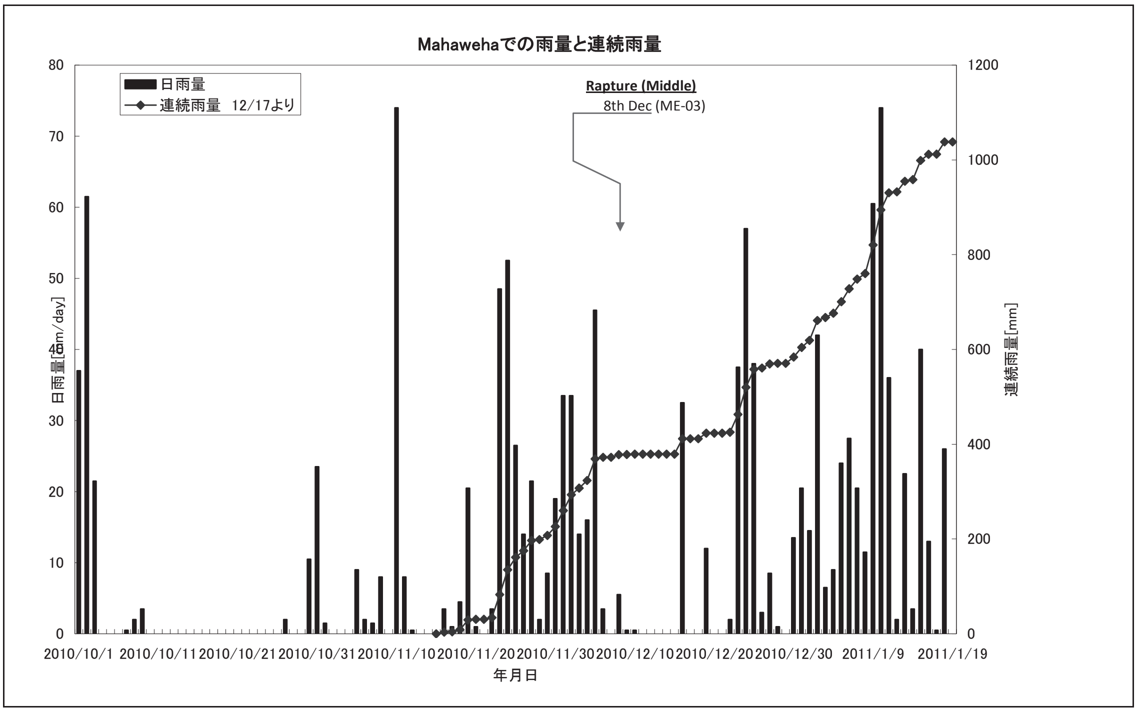

Figure 5.7.2 Trends of the Rupture (red allow), Daily Rainfall (black bar) and Accumulative Rainfall (blue curve)

2) Trial Analysis of Warning Standards at Galaboda Site

The depth where the Factor of safety becomes 1.00 can be estimated from the monitoring results of the groundwater gauges and the extensometers.

The correlation between the actual groundwater levels and the calculated effective rainfalls amount is shown below. According to the graph below, the effective rainfall is approximately 150mm on the regression curve when the Factor of safety becomes 1.00 at the depth of -1.5m [GLm].

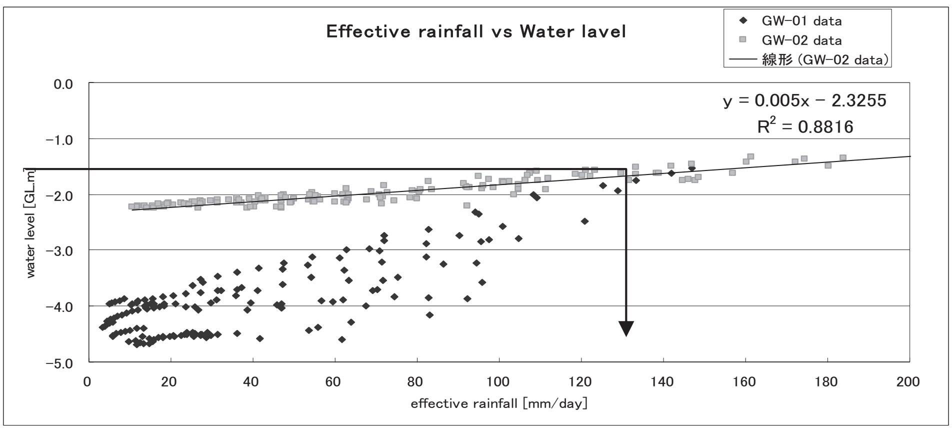

Figure 5.7.3 The Location of the Monitoring Sensors on Galaboda Site

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