CHAPTER 6 DETAILED STUDY

6.1 Brief Review of Investigation

This chapter introduces the following survey methods as standard approaches in Detailed Study. Specific principle and procedure of each method are described in BS and technical documents, so that this chapter deals with considerations mainly for implementation.

- 6.1.1 Boring investigation
- 6.1.2 Geophysical survey
  - Seismic refraction survey
  - Resistivity image profiling
- 6.1.3 Others
  - Sounding
  - Sampling
  - Laboratory test
  - In-situ test and borehole logging

Details of instrumentations are shown in III-1 EARLY WARNING SYSTEM.

6.1.1 Boring Investigation

Rotary core drilling is a basic boring method and implemented with reference made to JKR GEOGUIDE, BS-5930:1999 (20.7, 45 to 47), etc. In all stages of planning, implementation of survey, and analysis, attention should be given to the following points.

Engineers responsible for the implementation plan are required to clarify geological information used for Detailed Study. They are also required to provide the boring contractor with correct information on the hardness of rocks and the geology and geological structure of fracture-crushed zone, that are expected in Preliminary Study. In this way, engineers must develop a feasible plan and make clear description in the specification to prepare materials and equipment necessary for boring operation. It is also important for engineers to provide guidance and supervisory services appropriately concerning preparation of materials and equipment, their carry-in to the site, and the use of proper tools. The quality, quantity, and operation safety of surveys, process, and costs are to be supervised, under appropriate guidance and supervision of the consultant engineer, so that they do not deviate from objectives of the project. This is the joint responsibility of the consultant and contractor.

JKR GEOGUIDE-2 (6. Subsurface data collection, Table6.2), BS 5930-1999(22 Sampling the ground), etc. describe the selection of samplers appropriate to the geology concerned. Increase in the boring core recovery requires improvement of the boring technology of driller and supervisor. It is essential that their training and guidance will improve the sense and adaptability to select the sampler, bit, and slurry appropriate to the geology and to cope properly with any observed change in the machine fixing condition and borehole condition.

Necessary geological information is collected at the site. Engineers are required to stay at site as much as possible to check the boring core and to give instruction on the survey details based on appropriate judgment of the geological condition. Staying resident of the engineer at site is not a negligible element for which there is no alternative, ensuring adequate design and implementation of the countermeasure against the road slope. Engineering should be implemented with a stress on reduction of the total cost.

6.1.2 Geophysical Survey

When compared with boring investigation providing spot data, geophysical survey is more advantageous for investigation of slope failure requiring urgent countermeasure in its ability to obtain data on underground structures over a wide area within a relatively short period. However, data obtained from geophysical survey remain to be specific physical properties of the ground. Besides, the resolution of geophysical survey varies depending on geological conditions and operational restrictions. Therefore, interpretation of the geology and geological structure is essential by geophysical engineers. In order to implement geophysical survey, objectives should be clearly defined and the appropriate method should be selected according to the applicability of each physical quantity and their limit for each objective. After implementation, data obtained from site reconnaissance and boring investigation are combined for overall geological analysis.

There are various land physics as shown in BS-5930:1999 (35) and the appropriate method should be developed according to the necessity.

General practices applied to the site investigation of road slope are seismic prospecting (refraction method) and electric exploration (resistivity method). Their planning, implementation, and analysis that require attention are described below.

The new exploration method is introduced in Chapter 7.

6.1.2.1 Seismic Refraction Survey

Considerations for operation of seismic refraction survey on the road slope

i) Normally, dynamite is used to generate the elastic wave. The stacking method is less applicable in sites where the arrival distance of wave is short, the operation efficiency is deteriorated excessively, and there is much noise in the neighbourhood of the road. Because of considerable time required for the application procedure to obtain approval for the use of dynamite, it is essential to take the careful preparatory steps. The person in charge of handling of explosive must take the responsibility everyday for transport from the storage place to the site, storage, and consumption. Therefore, the operation schedule must be determined taking into account the process of this responsible person.

ii) Generally, site conditions of the slope cause the time for transfer of persons and material/equipment. To ensure the efficiency and safety, preparatory in-depth negotiation and mutual understanding of case-by-case actions are essential among operation team members.

iii) Depending on objectives (depth, etc.) of investigation, blasting should be made with the amount of charged explosive appropriate to the geological condition of the section covered by observation. It is essential that the blasting plan is developed by the well-experienced prospecting engineer. Since blasting in water is more effective than in soil, blast points should be provided in the valley as far as site situations allow. During blasting, utmost care must be taken to prevent scattering stones from damaging properties in the neighbourhood.

Cautions for application of seismic refraction survey on slope stability

i) In V-shaped valleys and steep slops, the depth of weathered layer and bed rock tends to be estimated shallower than practical.

ii) Any hard (rapid in propagation) rock body or boulders projecting from the slope or natural slope may readily cause misunderstanding of the structure of velocity layer.

iii) Any lower layers with low velocity cannot be detected.

iv) Intermediate layers may not be detected when thin.

v) It is essential that the line length is five- to six-fold of the prospecting depth.

vi) Low-velocity layers (fault, fracture crushed zone) are difficult to detect when their thickness is 3 m or less.

vii) Analysis is difficult in locations with complicated geological structure.

viii) The velocity varies greatly even when the degree of weathering or looseness is almost equal if the groundwater exists or the condition is dry.

ix) The rate of propagation is in almost the same order among soft rocks, fracture crushed zone, and weather rock, making their identification impossible if the line length is short.

x) In order to estimate the nature of crack in rock mass and that of fracture crushed zone from the elastic wave velocity, analysis considering geological observation results is necessary.

xi) Values obtained from seismic prospecting are obtained on the basis of assumption that the rock is an elastic body. Therefore, they do not necessarily indicate conditions contributory to stabilization of the slope.

6.1.2.2 Resistivity Image Profiling (computer controlled multiple electrode technique)

Conventional horizontal electrical profiling and vertical electric sounding are applicable to a location that is symmetrical in terms of topography and geology and as much flat as possible. In line with the progress of exploration and computer technologies, the two-dimensional exploration method has recently been applied in increasing numbers. This method proves more favourable and is expected to enable analysis with higher accuracy in investigation of structures more complicated in topography and geology.

Resistivity of the ground varies depending on the component rocks or grain composition of layer, void ratio, resistivity of pore water, porosity, and content of conductive materials (clay minerals, etc.). Accordingly, this method produces wide-varying resistivity values even when the layer is uniform geologically. The two-dimensional exploration method consists of determining the true resistivity distribution under the ground in the form of a two-dimensional sectional view through computer-aided inverse analysis of measurement data obtained with electrodes only arranged on the surface line. A method performing measurement enclosing the investigation area with boreholes or adits is also called a resistivity tomography, which is expected to produce results with much higher accuracy.

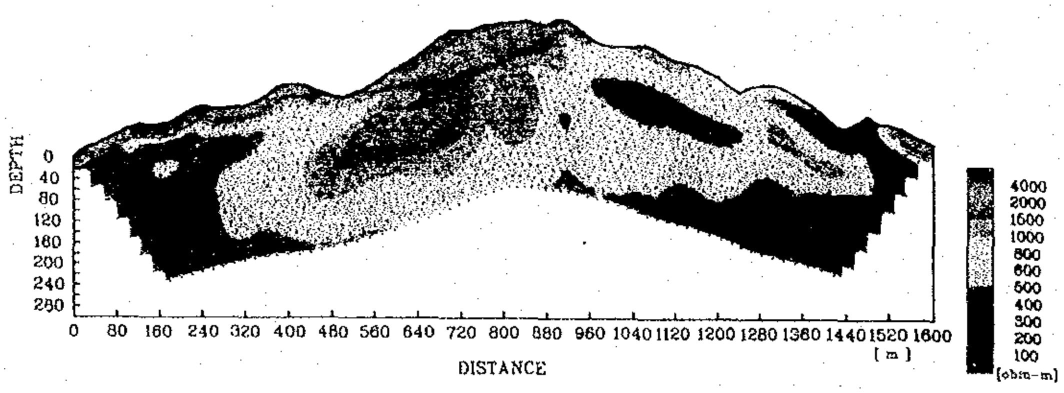


Figure 6.1.1 Example of analytical results of the resistivity imaging method
(Ref. *16) frontispiece 2.3.1)

Considerations for operation of the resistivity image profiling on the road slope

i) The electrode spacing (minimum electrode), exploration depth, and line length are to be planned with due consideration of objective of the investigation and site conditions. The electrode spacing is related to the resolution of exploration. Namely, smaller the spacing, the higher the resolution is. Normally, the spacing is set to about 1/10 to 1/15 of the exploration depth, and the arrangement of electrodes should be appropriate to the targeted exploration depth. Because of the principle of exploration and analysis, it is necessary to set lines on both sides of the section concerned in the length larger by 1/2 to 1-fold than the exploration depth.
ii) Analysis error can be decreased by providing lines normal to contour lines.
iii) When a remote electrode is provided in the pole-pole array method, it is recommended to distance such electrode from the line terminal by more than ten times the maximum electrode spacing. In the case of four-pole method, the remote electrode is not necessary. In any case, minimizing the earth

resistance of electrode will contribute to enhancement of the exploration accuracy.

iv) The resolution of a structure that can be analysed is approximately equivalent to the minimum electrode spacing around the ground surface and is deteriorated as the depth increases.

v) Because of noise contained in measurement data and deterioration of the analysis accuracy (reliability) around the section concerned, a ghost of underground structure that actually does not exist under lines may appear in the analysis section. This must be taken into account during interpretation of analysis section.

vi) The performance of instruments varies greatly, so that the appropriate one must be selected according to the target exploration depth.

vii) To insert electrodes into the ground, smooth insertion should be ensured without resistance through contact with the ground. When the ground surface is dry sand, water should be sprayed around electrodes.

Cautions for application of resistivity image profiling on slope stability

i) Investigation is made on the apparent resistivity distribution of the ground, determining the thickness of clayey soil and gravel layers and weathered zones as well as the shape of bedrock. Based on the result, judgment is made on the thickness and pattern of landslide layer. Besides, this method is often applied to detect high-velocity and low-velocity seams that are difficult to recognize by seismic prospecting.

ii) The accuracy of the method is deteriorated when there is a transmission line or railway near the lines. Any location with metallic buried structures or the underground cable causing the stray current should be avoided because they may cause decisive adverse effects on measurement.

iii) Electrical exploration should be combined with other approaches, such as the seismic prospecting or boring investigation, to ensure overall interpretation of the geology.

6.1.3 Other Site Investigations

In Malaysia, soil materials around the surface of road slope or road embankment consist generally of residual soil containing weather gravel. JKR GEOGUIDE calls it Tropical weathered in-situ materials (TWIMs), presenting the concept and procedure for site investigation and test methods appropriate to characteristics of these soils. This guideline specifies implementation of the soil survey basically in accordance with JKR GEOGUIDE, BS-1377:1990, BS-5930:1999 (5 to 23, 36 to 45).

The standard investigation conducted in Detailed Study is classified roughly into three types. They are 1) sounding, 2) laboratory test of samples, and 3) in-situ test/borehole logging.

Considerations for planning and implementation of sampling, soil test, and in-situ test are described below.

6.1.3.1 Sounding

i) Sounding is a simplified method to investigate the soil composition and characteristics. Except for the case of standard penetration test, direct observation of core cannot be made. This enables simple and inexpensive investigation and supplements the boring investigation.

ii) Standard Penetration Test (SPT) : When the core recovery of all-core boring to search the slide surface is extremely low during boring, the standard penetration test is made in a 50 cm pitch, taking samples from all of layers in the depth direction for confirmation.

iii) Dynamic probing (Macintosh test) : This test is extremely simple with a lightweight (total weight of 10 kg) instrument. Since penetration is manual, its application is limited because the N value of applicable soil is 5 or less. As rapid investigation of about 3 to 5 m is possible, the instrument should be carried around during survey.

iv) Swedish sounding (Weight sounding test) : This type of sounding is applicable to all soils not containing boulders and gravel. The limit depth is about 10 – 15 m. As the instrument is as heavy a 100 kg in total weight, this is not suitable for transport and test on the slope.

6.1.3.2 Sampling

i) The prerequisite for stable analysis of the slope is obtaining of the undisturbed sample.

ii) In the site where disaster occurs actually on the road slope, it is extremely difficult in many cases to take the sample in an undisturbed condition for the strength test from boreholes by using the sampler.

iii) For soft heavily-weathered rocks or loose rock mass or layers with many fractures where the core recovery with normal core barrel (Double core barrel or Triple core barrel) is extremely deteriorated, Mazier sampler is used. (See Geoguide-2, 6.2, Table6.3)

iv) Where the shear test for stable analysis is necessary on relatively soft soil that does not contain any large gravel, the thin-wall sampler or Denison type sampler is applicable.

v) When sampling using test pits, adits, and shafts is possible, undisturbed samples can be taken. If possible, in-situ tests and laboratory tests using samples thus taken should be made.

6.1.3.3 Laboratory test

i) It is relatively rare to use values determined from the soil test as they are in the design of countermeasure. Therefore, there is not much necessity to perform this test.

ii) In the Detailed Study on landslide to estimate the shear strength of slide surface, the triaxial compression or box shear test using undisturbed sample is made if necessary.

iii) The objective of the test is to determine the basic nature of soils that make up the slope. Using samples from boring and standard penetration test, tests for physical properties, such as natural water content and grain size analyses, are made for each layer.

6.1.3.4 In-situ test and borehole logging

Grounds developing landslide are mostly exposed to noticeable loosening and lateral pressure, which often causes jamming of core tube and instrument in boreholes. Safety measures such as protection of hole wall with a casing, etc. are necessary.

i) Pressuremeter test:
Depending on the type of countermeasure, the borehole horizontal loading test is made to determine the ground constant necessary for design of the bearing capacity and prevention piles. (See BS 5930-1999, 25.7.)

ii) Borehole television and televiewer:
Boring is generally sampled in the disturbed condition from the deteriorated rock mass portion. When a borehole camera is used, the condition before disturbance can be observed. The camera enables direct observation of the directionality and dirt nature of the weak layer and slide surface that exerts critical effects on the stability of slope. Therefore, this is an effective investigation method for clarification of the rock-mass fracture mechanism. However, this is expensive and not yet easily applicable in Malaysia though the price has lowered in these days. Besides, the site develops jamming in borehole readily as described above. Consequently, this method should be planned according to the importance and necessity of investigation.(refer BS 5930-1999/35.5.1.5 - 35.5.1.7.)

iii) Electrical methods:
Boring is basically all-core boring. Because of low core recovery, actually, geological information may remain insufficient in spite of boring investigation. In such a case, borehole logging (electric type, etc.) will prove effective in determining geological characteristics. Electric borehole logging can be made from the inside once the PVC pipe with slit is installed in boreholes. Besides, this method is free from jamming concerning collapse of hole wall as

described above and thus useful. Boring diameter should be determined after thorough review on the outside diameter and length of applicable logging probe, borehole diameter and PVC pipe inside/outside diameter allowing insertion after drilling, verticality of borehole, and whether or not the slide soil mass is in motion.

6.2 Study on Disaster Type

6.2.1 Investigation against Collapse (CL) / Rack Fall (RF) / Rock Mass Failure (RM)

The detailed study is intended to ensure implementation of appropriate countermeasure (design and implementation of countermeasure or monitoring through instrumentation).

Generally, CL / RF / RM have less precursory phenomena than landslide (LC) and the location and range of slope failure are actually extremely difficult to estimate appropriately through previous investigation. When designing the countermeasure on the basis of data collected in this investigation, selection should be made for the location where the possibility of slope failure is elicit and the countermeasure plan can be reasonably developed, that is to say, the slope indicating remarkable deformations allowing estimation of the collapse range to a certain degree, such as fracture, step, and overhang of the surface, distinct loosened zone, deflected configuration due to surface creep, etc.

In the study, boring investigation, geophysical survey, groundwater survey, measurement, soil investigation, etc. are applied individually or in combination according to site conditions and objectives.

(1) Development of the Detailed Study Plan

Main purpose of detailed study is;

For Collapse	-	to confirm the depth of weathered rock or soil which covers the slope
For Rock Fall	-	to confirm the size of unstable rocks on the slope and to expect the rack fall wake
For Rock Mass Failure	-	to confirm the size of loose rock mass and to expect the wake of rock mass

The items, methods and applicability of the detailed study are summarised in Table 6.2.1. Referring to the preliminary study, the necessary items should be selected for the detailed study. There are some items which are same as the preliminary study. They are for improving the precision of site investigation.

Table 6.2.1 Useful Survey for CL, RF, RM

Category		Aerial Photograph Interpretation	Topographic Survey	Topographic Investigation	Geological Survey	Investigation Boring	Seismic Survey	Resistivity Survey	Rock Test (Laboratory)	Hydrological Survey	Botanical Survey	Remarks
Topography	Shape of Slope	B	A	B								These Categories could be Investigated in Preliminary Study
Topography	Angle of Slope		A	B								
Topography	Height of Slope, Distance from Road		A	B								
Topography	Progress of Shaped Slope	B		C								
Topography	Existence of Overhung	C	A	A								
Topography	*Existence of Knick Line*	A	*B*	B								
Topography	Microtopography of Slope	C		A								
Geology	Type and Quality of Rock	C			A	A	B	C	C	C		Hardness of Rock, etc.
Geology	Weathering Grade				C	B	A	B		C		
Geology	Rock Density					C			A			
Geology	Distribution of Fault, Shear Zone, Discontinuous Plane				A	A	B	B				
Geology	*Dip/Strike of Discontinuous Plane*				B	A						
Geology	Situation of Discontinuous Plane				B	A				B		Filler
Geology	Coefficient Values								A			
Geology	Existence of Weak Rock in Slope			C	C	B	C	C	C			Share Zone, etc.
Groundwater					C	B		A		B		
Estimation of Pore Water Pressure						C				C		
Distribution of Vegetation		C									A	
Estimation of Rockfall Process		C		B								
Situation of Existing Countermeasure		(Structural Investigate should be Necessary)										
Phenomenon	Disaster History	These Categories could be Investigated in Preliminary Study										
Phenomenon	Opened Crack											
Phenomenon	Small Collapse, Rockfall											
Phenomenon	Unstable Rock											
Phenomenon	Brittle Rock, Layer											

A: Necessary B: Effective C: Effective in Some Cases

(2) Filing of Results

Collapse

i) Estimation of the collapse range

As regards slope types where collapse occurs readily (a. slope on the head of valley, b. head at source of swamp and seepage location, c. near the dissected front (knick line) on the mountainside slope (valley wall) and top portion of collapse site, d. rim of the highland and terrace cliff), the identifiable range is indicated. The range of the location where deformation has already occurred or where the risk is considered high when judging from the collapse history is also indicated.

ii) Estimation of the collapse depth

Generally, the depth is set in the boundary between the subsurface layer and bedrock. When there are cases of collapse in the surrounding, the geological position of collapse surface (e.g., the bottom surface of the loam or collapse soil) and the degree of weathering are used as reference.

iii) Estimation of the stability
Analysis of stability is made through slope stability analysis using the model constant calculated backward from collapse examples in the neighbourhood or using investigation results from the soil test.

Rock Fall

i) Estimation of the range of rock fall.
Determine the range through Site reconnaissance on surface deformation with fracture and elevation, faulting and cave-in, distribution of grooved topography, etc.

ii) Estimation of the rock fall depth and rock fall volume.
This estimation is made from the thickness of unstable layer (weathered zone, etc.), slope deformation range, and geological structure.

iii) Existing countermeasure condition.
Fracture and squeezing, peeling and deterioration of concrete, cut and corrosion of net, rope, and wire, loosened anchor.

iv) The road disaster pattern
It is governed by the positional relationship between the rock fall and road. The pattern is estimated on the basis of overall evaluation on the location, scale, pattern, and failure route of the phenomena possibly affecting the road as well as effectiveness of existing countermeasures.

Rock Mass Failure

i) Estimation of the rock mass failure range
Concerning the slope pattern that readily develops rock mass failure, such as a. rock mass slope along the coast (sea cliff), b. cliff along the river, c. overhang, d. location where the knick line is clear, and e. positive topography (ridge), any identifiable range is estimated. The range of the location where deformation has already occurred or where the risk is considered high when judging from the rock mass failure history is also indicated.

ii) Estimation of the rock mass failure depth
Generally, the depth is set in the boundary between the surface course and bedrock. When there are cases of rock mass failure in the surrounding, the geological position of rock mass failure surface (e.g., the bottom surface of the loam or rock mass failure soil) and the degree of weathering are used as reference.

iii) Estimation of the stability

Analysis of stability is made through slope stability analysis using the model constant calculated backward from rock mass failure examples in the neighborhood or using investigation results from the rock test. If there is a high possibility of large-scale rock mass failure and the disaster thus incurred is difficult to estimate, an approach to estimate the rock mass failure pattern to the road and the route by means of failure simulation.

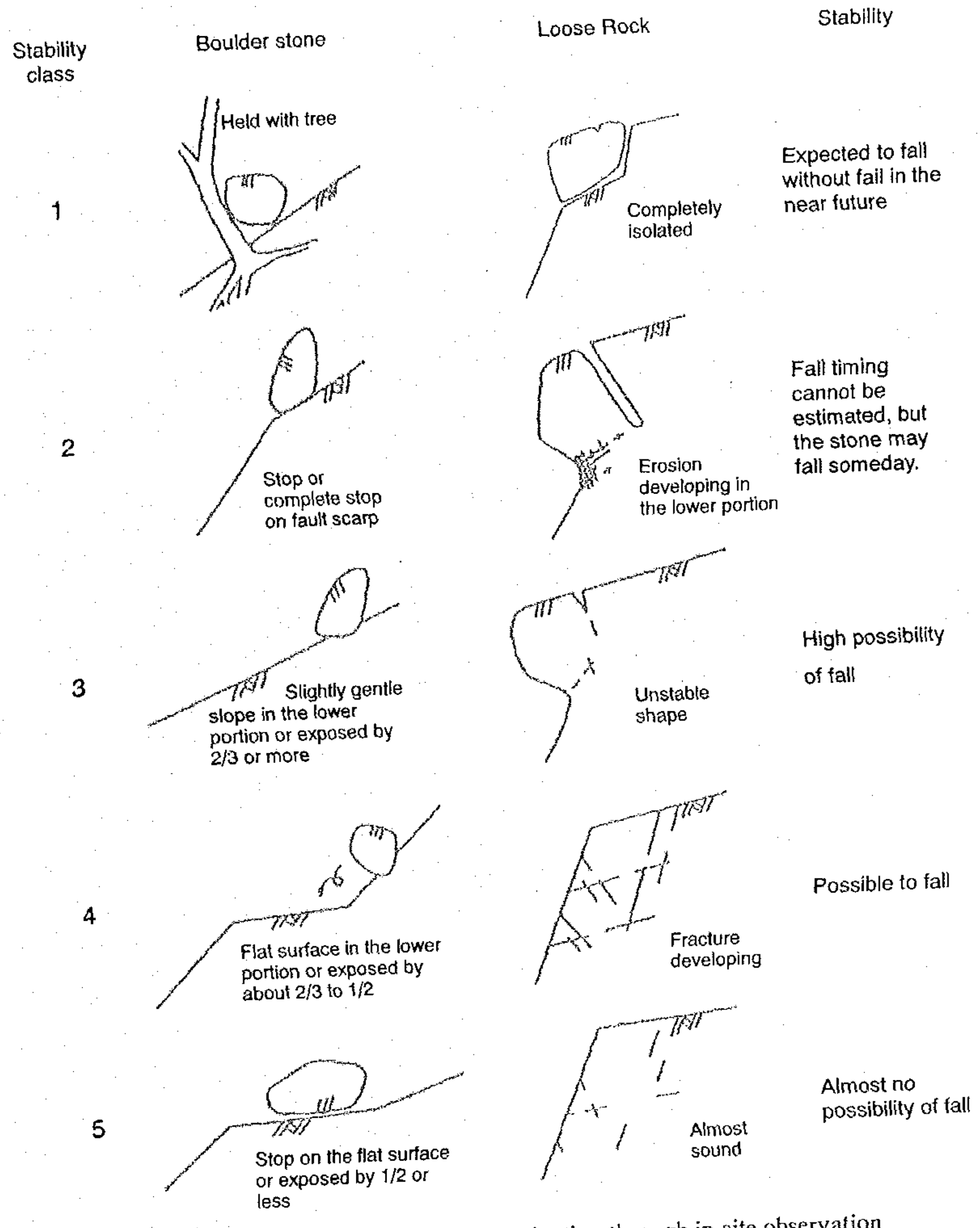


Figure 6.2.1 Typical stability evaluation through in-site observation
(Ref. *9) p.53 Figure2-9)

(3) Monitoring

Most of Collapses / Rock Fall / Rock Mass Failure occur and extinct within a relatively short period, for which deformations to indicate eminent occurrence, such as fault or cave-in, are difficult to identify. The monitoring system such as for Landslide is not useful in most cases.

Following two types of monitoring are useful for Collapse / Rock Fall / Rock Mass Failure.

i) Sensor system
Instrumentation system to detect occurrence of rock mass failure and actual rock mass failure

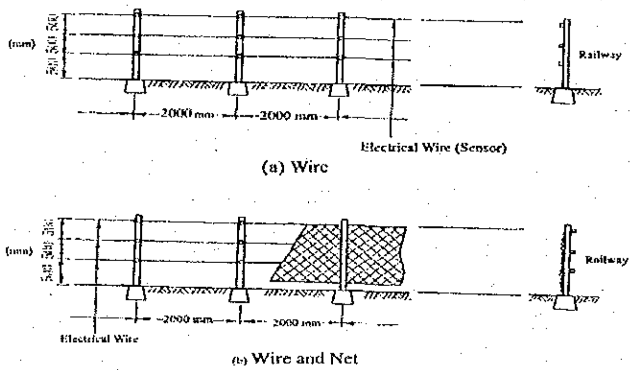


Figure 6.2.2 Example of Rock Fall Detector

ii) Rock mass failure monitoring system
System to measure deformation, tilting and stress change of loose or unstable rocks on the slope, keeping observation for any abnormality

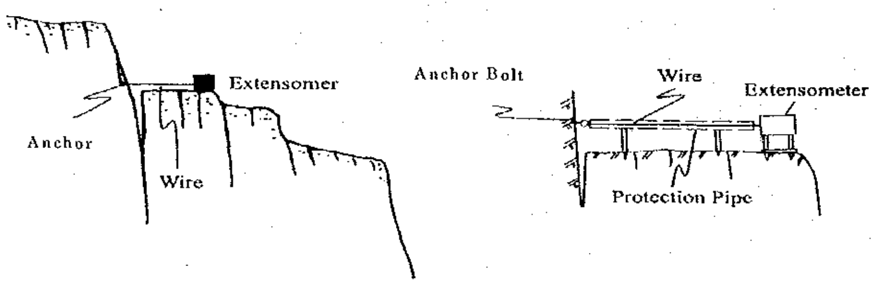


Figure 6.2.3 Example of Monitoring on Rock Mass Failure

6.2.2 Investigation against Landslide(LS)

This investigation is made when Slope Inspection proved high risk of landslide (LS) or when landslide has already occurred. The investigation is intended to ensure implementation of appropriate countermeasure (design and implementation of countermeasure or monitoring through instrumentation).

This investigation should produce following information:

i) Location, scale, and pattern of landslide

ii) Effectiveness of existing countermeasure against landslide and its effects on the road

iii) Landslide direction, velocity, and presence of slide

iv) Stability of landslide activities and change in the safety factor because of earth work

v) Mutual relationship between landslide activities and triggering factors

vi) Extraction of essential monitoring, simplified measurement, and instrument locations

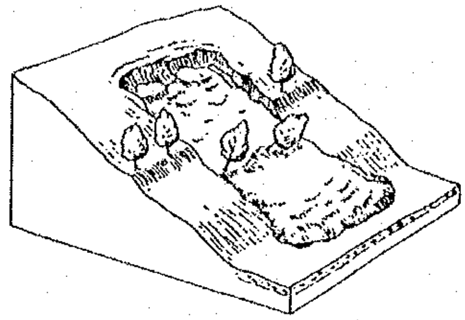


Figure 6.2.4 Landslide

In the study, boring investigation, geophysical survey, groundwater survey, measurement, soil investigation, etc. are applied individually or in combination according to site conditions and objectives.

For deformed locations, such as fault, etc., secular change is followed by means of simplified measurement.

(1) Development of the Detailed Study Plan

Survey necessary to confirm the landslide mechanism assumed in Preliminary Study is developed.

i) Division into movement blocks
On the basis of Preliminary Study result, the landslide area is divided into several landslide movement blocks.

ii) Set up of the investigation line
On the basis of Preliminary Study results, the line is set in such a location and direction as to enable specific confirmation of the geology and surface fluctuation of blocks and to ensure the basic plan and design of countermeasure.

iii) Selection of investigation items

After confirmation of occurrence and mechanism of landslide estimated from Preliminary Study, investigation items necessary for development of more precise countermeasure plan and design are selected according to the objective.

(2) Measurement of surface fluctuation

Measurement of surface fluctuation is made to understand the range, and direction or activeness of landslide as well as the relationship with meteorology and other triggering factors. Standard practices are those using the wire extensometer, ground survey, as described below. Other approaches may be considered according to site conditions.

i) Wire extensometer (for details of instrument, refer to section 3.1 in Guide III-1)

Investigation with this instrument is to predict occurrence of landslide or to understand relationship between the landslide activity and triggering factors by measuring extension and shrinkage of the ground. When any abnormality is found on the slope, this extensometer is installed on top of the tension crack to measure elongation to predict the timing of slide or provided with an alarm (issuing alarm at 4 mm to 1 mm/hour).

ii) Investigation through ground survey

Investigation through ground survey is made mainly when the landslide direction is not clear or when the landslide is extremely active. Accordingly, cross sectional survey or triangular or aerial triangular survey is made using fixed points outside the landslide area as control points.

(3) Geological investigation

i) *Fundamentals*

Geological investigation is made mainly through vertical boring investigation to investigate into the slide surface and groundwater, geology, and soil quality. As a rule, all-core sampling is made. In the case of the soil ground mixed with gravel that is difficult for all-core sampling, the standard penetration test is made consecutively to take samples.

ii) Layout and length of borings

Boring investigation is made at a right place in a required length to clarify the slide surface, geology and geological structure in the landslide area.

Boring is made at least at three points inside the landslide area and one point outside the area. As a rule, the boring interval is 30 m or less along the major line and 50 to 60 m along the secondary line. When the landslide is of a large scale, boring investigation must be made over the wide area.

The boring length must be such as to penetrate at least 5 m into the bed rock below the estimated sliding soil lump surface.

To file the result of boring investigation, findings from observation on items necessary for review of the geology and soil of the landslide land as well as the landslide surface are compiled into the boring column. Principal items are core-based observation of geology and soil, remarks on the excavation condition, borehole water level during and at the final stage of excavation, and core recovery.

iii) Geophysical survey

Geophysical survey is made along with boring investigation when the landslide area is wide and bed rock distribution is expected to be extremely irregular.

(4) *Investigation on the slide surface*

Slide surface investigation is made by i) judgment on boring core and ii) borehole inclinometer and other instrumentation.

i) Core judgment

- Engineering geologists or geotechnical engineers draw judgment on the slide surface after careful observation of boring cores and by taking into account the following points:
- Slide surface is a boundary between colluvial deposit and rock mass.
- Boundary surface between heavily and lightly weathered rocks
- Clay layer and weak layer existing inside rock mass
- Depth at which jamming occurs during boring when the landslide velocity is high
- Depth at which crescent cores are sampled in the next morning
- Portion where around 10 cm cores are not taken, which exist in the fresh rock mass

ii) Inclinometer

Instrumentation utilizing difference in the displacement between upper and lower portions of the slide surface is the borehole inclinometer installed in boreholes. This instrument determines relative displacement to understand landslide soil mass. Namely, a grooved casing pipe is inserted into a borehole, with grouting made between the bore wall and casing, allowing measurement of inclination of the casing. This instrument is available in two types; an insertion type in which a probe is inserted into the casing for measurement of the inclination angle of casing sequentially in a given interval and a stationary type in which the inclinometer is fixed to the casing to measure changes in the inclination angle at the point. The former is used for continuous measurement while the latter for automatic measurement.

In addition, a pipe strain gauge may be used for short-term automatic measurement or for investigation into the slide surface. Generally, the insertion type inclinometer is used for investigation of the slide surface.

(5) Groundwater survey

Borehole may be used to provide a groundwater observation hole. When multiple aquifers are expected to exist within the landslide soil mass, observation must be made on the pore water pressure of each aquifer.

Landslide occurs frequently during heavy rain and becomes more active when the groundwater level rises. Knowledge on the groundwater condition in the landslide area is indispensable for analysis of the landslide occurrence mechanism and the stability while enabling effective countermeasure implementation by means of dewatering.

i) Observation of the groundwater level
This observation is made to understand fluctuation of the groundwater level in the landslide area and implemented through the year. Observation before and after implementation of the countermeasure will prove effective for judgment of its effectiveness.

ii) Observation of the pore water pressure
The piezometer provided in borehole is durable even during long-term measurement, and vibrating wire (VW) and Casagrande types are suited. Note that the water level in the observation hole may be considered as the pore water pressure in the case of permeable layers with the permeability coefficient of aquifer in the landslide soil mass being $10^{-2} \sim 10^{-3}$cm/sec or more and there is no permeable layers below the slide surface.
Setting the pore water pressure for the entire estimates slide surface is extremely important to ensure stable analysis. Geophysical engineers should determine the pore water pressure, on the basis of long-term observation results, taking into account geological and topographical conditions and seasonal fluctuation.
When there are multiple aquifers in the landslide soil mass, movement of landslide does not necessarily coincide with fluctuation of the groundwater level because of mutual effects of these aquifers. In this case, observation of groundwater level alone is not enough. Observation of the pore water pressure of each aquifer is necessary.
When the pore water pressure of slide surface has been observed, the observed value is used directly. If the exact slide surface depth is difficult to estimate beforehand, piezometer should be installed at various depths, taking into account the permeability or shear strength of the ground.

iii) Others

When the location and flow condition of groundwater in the fluid layer, aquifer, and groundwater system are considered to be complicated, groundwater logging or groundwater tracing using boreholes, electric prospecting, water quality investigation, or pumping test are made as required according to the plan.

(6) Laboratory test and soil investigation

To estimate the shear strength of slide surface, the soil test may be made by taking undisturbed samples.

The standard penetration test is made to determine the ground constant necessary for prevention works and their design.

(7) Filing of results

i) Preparation of fundamental data for the countermeasure

- Investigation results are described and compiled on the plan view to facilitate identification of the landslide range from the slope gradient, micro topography, deformation, and surface condition.
- The geological cross section is prepared for each line.
- Considering geological investigation result, measurement result, and aquifer distribution from overall point of view, the depth of slide surface is estimated.
- The ground constants necessary for review of the countermeasure are compiled from results of geological, groundwater, and site investigations.

ii) Summary of measurement results

Results from measurements on surface fluctuation, fluctuation in boreholes, and groundwater are filed according to the data filing method described in Chapter 5.

(8) Monitoring

Most important purpose of monitoring is

i) to confirm the movement
ii) to confirm the relation along rainfall, pore water pressure and movement

Monitoring is made as required depending on the scale and pattern of expected landslide, the way to take the countermeasure. Typical instrument layout is shown in Figure 6.2.5.

The guideline for variables that lead to determination that considerably active landslide is occurring is shown below:

i) 1mm/day or more on the extensometer for consecutive 10 days
ii) 1cm/day or more on the extensometer for two or more consecutive days
iii) Cumulative inclination for one week of 100 sec or more on the borehole inclinometer
iv) Average inclination variation for one week of 30 sec/day or more on the borehole inclinometer
v) The guideline that causes restriction of access into the landslide area is as follows:
vi) 2mm/hour or more on the extensometer continuing for two hours or more
vii) Cumulative inclination observed on the borehole inclinometer and the maximum inclination variation per day of 100 sec or more

The way of crack opening is related to the scale of landslide and the soil quality. Clayey soil does not develop slide readily even when the strain rate is relatively high. When the soil consists of sandy soil or weathered rock, slide tends to occur within a short period.

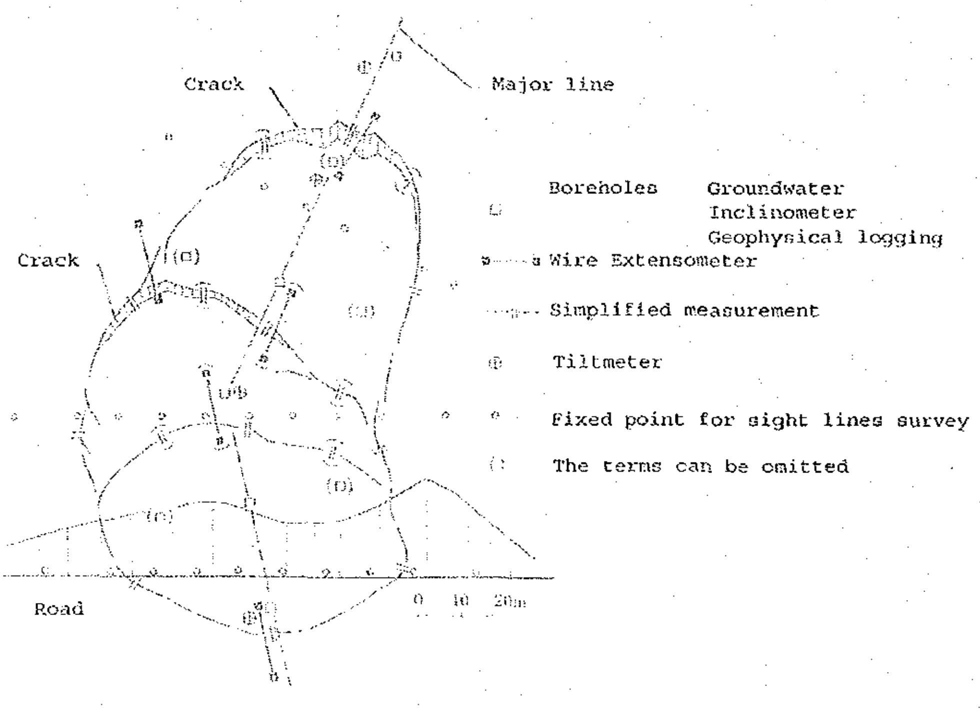


Figure 6.2.5 Typical layout of monitoring instruments
(Ref. *8) p.120 Figure2-28, p.128 Figure2-33)

To predict the slide timing, extensometers are installed on both sides of fracture to measure the moving velocity. Since sudden increase in this velocity is observed immediately before landslide, the timing of slide may be predicted in advance.

6.2.3 Investigation against Debris Flow(DB)

This investigation is made when Slope Inspection proved high risk of debris flow (DB) or when debris flow has already occurred. The investigation is intended to ensure implementation of appropriate countermeasure (design and implementation of countermeasure or monitoring through instrumentation).

This investigation should produce following information:

a) Investigation on occurrence of debris flow frequency (history), scale, sediment yield, maximum grain size
b) Rainfall conditions causing debris flow
c) Presence, data, and effectiveness of existing checkdam and soil conservation facilities, effects on the road in case debris flow occurs

Table 6.2.2 Items related to Debris Flow (DB) in Preliminary Study

Survey items	Description of in-situ survey
Frequency	Existing disaster data, hearing, and in-situ survey
Survey at the source of debris flow	Development of natural dam
	Sedimentation soil on the stream bed
	Wide-ranging gully erosion of the slope
	Failure site and surplus soil
	Signs (fracture, slide cliff) of new failure and landslide
	Soil instabilized through development activities
	Wide-ranging windfall and uniform felling area
	Bare ground, burnt field, grassland, wasted forest
Sedimentation in existing checkdams and anti-erosion facilities	Sedimentation condition
	Damages by disaster function loss
Stream condition at crossing of roads	Plane, longitudinal, and cross configuration of the stream at the point concerned
	Sedimentation condition of boulders, driftwoods, etc.
Rainfall conditions	Analysis for existing rainfall data and caused debris flow
Survey	Check for presence of existing drawings
	If not, prepare drawings newly.

Generally, debris flow may occur in a negative topography where rainwater is collected or in the mountain stream where flowing water gathers. The rough standard to expect debris flow is that the catchment area on the upstream side of the point with the stream bed gradient of 15 degrees is 5 ha or more and sediments to make up the debris flow exist on the stream bed. If the above catchment area is less than 5 ha, debris flow may occur when the geology, seepage, and collapse history of the area indicate the possibility of relatively large slope failure.

Debris flow is said to occur once every few decades to 200 to 300 years in ordinary mountain streams. Survey around the outlet of valley helps understanding the scale of debris flow, gravel contained, and the scope of outflow and sedimentation.

(1) Frequency of debris flow

To understand the recent occurrence and frequency around the stream concerned, investigation of existing disaster data, hearing, and in-situ survey are made.

(2) Survey at the source of debris flow

Engineering geologists or geotechnical engineers conduct in-situ survey, estimating the sediment yield, maximum grain size of debris flow, and estimation of the inundated area. Following points should be taken into account during survey:

i) Development of natural dam
Check is made to see if a natural dam has been formed by slope failure or landslide soil mass blocking the river channel. If any, the catchment condition, size, grain size distribution of sediments, and gradient of river channel are determined.

ii) Sedimentation on the stream bed
Mainly on the area with the stream gradient of 10° or more that is considered a source of debris flow, presence of large amount of sediment on the stream bed, approximate sedimentation thickness and range, grain size composition, and vegetation are determined.

iii) Wide-ranging gully erosion of the slope
Development of gully causes debris flow. Its development range, density, and forms are determined.

iv) Failure site and surplus soil
Debris flow occurs from surplus soil in the site of large failure. The position and route to the stream, approximate amount, vegetation (to estimate the stability), and trend of expansion of the failure site are determined.

v) Signs (fracture, slide cliff) of new failure and landslide
New failure or landslide occurring on the mountain side and slope during heavy rain may develop into debris flow. Presence of any signs, effects on the stream by debris flow if any, etc. are determined.

vi) Soil instabilized through development activities

The work site with inadequate drainage and slope protection as well as surplus soil from the work may cause debris flow. Presence, position, and scale of unstable soil are determined.

vii) Wide-ranging windfall and uniform felling area

Wide-ranging windfall, uniform felling area, and slush-and-burn, if any, are also causes of debris flow including drift wood. Their location and range are determined.

viii)Bare ground, burnt field, grassland, wasted forest

These lands are readily eroded in the surface and may develop failure over a wide area during heavy rain. Their location and range are determined.

(3) Sedimentation in existing checkdams and anti-erosion facilities

For existing checkdams if any, the sedimentation condition (the height allowing sedimentation on the upstream side of dam) and data of facilities are determined to evaluate the effectiveness of the dam.

(4) Stream condition at crossing of roads

Road disaster by debris flow occurs at a point where the road crosses the stream because of inundation of debris flow. Plane, longitudinal, and cross configuration of the stream at the point concerned, its structure, and condition are determined to estimate effects on road structures by debris flow arriving at the road crossing point.

i) Determination of the structure (section, longitudinal and plane configuration, and the construction of bridges, culverts, and drainage conduit)
ii) Determination of topographical features (generally, the sedimentation trend in the alluvial fan and the river channel with the gradient of 1/10 or less) to estimate whether the road crossing point is located in the sedimentation area in terms of soil and hydraulics
iii) Checking for any existing disturbance by boulders, driftwoods, etc. at the road crossing point

(5) Monitoring

Rock Fall Detector or Slope Failure Detector could be useful at the crossing point of stream to detect debris flow.

6.2.4 Investigation against Embankment Failure (EB)

This investigation is made when Slope Inspection proved high risk of embankment failure (EB) or when embankment failure has already occurred. The investigation is intended to ensure implementation of appropriate countermeasure (design and implementation of countermeasure or monitoring through instrumentation).

This investigation should produce following information:

a) History of embankment failure. Understanding of prime factors and inducements. Topography (gradient, longitudinal and traverse configuration), geological condition, geological structure, hydrology (precipitation), vegetation, etc.
b) Understanding of the present state. Estimated location (range) and scale (embankment failure depth), pattern, stability, location of the existing countermeasure, presence of structures, relationship between the road and embankment, etc.
c) Effectiveness of existing countermeasure in case of embankment failure and its effects on the road
d) Extraction of essential monitoring, simplified measurement, and instrument locations

Generally, embankment failure occurs frequently because of heavy rain. Within a certain period of time after heavy rain, water that has infiltrated into the embankment may cause, though rarely, landslide or failure.

Embankment failure pattern is greatly governed by the topographic conditions of the location where the embankment exists.

Generally, concerning embankment failure, it is essential to trace the progress of fracture, settlement, and other deformations according to the time to see if they may develop into any critical deformation.

It is recommended to conduct in-situ survey by assuming approximate disaster patterns on the basis of the results of Slope Inspection while referring to Table 6.2.3.

Table 6.2.3 Principal disaster factors and patterns by type of embankment(EB)

Type of embankment and ground	Principal disaster factors		Expected major disaster patterns
	Internal	External	
Cutting and embankment	• No gutter on the cut side or insufficient section • High permeability of the ground, with inadequate underground drainage of embankment • Water collecting ground	• Surface water flowing from cut slope to embankment slope • Infiltration of groundwater from ground to embankment	• Scouring of slope • Sliding failure in the boundary between the ground and embankment
Stream passing the crossing point	• Insufficient section of crossed drainage facilities or soil sedimentation • Inadequate protection of the slope	• Water from a valley • Inlet blocked with driftwood, etc. • Infiltration of flowing water into embankment	• Scouring of slope and washout of embankment by overflow • Sliding and failure of slope by seepage water
Cut-embankment boundary	• Inadequate connection from the gutter of cut to longitudinal and vertical gutters • Inadequate underground drainage	• Overflow of surface water from the cut at connections or vertical gutter • Infiltration from the ground on the cut side to embankment	• Scouring of slope of longitudinal gutter section • Slide, failure
Inclined area	• No or inadequate gutter at top of slope on the mountain side • Ground is of a water collecting topography and highly permeable.	• Surface water or infiltration water on the mountain side is infiltrating into embankment.	• Slide, failure
Flat area	• Insufficient section and inadequate connection of road gutters and vertical gutters • Inadequate slope drainage • Clogging of ditch with sand	• Overflow from connections or vertical gutter	• Scouring or sliding/failure of slope

(1) Geological investigation

i) Fundamentals

Site investigation includes geophysical survey, boring investigation, laboratory test, and in-situ test, determining the embankment failure location and scale, failure surface, soil composition and strength, groundwater behaviour, and embankment behaviour.

(2) Site reconnaissance

Site reconnaissance consists fundamentally of visual and careful investigation of any deformation of the ground surface in addition to geological, topographical, vegetation, and hydraulic condition by engineering geologists or geotechnical engineers.

Deformation points to be highlighted in the embankment are illustrated in sketches as well as described in the drawing.

When there is any deformation that may indicate possible embankment's failure or significant settlement, simplified measurements are made. They include the measurement of a distance between pins and nails on both sides of fracture of a structure, observation of deformation of asphalt applied to patch up fractures, measurement of displacement of batter boards provided on both sides of fracture and step in the embankment.

In the study, boring investigation, geophysical survey, groundwater survey, measurement, soil investigation, etc. are applied individually or in combination according to site conditions and objectives.

For deformed locations, such as crack, etc., secular change is followed by means of simplified measurement.

i) Boring investigation

Boring is made for investigation of the soil composition, sampling of soil test samples, in-situ test such as a standard penetration test, groundwater level measurement, and installation of instruments in the borehole. Mainly, vertical boring investigation is made. As a rule, the standard penetration test is made to check the inside of embankment, and all-core sampling is made when the ground is rock mass.

The boring length must be such as to penetrate at least 5 m into the original ground below the estimated sliding soil lump surface.

To file the result of boring investigation, findings from observation on items necessary for review of the geology and soil of the embankment land as well as the failure surface are compiled into the boring log. Principal points include observation of the soil quality by using SPT sample, remarks during drilling, and borehole water level during and at the final stage of drilling.

ii) Sounding

Sounding is made to check the location and shape of estimated failure depth and the in-situ relative strength of the ground. Investigation of embankment's slope includes the simple penetration test, Swedish sounding, and standard penetration test.

iii) Soil observation

As a rule, indirect investigations such as sounding and geophysical survey should be accompanied by soil observation. When overburden is so thick that there is no outcrop, auger boring, machinery boring, and test pit should be made to facilitate soil observation.

iv) Sampling

Sampling is to take samples for the soil test. For disturbed sample for the geophysical test, samples taken by auger boring or those for the standard penetration test are used. In order to obtain undisturbed samples for the mechanical test, a dedicated sampler appropriate to the soil quality is used.

v) Geophysical survey

When investigation is to be made on the embankment's slope, approaches such as seismic, resistivity, and electric prospecting are effective. They are advantageous in that they can cover a wide area within a relatively short period. However, values obtained are indirect, so that data from site reconnaissance and boring investigation should be combined for overall interpretation during geological analysis.

vi) Groundwater survey

Where behaviour of groundwater is considered to be a great factor causing embankment failure, measurement of the groundwater level, groundwater tracing, groundwater logging, measurement of the pore pressure should be made to investigate any change in the groundwater level, direction and velocity of groundwater, location of the flow layer, and pore pressure. Where discontinuity of permeability in soil layers near the surface is a problem, the permeability test is made.

vii) Laboratory test

In order to understand natures of the ground, which are to be used as fundamental data for calculation of the slope stability and setup of design conditions, following laboratory tests are made as required:

a. Physical test

This test is made to understand basic geophysical characteristics of the slope (grain size distribution, moisture content, unit weight, liquid limit, specific gravity).

b. Soil mechanical test

This test is made to understand soil mechanical properties of slope (strength of undisturbed soil, etc.).

(3) Filing of results

i) Preparation of fundamental data for the countermeasure

Investigation results are described and compiled on the plan view to facilitate identification of the readily collapsible range from the slope gradient, deformation, and surface condition. As regards the location where the risk is so high as to require review of the countermeasure, the geological profile is prepared to estimate the failure depth.

ii) Estimation of the stability

Analysis of stability is made through slope stability analysis using the model constant calculated backward from embankment failure examples in the neighbourhood or using investigation results from the soil test

(4) Monitoring

If the countermeasure is judged unnecessary for the time being as a result of Detailed Study, mainly simplified measurement and visual monitoring are made. Note that monitoring instrumentation, if provided during Detailed Study, may used as required for monitoring before and after the rainy season and after heavy rain.

CHAPTER 7 NEW TECHNOLOGIES OF INVESTIGATION

This chapter introduces the investigation method and equipment, which are relatively new or not so much used because of economic reasons, but will prove appropriate for the slope site investigation and monitoring in the near future. Technologies dealt with in this chapter include those that are not new in terms of principle, but applied generally in civil engineering and geological fields thanks to amazing development of computer-aided analysis technology in recent years.

As regards geophysical survey, geotomography and thermal infrared approaches are introduced. A bore-hole television is introduced concerning borehole logging.

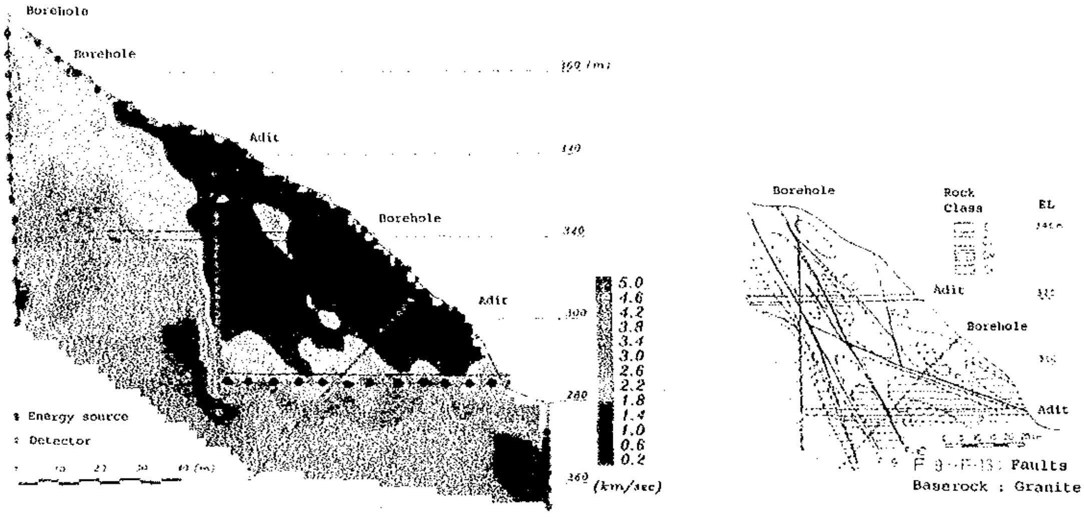
7.1 Geotomography

Geotomography consists of application of the concept of medical CT (Computed Tomography) to site investigation. In this technology, after combination of tunnel-tunnel, shaft-shaft, adit-adit, borehole-borehole, or ground surfaces, observation points are arranged to enclose the section to be investigated. The reconstructive image of physical quantity is determined for the ground in the section concerned from the measurement result.

Elastic wave, resistivity, and electromagnetic wave tomographies are put into practical application with success. They can offer the result higher in accuracy than the one obtained with explorations only on the ground surface.

The reconstructive image thus obtained is visualized in two dimensions, facilitating estimation of the geological structure (rock type distribution) and rock mass classification.

Figures 7.1.1 - 7.1.2 show a typical geotomography determined from each type of method.



(a) Final Velocity Model

(b) Rock Classification Result

Figure 7.1.1 Typical rock mass classification investigation with elastic wave tomography (Ref. *[16] frontispiece 3.3.1)

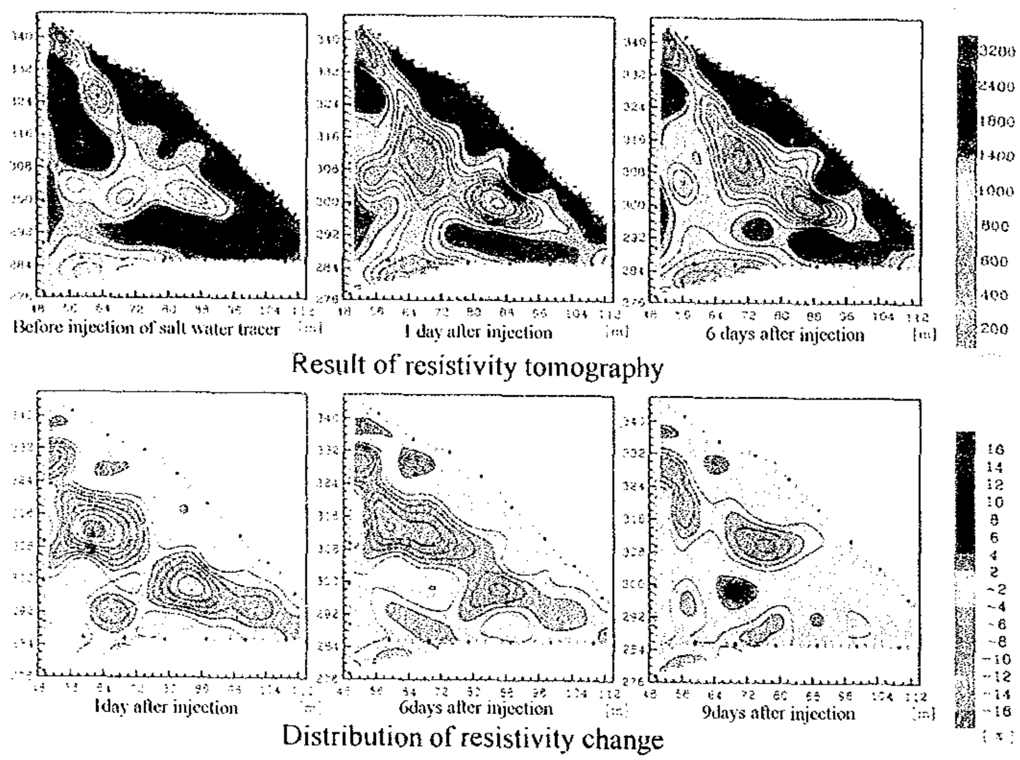


Figure 7.1.2 Secular change of resistivity through injection of salt water tracer according to resistivity tomography (Ref. *[16] frontispiece 3.3.3)

7.2 Infrared Technology

Infrared technology consists of measurement of the temperature distribution and change on the rock mass slope surface, determining the condition of weathering and open fracture of rock mass, loosened condition of rock mass, and wet condition. This technology is often used during diagnosis of grouted mortar.

Infrared photographing allows determination of the temperature distribution on the slope surface over time with the resolution of 0.1℃. Magnitude of temperature change thus determined plus the results of survey and other investigations enables overall evaluation of the rock mass slope.

The surface temperature of the slope under measurement reflects the thermal capacity and conductivity around the ground surface and does not include data in the deeper portion. This technology cannot be applied when the surface is covered with vegetation.

The figure below shows comparison of the same slope between normal photos and infrared photos. In the photos, the portion with high temperature change is represented in warm colour while that with low change in cold colour. Temperature difference of the portion with loose stone is large and thus in the considerably dangerous condition.

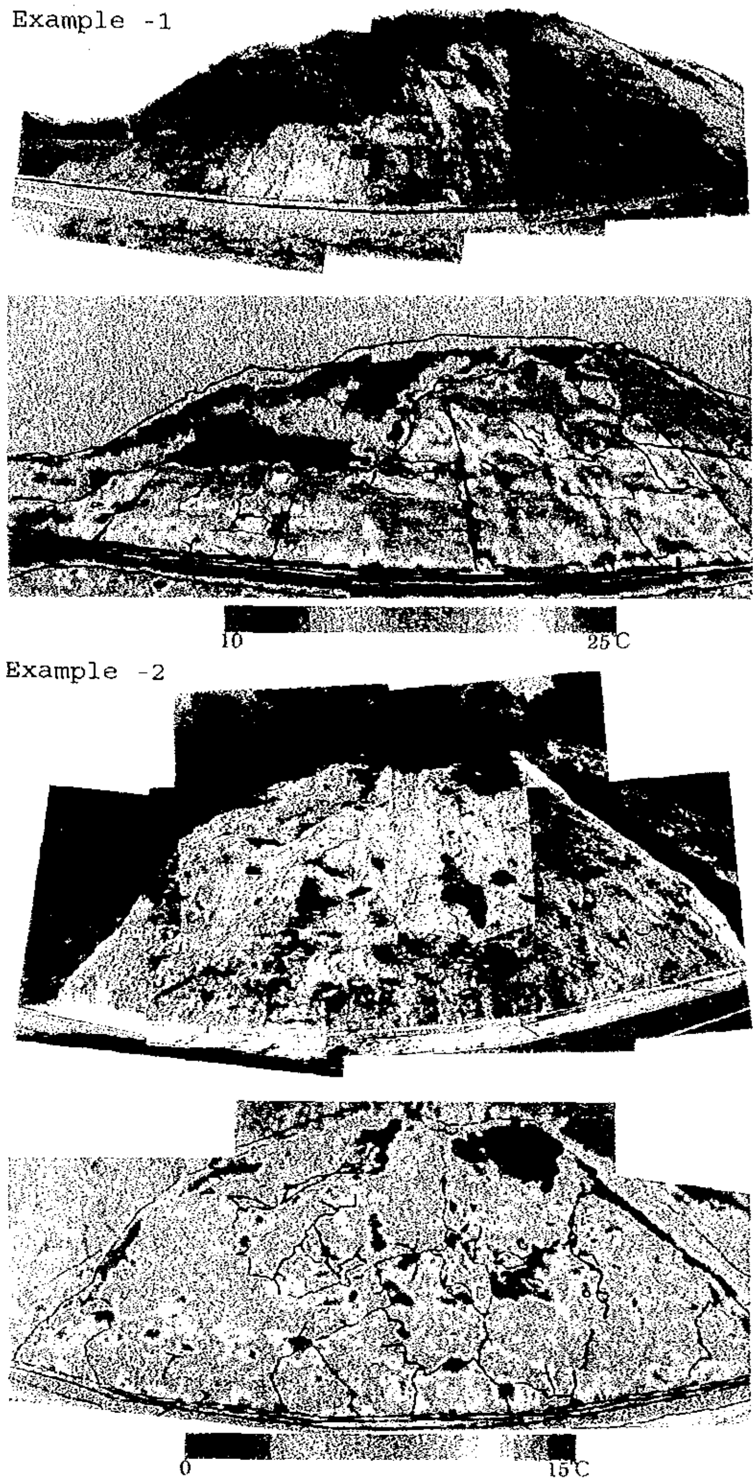


Figure 7.2.1 Typical rock mass slope photos with thermal infrared (Ref. *21) p.9, Fijiwara et al.)

7.3 Borehole Television

The borehole television is advancing yearly in terms of functions, accuracy, and economy along with recent remarkable development of electronics technology. Concerning analysis of rock slope, data on the distance and strike/dip, opening width, and presence of filling materials of discontinuous planes of underground faults and joints is important. Such data cannot always be obtained in sufficient amount from boring core observation.

The core wall development image obtained with the borehole camera and the core image diagram reconstructed from data are shown in Figure 7.3.1. Figure 7.3.2 shows comparison between the hole wall fracture distance (hole RQD) and boring core RQD. This table indicates the possibility that RQD of considerable number of cores is substantially underestimated though this may vary depending on the rock type and quality.

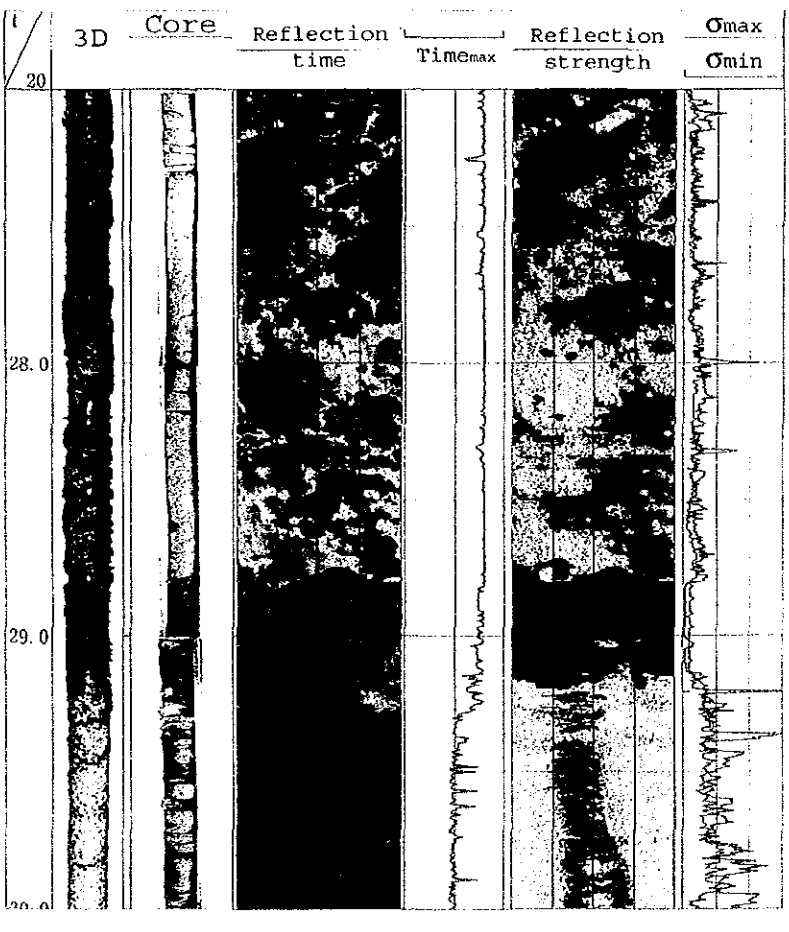


Figure 7.3.1 Typical core reconstructed image from hole wall development image with the borehole camera (Ref. *22) p.14, Yamazaki et al.)

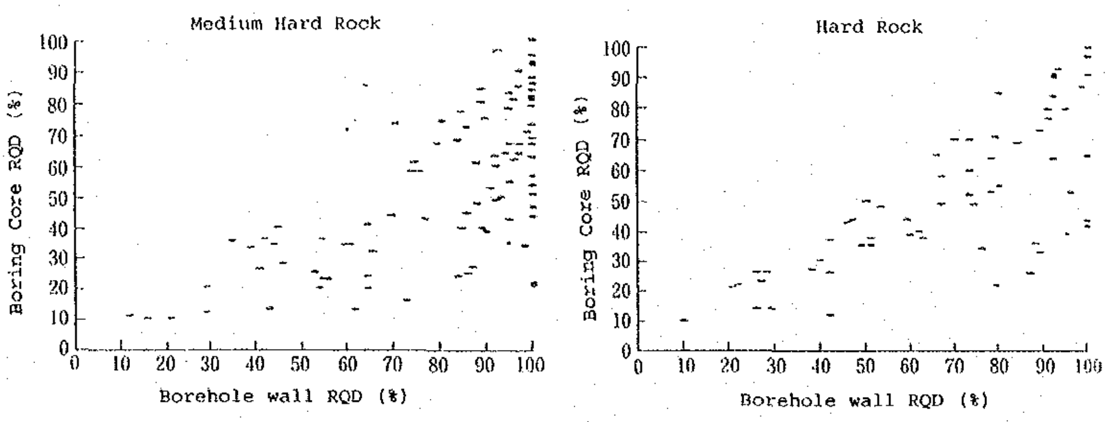


Figure 7.3.2 Comparison of RQD between core and borehole wall
(Ref. *14) p.262, Fig.9.1.6)

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