ROAD DISASTER PREVENTION MANAGEMENT MANUAL

GUIDE V

DISASTER PREVENTION WORKS

ABC
JICA

CONTENTS

GUIDE V DISASTER PREVENTION WORKS

CONTENTS

OUTLINE

This is a guide for design of prevention measures and investigation for prevention measures.
Principal methods for preventive measures are described. There have been many road disasters related to water in Bolivia, therefore drainage methods are recommended as simple measure works, even some heavy prevention measures are introduced in this guide. The standard gradient of cut slopes and simple prevention measures are included in this guide. These simple prevention measures are recommendable for the high risk control sections in preference to the other sections. With limited budget, the places of prevention measures would be very limited in the year. The place of the prevention measures shall be selected deliberately by ABC Head Office taking total condition of the highways into conditions.
The investigation methodology is ordered for a detailed design. Investigation instruments, monitoring systems and protection of equipment are included.

The contents of Sections 1.2, 1.3 and Chapter 2 in this Guide are excerpted from the following publications.

1) Public Works Research Institute Japan, 2004.
Manual for Highway Earthwarks in Japan
2) JICA, 2002.
Guide III: Guide to Early Warning and Site Investigation.The Study on Slope Disaster Management for Federal Roads in Malaysia

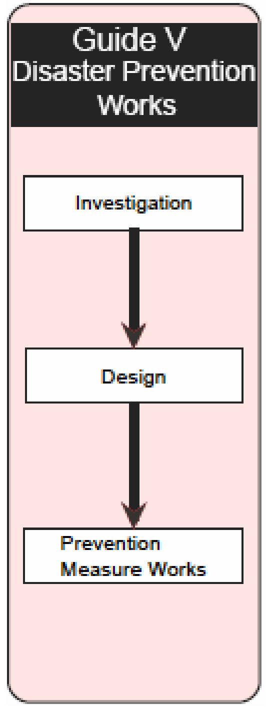


Figure 0.1 Contents of Guide V

1 BASIC CONCEPT

The basic concept of prevention measure shall be to remove the primary factor and the contributory factor.

The primary factor (constitution) is the ground's general condition of health, especially the ground's ability to remain health. It is the makings of the ground, such as geological or geomorphic characteristics.

The contributory factor is direct cause of landslides. It is natural phenomena such as heavy rain and earthquake, or factitious factors such as construction works.

The primary factor

- (a) Material Characteristics
- (b) Mass Characteristics
- (c) Reduced Shear Strength

The contributory factor

- (a) Removal of Support
- (b) Imposition of Surcharges
- (c) Transitory Stresses

Design concept of prevention measure for road disaster is;-

First :	Remove the primary factor and the contributory factor
Second :	Remove th primary factor or the contributory factor. (mostly contributory factor)
Third :	If it is difficult to remove neither the primary factor nor the contributory factor, control by force.
Fourth :	If it is difficult to remove both the factors and using force, leave from danger (diversion).

In Bolivia, the road on slopes in mountainous areas, daylight structures of geological stratums or poor vegetation in dry areas are the primary factors, and rainfall and earthquake are the contributory factors. There are many cases in Bolivia that inappropriate management of the rain water flowing over the ground surface (surface water) triggers slope failures. The contributory factors could be removed and the road disasters could be reduced, if the surface water would be managed properly. Preparation of road drainage such as ditches, cross drainage, proper surface water management on cut slopes, proper size of cross sections for cross streams, revetment against side rivers.

And small protection measures could keep the safety traffics in Bolivia.

These simple prevention measures can not prevent all of road disasters in Bolivia, however, they could be effective and could mitigate the road disasters in Bolivia.

2 RECOMMENDABLE PREVENTION WORKS

2.1 DRAINAGE

The following four types of disasters are common in Bolivia. Most of these disasters are caused inappropriate drainage on the road, slopes or cross channels.

(a) road collapse
(b) slope collapse (surface collapse)
(c) large road collapse
(d) debris flow

(a) Road collapse

Drainage is a critical issue for roads. The infiltration of rainwater and/or groundwater to the subgrade or base course can be a major factor for road surface damage while slope erosion due to running rainwater or slope failure due to seepage water destabilizes the filled up ground of an embankment.

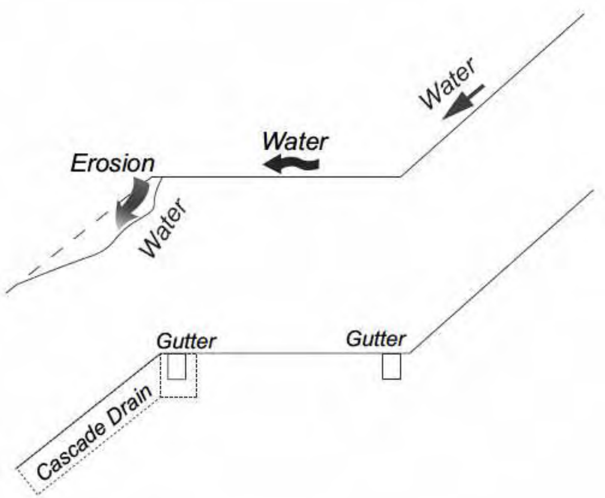


Figure 2.1 Road Shoulder Erosion (above) and Prevention Measures

Main cause : eroded by surface water which flow out from road surface
Prevention Measures : road side drains, transverse drains, and appropriate drainage

	Poor Surface Drainage This erosion might occur because of poor drainage of the road (Route 3)

2 RECOMMENDABLE PREVENTION WORKS

(b) Slope Collapse (Surface Collapse)

Surface drainage facilities on slopes are designed to reduce the amount of water running down the slopes to prevent slope erosion by surface water and to prevent the infiltration of surface water into the slope. The relevant facilities include a drainage ditch at the top of the slope, a vertical drainage ditch and a drainage ditch at the berm.

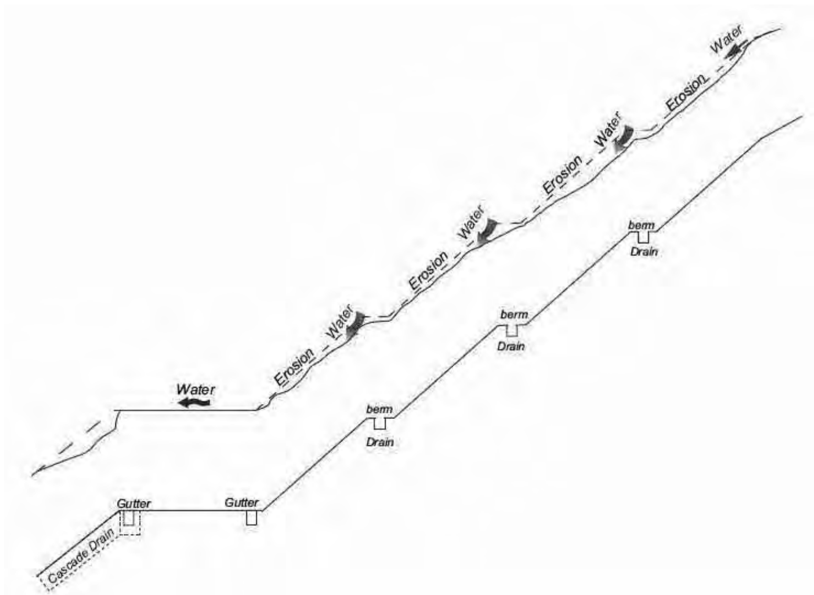


Figure 2.2 Water Erodes Cut Slope (above) and Prevention Measures (below)

Main cause : gully or erosion which caused by surface water (rainfall) developed and cause collapse.

Prevention Measures : Appropriate gradient of cut slope, berm and drain (on berm and cascade)

	Poor Surface Drainage If the proper drainage exists on this slope, surface erosion could be prevented.
	Poor Surface Drainage If the proper drainage exists on this slope, surface erosion could be prevented.
	Poor Surface Drainage This slope has been cut proper angle and has berms on it. However proper drainages do not exist on the bermes.

2 RECOMMENDABLE PREVENTION WORKS

(c) Road dollapse (Large Scale)

The most prominent damage to the national roads running along the river occurs when the bottom of the slopes under the road are eroded by rivers. When the slope bottoms are damaged, slope collapses can progress until the roads.

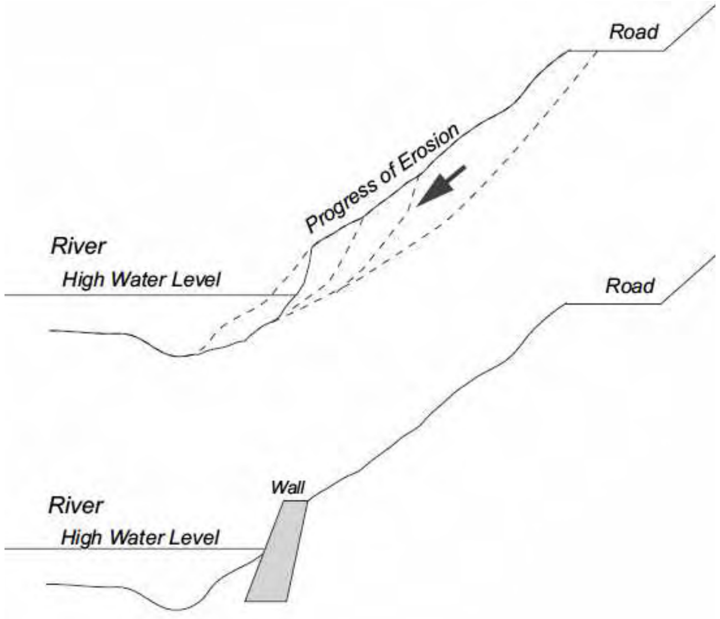
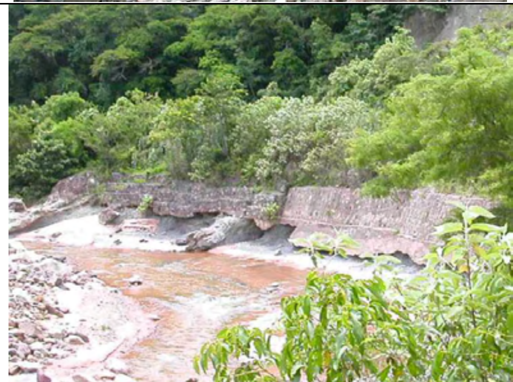


Figure 2.3 Prevention Measures for Road collapse
Main cause : eroded by river , Prevention Measures : river revetment works

	Slopes Eroded by a River River side of the slope were eroded by a river, even though the temporary protection work.
	Base of River Wall Eroded Base of the river wall were eroded
	Good Example Base of the wall was constructed propery

2 RECOMMENDABLE PREVENTION WORKS

(d) Debris Flow

In Bolivia, when a road crosses an originating or passing area of debris flow along a mountain stream susceptible to debris flow, the crossing roads do not provided by cross drainages with a sufficient cross-sectional area or a bridge with sufficient clearance. In the case of a mountain stream where high speed mud flow type debris flow is expected to occur at a mountain stream with a high debris flow frequency, a road crossing in the originating or passing area of debris flow should preferably be provided by a bridge with sufficient debris flow clearance, a debris flow shed or a tunnel.

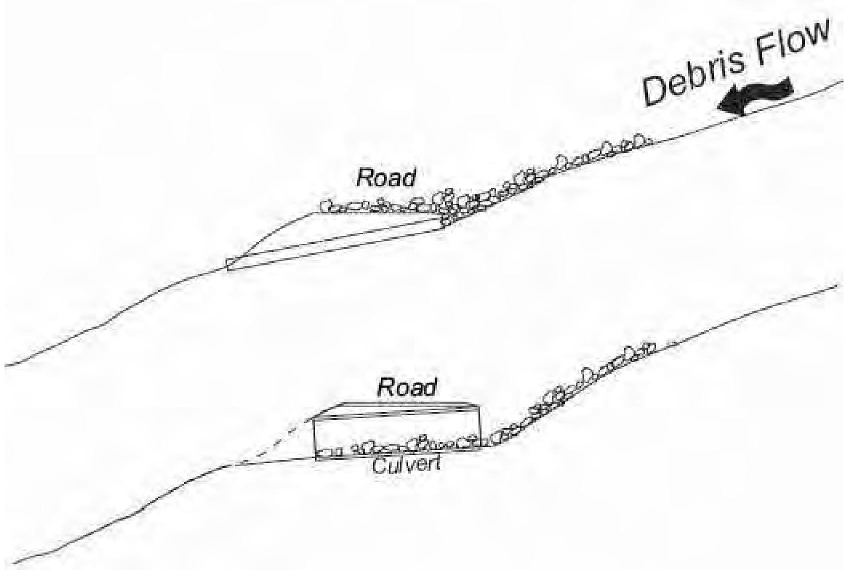


Figure 2.4 Prevention Measures for Debris Flow

Main cause : the cross sections of facilities across the road are not enough
Prevention Measures : enough cross section of facilities across the road

	Small Cross Drainage Because of limited capacity of the cross drainage, debris flew over the road.
	Small Cross Drainage Because of limited capacity of the cross drainage, debris flew over the road.
	Narrow Dranage Because of limited capacity of drainage on hill side of the road, debris flew over the road.

2.2 PROTECTION MEASURES AGAINST ROCK FALL AND SURFACE COLLAPSE

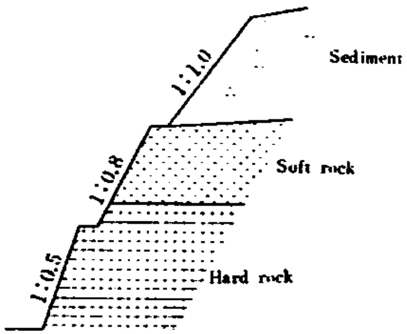
The following measures are not common in Bolivia, but they are effective in terms of protection of vehicles on the roads.

(a) appropriate gradient with berms on cut slopes
(b) shotcrete on natural slopes
(c) rock catch wall

	Steep Slope Cutting with proper angle and berms with drainage are required on this slope.

(a) Appropriate Gradient with Bermas on Cut Slopes

The rock mass and soil layer forming the existing ground can be classified from the viewpoints of the excavation difficulty and slope stability. Empirically established standard slope gradients are then applied to the classified ground, assuming non-treatment, sodding or simple protective work such as netting, to determine the slope gradient and shape corresponding to the soil and rock properties, and cutting height.



Figurer 2.5 Example of Cut Slope Gradient

2 RECOMMENDABLE PREVENTION WORKS

(b) Shotcrete on Natural Slopes

Shotcrete works include mortar spraying and concrete spraying. They are commonly used on steep slopes of highly weathered or heavily jointed rocks on which vegetation is not possible. Shotcrete works are intended to chiefly prevent surface weathering and erosion, and in some cases, to control small-scale rock falls.

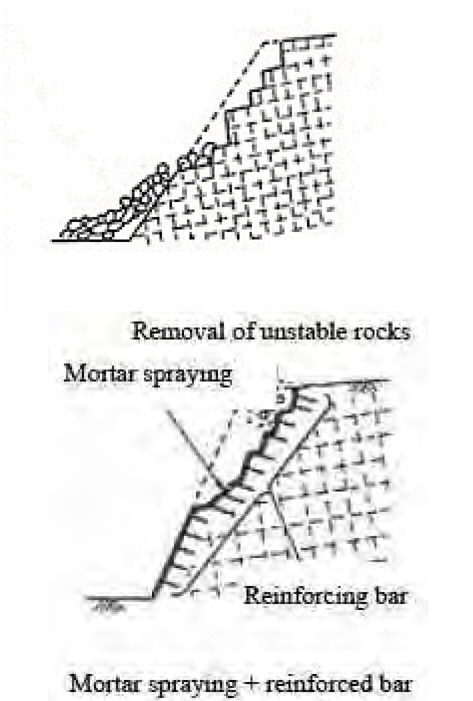


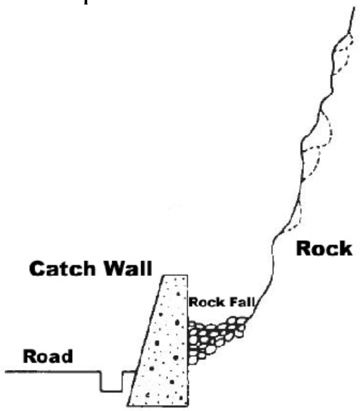
Figure 2.6 Surface Collapse on Rock Slope (upper) and Shotcrete (Mortar Spray) (lower)

	Steep Slope with Rock Face Shotcrete works is useful for the slopes consist of hard rocks like this slope to prevent small rock fall and weathering.
	Steep Slope with Rock Face Shotcrete works is useful for the slopes consist of hard rocks like this slope to prevent small rock fall and weathering.

2 RECOMMENDABLE PREVENTION WORKS

(c) Rock Catch Wall

A rock fall protection retaining wall is used as a protection works to prevent rocks from falling onto a road and is often used at sites where the slope gradient at the back is gentle or sites where there is ample room at the roadside.



gabion wall also is effective

Figure 2.7 Prevention Measure for Rock Fall and Collapse

	too small pocket behind the wall debris and many rocks flew over the wall

	wall without pocket There is no pocket behind the wall, but width of the wall is large enough comparing the height of the slope.
	example of wall with pocket most of falling rocks has been stopped at the wall
	concrete walls with pocket volume of the pockets of the wall are not enough. A lot of debres flew over the wall.

3 DRAINAGE WORKS

3.1 Surface Drainage Facilities

Damage of slope due to water can be roughly divided into the surface erosion due to slope surface water and failures due to the increase in pore water pressure or the decrease in shearing strength of earth forming the slope by scouring and water seepage. Figure 3.1 shows the drainage facilities for roadside slopes.

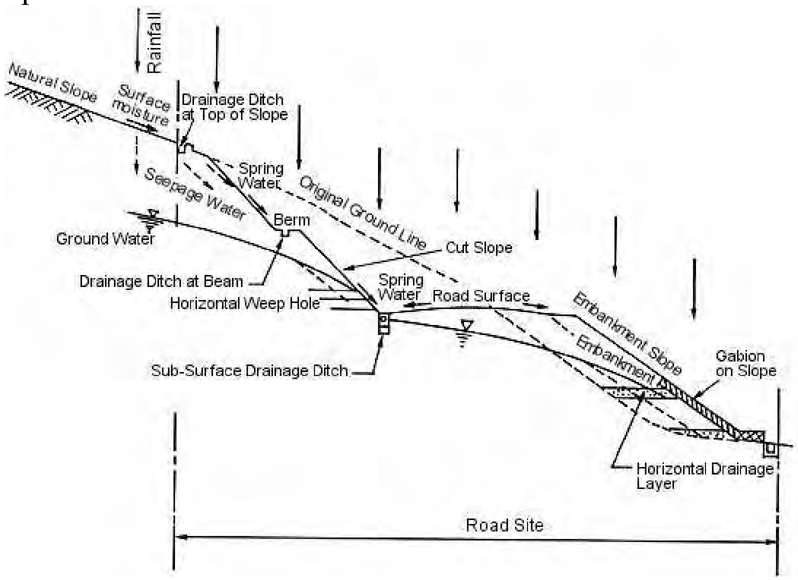


Figure 3.1 Slope of Road and Flow of Water

3.2 Road Drainage

Drainage is a critical issue for roads. The infiltration of rainwater and/or groundwater to the subgrade or base course can be a major factor for pavement damage while slope erosion due to running rainwater or slope failure due to seepage water destabilises the filled up ground of an embankment. There are many types of damage which are directly or indirectly caused by water, including cut slope failure and damage to retaining walls and other structures due to erosion by rainwater.

Even if water does not cause any structural damage to roads, poor drainage from the road surface can cause traffic congestion or slip accidents by standing water and can also inconvenience pedestrians and people living along roads.

There are many road drainage systems as shown in Figure 3.2. Depending on the type of target water, these are basically classified as surface drainage, underground drainage, slope drainage and drainage from the backfill part.

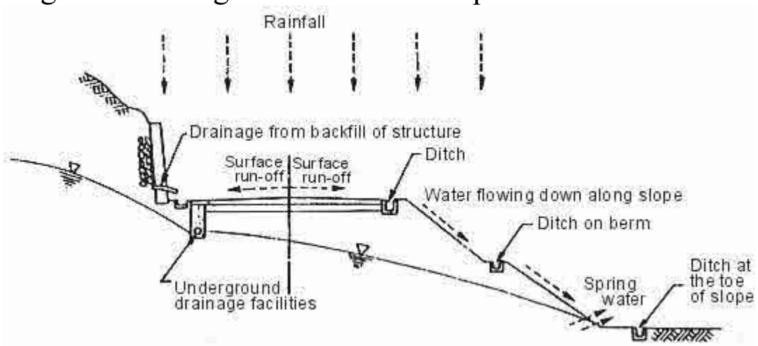


Figure 3.2 Type of Drainage

According to example of failures after completion of embankment in Japan, caution is required shown as following cases.

<u>i) Places where rainwater gathers</u>

In the case of curved section of road where the cross grade of the road becomes a super-elevation, and where the surface run-off on the road concentrates on such places as A and B as shown in Figure 3.3 and runs away outside of road when water volume exceeds the drainage capacity of inlets at A and B thereby sometimes resulting in the erosion of slope surface.

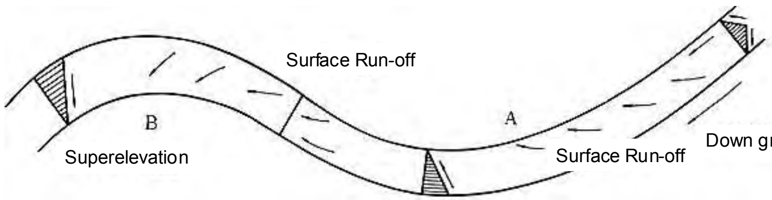


Figure 3.3 Concentration of Water on the Surface of Curved Section

ii) Half-bank and half-cut section

Rainwater falling on to the cut slope side may not be drained to the side ditch at the bottom of the slope and may cross the road surface to run down the embankment slope, causing scouring there.

iii) Places with transverse drainage facilities across the road

A major slope collapse or complete washing away of the embankment may occur due to overflow, in turn caused by an excessive volume of running water beyond the capacity of the drainage facilities across the road (culvert) and/or clogging of the entrance by driftwood and/or sediment.

iv) Embankment at the site of poor subsurface drainage in a mountain area

When the gradient of the ground is relatively steep and the seepage water in the ground is poorly drained, deep failure could occur.

3.3 Subsurface Drainage

The drainage facilities used for subsurface drainage include sub-surface drainage ditches, transverse sub-surface drainage ditches and an impermeable layer. When groundwater inflows from only one side of a road at sloping land, a sub-surface drainage ditch is introduced at the road side near the mountain as shown in Figure 3.4-(b). When the groundwater surface is virtually flat, a sub-surface drainage ditch is introduced on both sides of the road (Figure 3.4-(a)). An additional ditch is required below the median when the road width is very large (Figure 3.4-(c)). It appears that subsurface drainage is designed based on previous work which took place at sites with similar conditions instead of conducting new calculation in many cases. However, examination of the seepage flow based on survey data is necessary for important drainage facilities.

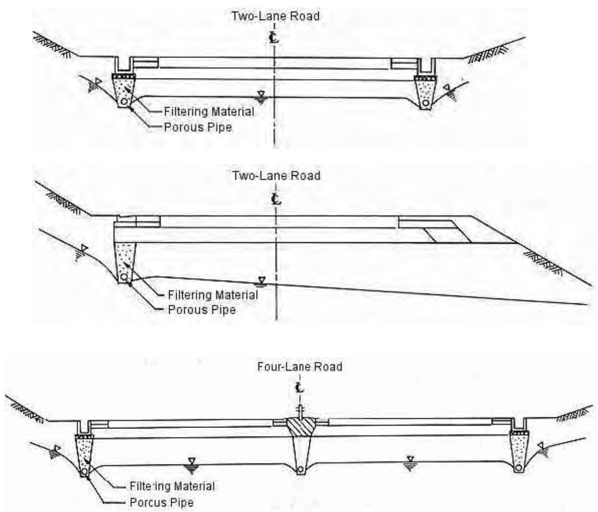


Figure 3.4 Sub-Surface Drain Ditch

3 DRAINAGE WORKS

In areas with particularly abundant groundwater, sub-surface drainage alone is insufficient. A horizontal impermeable layer is, therefore, introduced at the boundary between the subgrade and base course or inside the subgrade or filled up ground to guide the seepage flow into a sub-surface drainage ditch.

In the case where it is necessary to reduce the inflow of groundwater, which is bolstered by much seepage water from a cut slope, to the embankment at half-bank and half-cut section of a road or the longitudinal boundary between the cutting section and banking section of a road, the sub-surface drainage ditches shown in Figure 1.8 should be introduced.

In many cases, a depth of some 1.0 – 2.0 m is required for roadside sub-surface drainage ditches. However, the actual requirement varies depending on the topographical and geological conditions and the groundwater level. In principle, a drainage pipe should be installed at the bottom of a sub-surface drainage ditch (Figure 3.5). Although a porous concrete pipe is often used as the drainage pipe, other types, such as a permeable pipe, may be used to suit the specific site conditions.

The protection of a porous pipe with a good quality filtering material is desirable to prevent the inflow of soil into the pipe. It is essential for the backfilling material for the drainage ditch to be a highly permeable filtering material which is capable of preventing the inflow of minute soil grains from both sides of the ditch.

The requirements for filtering materials are high stability of the grains to resist weathering or dissolution into water and an appropriate particle size distribution curve. The particle size distribution curve required must indicate that the selected filtering material prevents the clogging of a porous pipe by the inflow of the subgrade or base course soil and provide sufficient permeability compared to the subgrade soil. It is, therefore, desirable for filtering materials to satisfy the following conditions.

$$\frac{D_{15}(filtering\ \ material)}{D_{85}(subgrade\ \ soil)} < 5$$

$$\frac{D_{15}(filtering\ \ material)}{D_{15}(subgrade\ \ soil)} > 5$$

$$\frac{D_{85}(filtering\ \ material)}{D(pore\ \ diameter)} > 2$$

Here, D_{15} and D_{85} are the particle sizes corresponding to 15% and 85% of the pass percentage by weight respectively in the grain size distribution curve.

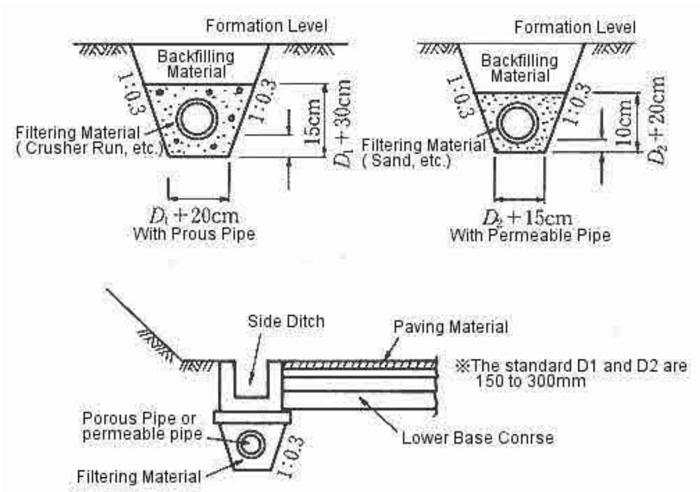


Figure 3.5 Example of Sub-Surface Drainage Ditch

3.4 Cut Slope Drainage Facilities

The drainage facilities introduced to stabilise slopes target either surface water or seepage water as well as groundwater and the main types are listed in Table 3.1.

Surface drainage facilities on a slope are designed to reduce the amount of water running down the slope to prevent slope erosion by surface water and to prevent the infiltration of surface water into the slope. The relevant facilities include a drainage ditch at the top of the slope (Figure 3.6), a vertical drainage ditch and a drainage ditch at the berm. In addition, extra consideration, such as the introduction of a downward gradient at the berm, is necessary to prevent the concentration of surface water on the berm to create another downward flow of surface water on the slope surface below the berm.

The destruction of slope drainage facilities is mainly caused by scouring outside or below the ditch by water which has failed to run through the ditch. Those drainage facilities of which the purpose is to collect surface water must have a sufficient depth into the original ground to easily receive running water. At places where a rapid flow is anticipated, the introduction of certain measures is necessary. These include the use of a lid to prevent water from splashing out and drainage ditch protection using turf or stone pitching to prevent scouring due to splashing water.

In the case where minor spring water is observed at a slope, one good idea is the digging of holes as shown in Figure 3.7 and the insertion of porous piping in these holes. The length of these holes should generally be at least 2 m.

Table 3.1 Types of Slope Drainage

Purpose	Type of Drainage Works	Function
Surface drainage (drainage from road surface, adjacent area and slope surface)	▪ Drainage ditch at the top of a slope ▪ Vertical drainage ditch ▪ Drainage ditch at a berm	▪ Prevention of descending surface water to the slope surface ▪ Guidance of rainwater on the slope surface to a vertical drainage ditch ▪ Guidance of water in a drainage ditch at the top of a slope and in a drainage ditch at a berm to the base of a slope
Subsurface drainage (drainage of seepage water and groundwater from slope surface)	▪ Subsurface drainage ditch ▪ Gabion works ▪ Lateral drainage hole ▪ Vertical drainage hole ▪ Horizontal drainage layer	▪ Drainage of groundwater and seepage water from the slope surface ▪ Reinforcement of the base of a slope along with a subsurface drainage ditch ▪ Drainage of spring water from the slope surface ▪ Drainage of seepage water from the slope surface through a drainage well ▪ Drainage of water from an embankment or seepage water from the ground to an embankment

3 DRAINAGE WORKS

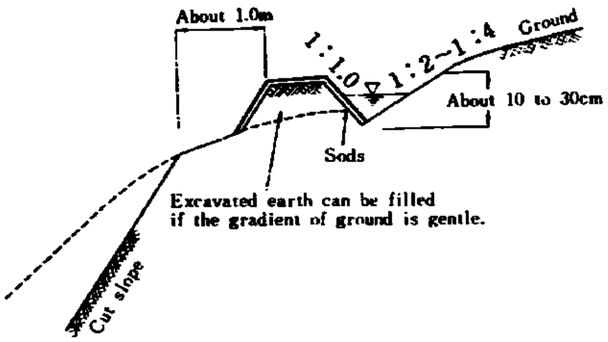


Figure 3.6 Unsupported Gutter

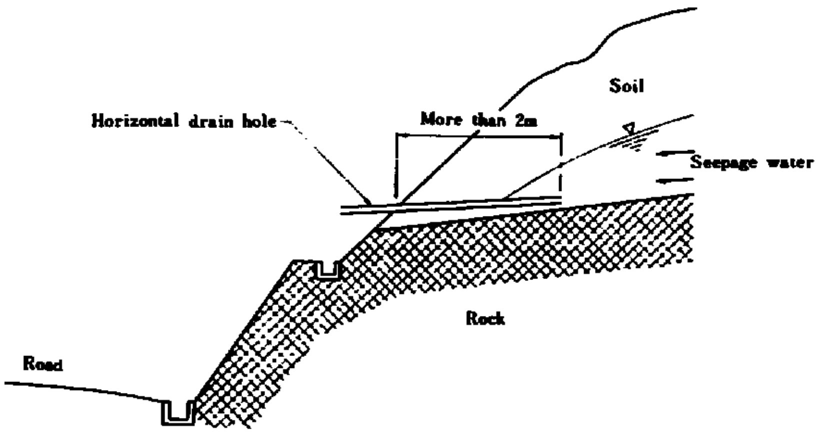


Figure 3.7 Horizontal Weep Holes

4 RIVER REVETMENT WORKS

4.1 DESIGN CONDITION FOR REVETMENT WORKS

Revetment works are constructed for the main purpose of protecting dykes from erosion at the time of flooding and consist of several components as shown in Figure 4.1.

The conditions to be considered for the design of revetment works include such external forces as the fluid force and earth pressure, etc., changes of the topography near the river course due to changes of the riverbed at the time of flooding, abrasion and damage due to the impacts of flowing sand and gravel, seepage of flowing water and rainwater, natural environment, use of river, workability and construction cost (Table 4.1).

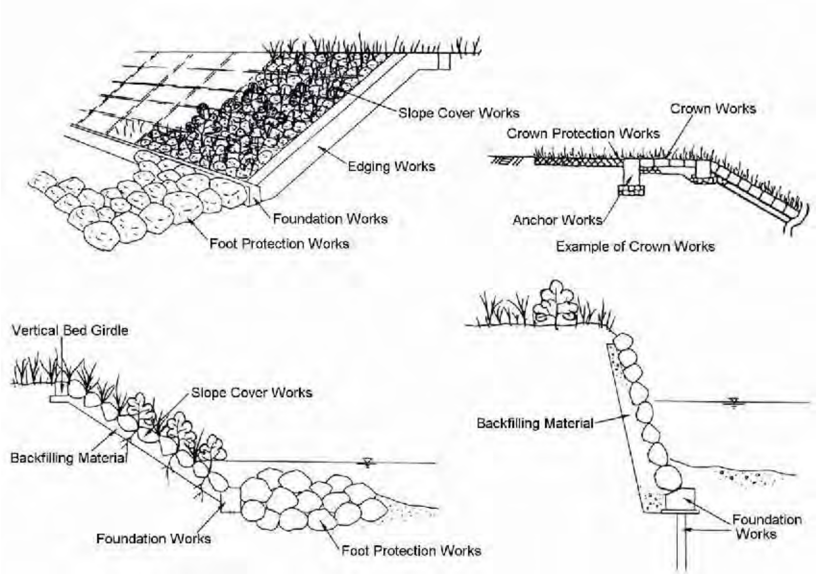


Figure 4.1 Configuration of Revetment Works

Table 4.1 Design Conditions for Revetment

Design of Stability	▪ External forces of running water and soil pressure, etc; riverbed fluctuation at the time of flooding ▪ Abrasion, damage and degradation due to the impacts, etc. of flowing sand and gravel ▪ Suction due to the seepage of running water or rainwater
Design of Functions	▪ Prevention/mitigation of erosion ▪ Preservation/improvement of river environment
Design of Rationality	▪ Construction cost and workability

Prior to the design of revetment works, it is essential to study past examples of damage in order to establish a full understanding of the main cause of damage to each component and the characteristics of damage suffered by different types of structures of revetment works as listed below.

i) Damage by scouring of the riverbed
ii) Damage starting from the apron
iii) Damage to slope protection works
iv) Loss of crown works and crown protection works
v) Suction of backfilling soil

4 RIVER REVETMENT WORKS

4.2 SLOPE PROTECTION WORKS

As slope protection works are the dominant structural part of revetment works, the design must ensure a stable structure against the impacts of flowing water and driftwood, earth pressure and other forces, taking ecology and landscape into consideration. Although weep holes are not generally introduced for bank protection works, they may be required to combat high residual water pressure in some cases.

Suction prevention materials are used to prevent the suction of the backfilling soil through voids of the slope protection works when residual water behind the bank protection works escapes or when high speed flowing water acts on the bank protection works.

4.3 FOUNDATION AND FOOT PROTECTION WORKS

The most prominent damage to revetment works occurs when the foundation and slope protection works are damaged by lifting of the foundations as a result of scouring of the riverbed by a flood. When the foundations are damaged, suction of the backfilling soil could occur, resulting in much wider damage. Because of such a prospect, the decision on the elevation of the foundations (embedment depth) is the most important aspect of foundation design.

The elevation of the foundations must be decided by evaluating the deepest riverbed elevation based on past observation results as well as the relevant survey/research results so that lifting of the foundations of the revetment works does not occur despite scouring by a flood. When the required embedment depth is quite deep, the elevation of the foundations can be raised by introducing foot protection works.

The type of foundations should be spread foundations in the case of good ground. Piles or sheet piles are often used for soft ground. Sheet piles are sometimes used at sites with a high ordinary water level and sites where the likely occurrence of scouring must be taken into consideration.

Foot protection works are used to reduce the velocity of the riverwater flow and also to mitigate rapid scouring by means of directly covering the riverbed. As foot protection works are introduced at sites with a high riverwater velocity, sufficient weight to withstand the fluid force, sufficient volume to prevent scouring of the front part of the foundations of revetment works, a high durability level and a flexible structure to follow changes of the riverbed are required. Typical types of foot protection works are shown in Figure 4.2.

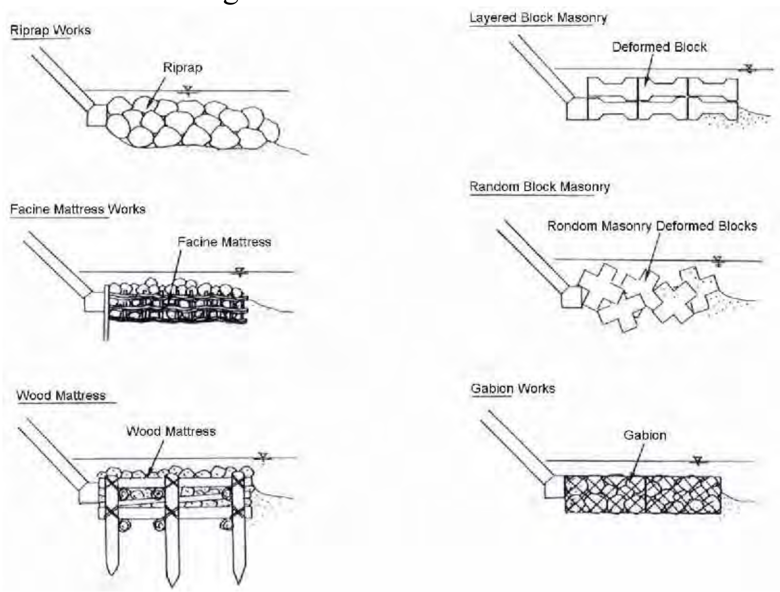


Figure 4.2 Typical Examples of Foot Protection Works

5 PREVENTION WORKS AGAINST DEBRIS FLOW

5.1 SELECTION OF COUNTERMEASURES FOR DEBRIS FLOW

For the selection of a prevention measure for debris flow, the expected type (mud flow type debris flow or gravel type debris flow) and frequency of debris flow are firstly considered. In general, when a road crosses an originating or passing area of debris flow along a mountain stream susceptible to debris flow, crossing should be provided by a culvert with a sufficient cross-sectional area or a bridge with sufficient clearance. In the case of a mountain stream where high speed mud flow type debris flow is expected to occur at the foot of a volcano or a mountain stream with a high debris flow frequency, a road crossing in the originating or passing area of debris flow should preferably be provided by a bridge with sufficient debris flow clearance.

At a site where the gradient of the upstream section of the debris flow sedimentation area is 3 – 10°, the occurrence of debris flow causes considerable fluctuation of the streambed. It is, therefore, desirable to shifted to either the upstream or downstream and a crossing provided by a bridge with sufficient clearance (Figure 5.1).

When the road surface is not much higher than the streambed, the introduction of a ford (low level crossing) should be considered. When the road surface is lower than the streambed, the introduction of a debris flow shed should be considered.

If a change of the route or prevention measures is not deemed to be sufficient, it may be necessary to consider the construction of a dam to control debris flow. In the case of this option, it is necessary to fully coordinate with any sabo (erosion control) projects in the area.

For road sections which include an originating and/or passing area of debris flow, passage control should be introduced

according to need if the level of rainfall which is high enough to cause debris flow is predicted.

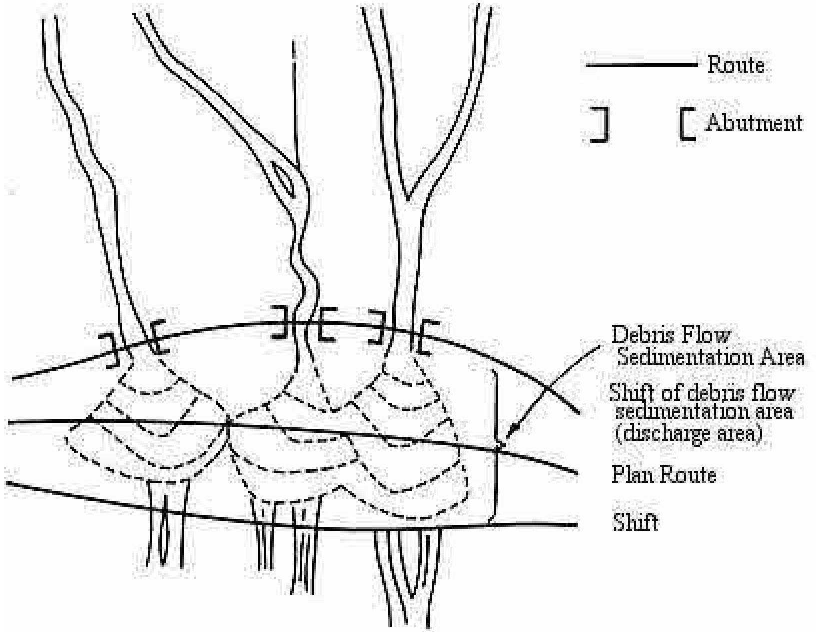


Figure 5.1 Minor Shift in Debris Flow Sedimentation Area

5 PREVENTION WORKS AGAINST DEBRIS FLOW

5.2 CULVERT

The planned cross-section of a culvert should allow passing of the peak debris flow discharge and both the height and horizontal width must exceed double the maximum particle size of the gravel contained in debris flow. The axis of a culvert, including the water channel upstream, should be as straight as possible to coincide with the flow direction of debris flow. Careful attention should be paid to avoiding a smaller cross-sectional area and gradient of the water channel downstream than those at the culvert.

Further attention must also be paid to the possible clogging of the culvert by driftwood. When the outflow of a large quantity of driftwood is anticipated, it is desirable to set up a boom(s) in the upstream (Figure 5.2).

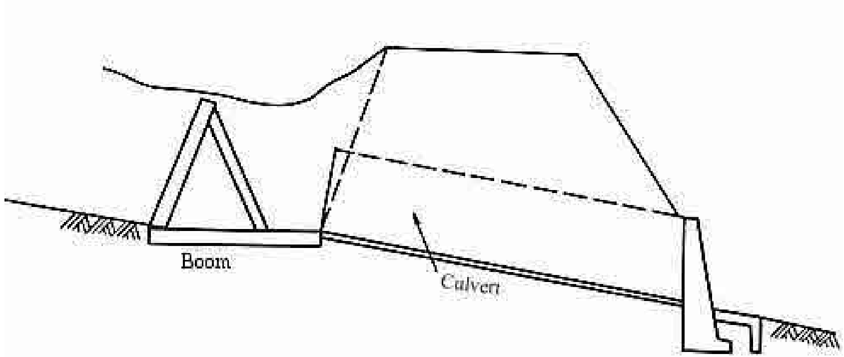


Figure 5.2 Culvert and Boom

5.3 BRIDGE

The planned cross-section of a bridge should allow passing of the peak debris flow discharge. The height of the bridge girders is determined by adding a clearance to the debris flow wave height. It is preferable not to place the bridge piers on the streambed. Special attention must be paid to avoiding narrowing

of the channel width at the bridge site. Even if it is necessary to place piers on the streambed, their positions should avoid the central section of the channel so that the piers are not destroyed by debris flow.

5.4 FORD

When there is little head between the streambed and the road surface in an originating or passing area of debris flow, the road should be given a structure (ford) which cannot be destroyed by the passing of debris flow over the road surface (Figure 5.3).

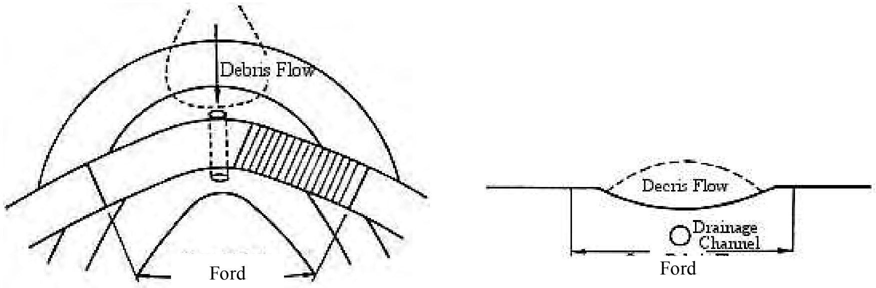


Figure 5.3 Ford

5 PREVENTION WORKS AGAINST DEBRIS FLOW

5.5 DEBRIS FLOW SHED

The structure of a debris flow shed should be similar to that of a rock shed. The longitudinal gradient along the flow direction in the channel should, in principle, be similar to the streambed gradient in the upstream so that there is no soil deposition above the shed. The width of the flow area should be identical to the width of the streambed in the upstream.

The side wall should have a height equivalent to the debris flow wave height plus a margin height and should be designed to guide debris flow from a mountain stream to the shed.

5.6 CAPTURE OF DISCHARGED SOIL BY DAM AND FENCE

One or several dams or fences can be used to catch an entire debris flow or large gravel and driftwood so that only soil and water, which can be drained by road drainage facilities in the downstream, are allowed to flow further downwards. The design sedimentation gradient should be half of the current streambed gradient. Concrete or steel permeable dams and fences are used to reduce the sedimentation volume during ordinary floods. The size of the opening should be less than 1.5 times of the maximum diameter of large gravel to catch debris flow (Figure 5.4).

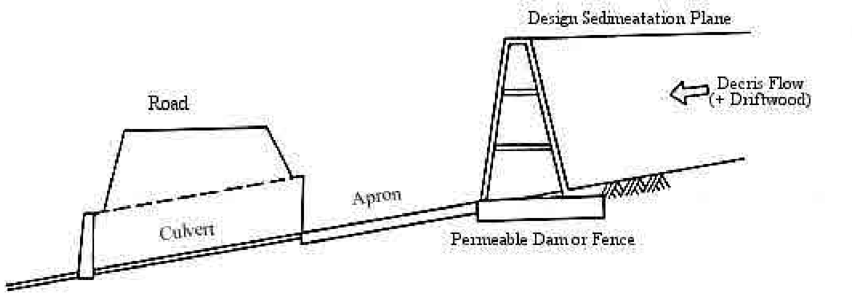


Figure 5.4 Capture of Discharged Soil by Permeable Dam or Fence

5.7 ESTIMATION OF SCALE OF DEBRIS FLOW

For the design of debris flow countermeasures, the volume of sediment, peak discharge, velocity of flow, water level (wave height), unit volume weight and maximum particle size of the anticipated debris flow should be estimated, if necessary, based on survey results for each mountain stream.

1) Peak Discharge

When a debris flow occurs due to destabilization of sediment deposited on the streambed, the peak debris flow discharge can be estimated using the following formula.

$$Q_{sp} = C_* / (C_* - C_d) \cdot Q_p \quad \ldots\ldots\ldots\ldots (1.1)$$

where.

Q_{sp} *: peak discharge of debris flow* (m^3/sec)

Q_p *: peak discharge of water alone* (m^3/sec)

C_* *: volume sediment density of deposited sediment at streambed* ($=1-n$; n *: void ratio)*

C_d *: density of debris flow on the move*

Meanwhile, the equilibrium sediment density of debris flow is given by the following formula.

$$C_d = \frac{\gamma_w \tan\theta}{(\gamma_s - \gamma_w)(\tan\phi - \tan\theta)} \quad \ldots\ldots\ldots\ldots (1.2)$$

Where,

γ_s *: unit volume weight of sediment* (kN/m^3 (tf/m^3))

γ_w *: unit volume weight of water* (kN/m^3 (tf/m^3))

ϕ *: shear resistance angle of deposited sediment at streambed (°)*

θ *: streambed gradient (°)*

5 PREVENTION WORKS AGAINST DEBRIS FLOW

The peak discharge of water only Q_p is calculated by the following formula for the critical rainfall causing a debris flow.

$$Q_p = \frac{1}{3} \cdot f \cdot r_e \cdot A \quad \text{(1.3)}$$

Where,

- f : *peak flow index*
- r_e : *mean rainfall intensity in flood concentration time (mm/hr)*
- A : *catchment area (km²)*

2) Velocity and Highest Water Level (Wave Height)

A Manning type uniform flow formula is used for the velocity of flow based on debris flow observation results in Japan.

$$v = \frac{1}{n} \cdot h^{2/3} (\sin\theta)^{1/2} \quad \text{(1.4)}$$

Where,

- v : *mean velocity of debris flow (m/sec)*
- h : *wave height of debris flow (m)*

The coefficient of roughness n to be used is approximately 0.03 for a fixed bed water channel and 0.1 for a movable bed.

The highest high water level can be calculated using the peak discharge, a velocity-wave height formula and the width of the streambed in the passing area of debris flow.

6 PREVENTION WORKS AGAINST ROCK FALL AND SURFACE COLLAPSE

As natural ground is generally complicated and its properties are not uniform, the rock mass and soil layer forming the existing ground must be classified from the viewpoints of the excavation difficulty and slope stability. Empirically established standard slope gradients are then applied to the classified ground, assuming non-treatment, sodding or simple protective work such as netting, to determine the slope gradient and shape corresponding to the soil and rock properties, and cutting height.

6.1 STANDARD SLOPE GRADIENTS

Natural ground is extremely complicated and not uniform in its properties, and cut slope tend to gradually become unstable An overall judgement should be made by fully taking account of the requirements for stability described later by referring to the standard slope gradients listed in Table 6.1. The table indicates the standard values of the gradient of slopes and have been empirically established based upon protection works such as sodding, netting or non-protection. The gradients referred to here are those for the individual slopes without a berm.

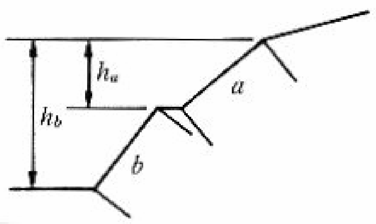
The difference between soft and hard rock referred to herein is judged on the basis of the degree of difficulty of excavation, and is mainly governed by the shearing strength of rock and the amount of rock cracks. The range of standard values shown in Table 1.3 is wider than that of standard values for embankments described later, so that determination of gradient of rock slope on the basis of these standard values alone seems to be difficult because there are so many factors involved.

Table 6.1 Standard Gradients of Cut Slope

Classification of Rock and Soil		Slope Height	Gradient
Hard rock			1:0.3 - 1:0.8
Soft rock			1:0.5 - 1:1.2
Sand	Not dense, and poorly graded		1:1.5 -
Sandy soil	Dense	< 5m	1:0.8 - 1:1.0
		5 - 10m	1:1.0 - 1:1.2
	Not dense	< 5m	1:1.0 - 1:1.2
		5 - 10m	1:1.2 - 1:1.5
Sandy soil mixed with gravel or rock masses	Dense, or well graded	< 10m	1:0.8 - 1:1.0
		10 - 15m	1:1.0 - 1:1.2
	Not dense, or poorly grade	< 10m	1:1.0 - 1:1.2
		10 - 15m	1:1.2 - 1:1.5
Clayey soil		0 - 15m	1:0.8 - 1:1.2
Clayey soil mixed with rock masses or cobble-stone		< 5m	1:1.0 - 1:1.2
		5 - 10m	1:1.2 - 1:1.5

Notes

ha: *cut slope height for slope surface a*
hb: *cut slope height for slope surface b*



-The gradient does not include a berm
-The cut slope height vis-à-vis the gradient means the total cut slope height covering the entire cut slopes above the cut slope in question.

6 PREVENTION WORKS AGAINST ROCK FALL AND SURFACE COLLAPSE

1) The cut slope height and gradient when a single gradient is not opted for because of the soil composition and other reasons are based on the ideas shown below.
2) Silt is to be classified into the Clayey soil.
3) The table is not applicable to soils not included in the above table.
4) In planning of planting for slope, it also takes into consideration the slope gradient suitable for planting.

The standard slope gradients shown in Table 6.1 may not be applicable in certain cases as follows, and more gentler gradient may be applicable with other prevention measures.
1) Cuts in Colluvial Deposits or Heavily Weathered Slopes
2) Cuts in Easily Erodible Ground such as Sandy Soil
3) Cuts in Quickly Weatherable Rocks such as Mudstone, Tuff and Serpentinite
4) Cuts in Rocks with Many Fissures
5) Cuts in Dip Slope Structures with Fissures
6) Cuts where Much Groundwater is Present
7) Large-Scale Slopes

SLOPE SHAPE
As shown in Figure 6.1, the gradient of slope varies depending upon the soils and the rocks, and berms are provided in many cases at transition points where the gradient changes.
A single slope gradient is generally used where the geology and soils are almost the same in the depth direction and in the longitudinal and transverse directions. Where the geology and soils vary considerably and complicatedly, a single gradient of slope suited to the soil of the gentlest gradient may be used even though this is somewhat uneconomical.

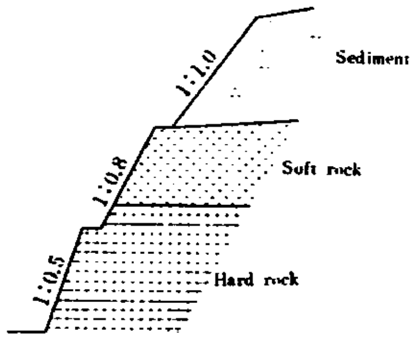


Figure 6.1 Ground Conditions and Shapes of Slopes

BERMS
A berm about 1 to 2m wide will be generally installed in the middle of a cut slope with a large height.

1) Purpose of berm
At the lower portion of a continuous, large slope, the discharge and current speed of the surface water increase, causing the scouring. In this case, the current speed can be reduced by providing a berm in the middle of the slope, or the concentration of the surface water at the lower portion of the slope may be prevented by making a ditch in the berm for draining water outside of the slope. The berm also is used as inspection step or as scaffo1d for repairing.

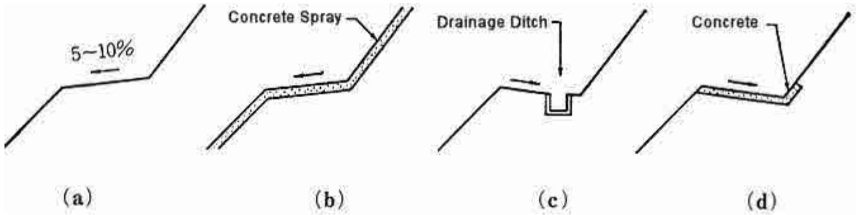


Figure 6.2 Cross- Sectional Gradient of Beam

2) Gradient of berm
Where the drainage facilities are not provided, about 5 to 10% of cross-grade is normally provided for the berm so as to drain water toward the bottom of slope (toe of slope). However, where the slope is considered to be easily flaked off or eroded, the gradient of the berm should be made in the reverse direction so as to drain water toward the ditch of the berm (Figure 6.2 (c)).

3) Location of berms
On the cut slopes, berms about 1 to 2 m wide are normally provided every 5 to 10 m of height depending upon the soil, rock and scale of slope. A wider berm is recommended where the slope is long and large or where the rock fall protection fences are to be installed.
berms should be designed by taking account of difficulty of the inspection and repair, gradient of slope, height of cut, soils of slope, construction cost and other various conditions.

6.2 SHOTCRETE

Among slopes with a rockfall hazard, those made of gravelly soil or weathered soft rock is liable to small-scale rockfall. For these slopes, the installation of a rockfall prevention net to hold down loose stones and/or rockfall prevention fences to prevent rocks from falling on to the road surface along with planting is necessary. In the case of highly cracked soft rock without spring water, mortar concrete spraying is appropriate. It is preferable to use rockfall prevention works for slopes containing an exfoliation-type rockfall on highly cracked slopes of hard rock and the additional use of rockfall protection works is even more desirable if the gradient of these slopes is very steep.

Shotcrete works include mortar spraying and concrete spraying. They are commonly used on steep slopes of highly weathered or heavily jointed rocks on which vegetation is not possible.

1) Purposes

Shotcrete works are intended (a) to chiefly prevent surface weathering and erosion, and in some cases, (b) to control small-scale rock falls.

2) Design Considerations

Shotcrete works do not have extra support against the mass of the unstable slope. For permanent applications, shotcrete should be reinforced to reduce the risk of cracking. Two common methods of reinforcement are welded-wire mesh and steel fibre. The mesh must be closely attached to the rock face and fully encased in shotcrete, with care being taken to eliminate voids within the shotcrete. The standard thickness of shotcrete generally is 8 to 10 centimetres for mortar spraying and 10 to 25 centimetres for concrete spraying.

In principle, drain holes should be provided through the shotcrete to prevent the creation of water pressure behind the face, with the drain holes usually located on 1 to 2-m centres to a depth of about 20 centimetres. The sprayed portion at the top of the slope should be completely embedded into the ground.

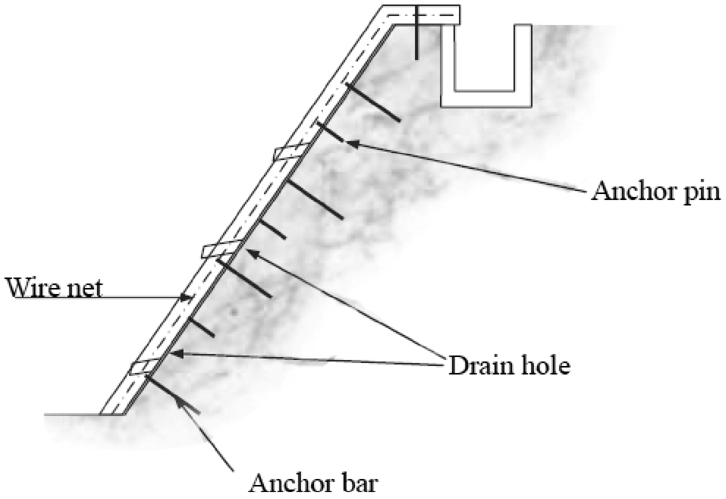


Figure 6.3 Typical Example of Mortar or Concrete Shotcrete

6.3 ROCK CATCH WALL

Rock catch wall is used as a protection works to prevent rocks from falling onto a road and is often used at sites where the slope gradient at the back is gentle or sites where there is ample room at the roadside.

This method is commonly used and is cost-effective when scale of rock fall is likely to be large and difficult to control.

Rock catch wall should be designed to safely absorb the energy of falling rocks with deformation of the wall itself as well as the bearing stratum after calculating the value of such energy.
In addition, it is desirable to establish a pocket at the back of this retaining wall so that fallen rocks as well as fallen soil can be deposited there to a certain extent. Figure 6.4 shows the conceptual arrangement of a catch fill and ditch.

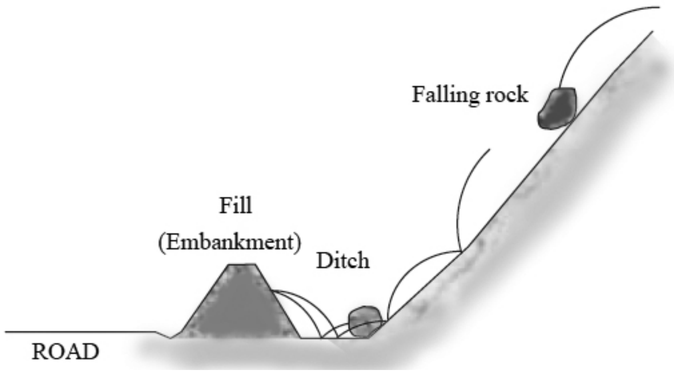


Figure 6.4 Diagrammatic layout of catch fill and ditch

Apart from embankment stability analysis, design considerations are concerned with the shape and dimensions of the catch embankment and ditch in terms of their capacity for arresting and accommodating falling stones. Table 6.1 lists the recommended shapes and dimensions of this structure in relation to slope gradient.

Table 6.1 Recommended Shapes and Dimensions of Catch Ditch

Gradient of slope (Vertical to Horizontal)	Height of slope (m)	Width of ditch (m)	Depth of ditch (m)
Nearly vertical	5 to 10	4	1.0
	10 to 20	5	1.5
	20 <	6	1.5
1:0.25 to 1:0.3	5 to 10	4	1.0
	10 to 20	5	1.5
	20to 30	6	2.0
	30 <	8	2.0
1:0.3 to 1:0.5	5 to 10	4	1.5
	10 to 20	5	2.0
	20 to 30	6	2.0
	30 <	8	2.5
1:0.5 to 1:0.75	0 to 10	4	1.0
	10 to 20	5	1.5
	20 <	5	2.0
1:0.75 to 1:1.0	0 to 10	4	1.0
	10 to 20	4	1.5
	20 <	5	2.0

Note) The width of ditch is the horizontal distance from the toe of slope to the top of embankment.

The energy of falling rocks (E_i) used for design purposes is calculated by the following formula.

$$E_i = (1+\beta)(1-\mu/\tan\theta)W \cdot H \quad \text{.....................} \ (1.5)$$

Where,

E_i : energy of falling rocks (kN・m)

β : coefficient of rotating energy (dimensionless)

μ : equivalent friction coefficient of slope (dimensionless)

(value ranging from 0.05 to 0.35 is used depending on the characteristics of the falling rocks and slope)

θ : slope gradient (°)

W : weight of falling rocks (kN)

H : height of fall (m)

6 PREVENTION WORKS AGAINST ROCK FALL AND SURFACE COLLAPSE

APPENDIX V-1

COUNTERMEASURE WORKS

APPENDIX V-1 COUNTERMESURE WORKS

A1-1 SELECTION OF COUNTERMEASURES

(1) General

In this guide, the countermeasure means the measure works against disasters which have occurred and occur repetitiously. However, the countermeasures introduced here would be useful as the prevention measures. The some countermeasures introduced here are expensive and may not be suitable for Bolivia in terms of the cost.

Suitable prevention measures against slope disaster should be based on a sound understanding of the characteristics of road slope disaster. In undertaking investigations of, or planning to prevent, road slope disasters, extreme care should be paid to the following points.

1) Field investigations should start with a comprehensive evaluation of general conditions (topography, geology, vegetation, etc). Investigators should not be unduly absorbed in detail from the beginning, because initial impressions of such detail may often mislead them from understanding the true condition of the site.
2) Where an existing road is threatened by large-scale collapse, rock fall, mass movement or debris flow that would be too costly or difficult to prevent, safe traffic movement must be maintained by relocating the road or applying traffic control. If a new road needs to be constructed, its alignment should be determined with the least risk of slope instability at the planning stage.
3) Large-scale fills or slope cutting in landslide-prone areas sometimes causes unforeseen disasters. Field reconnaissance and other necessary investigations, therefore, are essential for planning of safe roads. The cost of prevention measures after a slope disaster is often several times the cost of taking proper preventative measures before any failures can occur. In slope protection engineering and stabilization, experience is a highly important factor, and the standard gradient of fill embankments and cut slopes is determined on an empirical basis. Design of slopes must be made not by simply applying the standard gradient, but must also be based on the judgment of experienced engineers who are well acquainted with the geological, topographic, meteorological and other natural conditions of the area.
4) Roads are often constructed initially as simple structures at low cost and then gradually upgraded and enhanced with varied functions through maintenance. The situation, however, changes in due course and the roads have to be constructed as complete a structure as possible to cope with possible disasters and reduce the cost of maintenance.
5) Water is an essential factor in controlling slope stability. Drainage is the most important factor for the safety of both natural and artificial slopes. Drainage water and spring water and drainage of groundwater to achieve the largest possible drawdown of its level are important methods for stabilizing slopes.
6) Unexpected accidents, such as local slope disaster or rock fall, may sometimes occur in the course of slope cutting work. In such cases, the design and the work plan have to be reviewed by well-experienced expert engineers. The original design should not be persisted with.
7) The safety of a road from natural disasters should be maintained and enhanced for constant smooth traffic flow. Periodical field inspection along the route is highly important
8) If any slope or slope-protection work shows signs of deformation such as swelling or sinking, stabilization works should be started immediately to prevent a large disaster from developing.
9) To preserve knowledge and experience, it is recommended to compile, and keep for an appropriate time, the data used for

APPENDIX V-1 COUNTERMESURE WORKS

design, records of field inspection, histories of damage and repair works, records of additional stabilization work, and so on. These records can be very useful for future design, maintenance and general development of methods of preventing and treating road disasters.

Slope disasters occurring along national roads in Bolivia, are classified into the following six types based on their occurrence mechanism and the types of prevention measures that need to be applied.

Slope Collapse (DR) — the term SLOPE COLLAPSE is used to mean small-scale shallow failures marked by sudden and rapid movement without prior indication

Rock Fall (CR) — the term ROCK FALL is reserved for abrupt free-fall movement of materials away from steep slopes, ranging in size from individual rock blocks to small-size failures with volumes of less than 2 m^3. Rock falls of greater size, exceeding 1,000 m^3, are referred to as rock mass failure (see below).

Rock Mass Failure (FR) — the term ROCK MASS FAILURE includes toppling failures and rock slides, as distinct from rock falls, is characterized by failure masses of larger than 2 m3. Its occurrence is closely related to geologic structure.

Mass movement (DL) — the term MASS MOVEMENT is used to describe slow, long-term deformations of slopes underlain by soils or strongly weathered rocks and are usually characterized by recognizable sliding surfaces.

Debris Flow (FE) — the term DEBRIS FLOW is a fast dense flow of rock fragments, and earth and mud mixed with water, usually within a defined stream or river channel.

Road Collapse (FP) — the term ROAD COLLAPSE is used to mean small-scale failure occurring in embankment slopes.

Countermeasures for slope disaster involving roads are classified into seven groups, in consideration of size, purpose, application, and design method, as follows.

- Earth Work
- Surface Cover
- Water Drainage
- Slope Work
- Wall and Resisting Structures
- Protection Work
- Others

A suitable combination of these methods should be implemented after consideration of the mechanism and dimension of slope disasters, the importance of the objects to be protected, and the cost-effectiveness. Generally, countermeasures involve some or all of the following objectives:

1) Preventing erosion and weathering of the slope surface by the use of vegetation, shotcrete and surface drainage;
2) Reducing pore-water pressures in the slope by surface and subsurface drainage;
3) Reducing shear (or destabilising) force by removing the unstable materials from the upper part of the unstable slope;
4) Increasing shear strength (or stabilising force) by adding weight to the toe of an unstable slope or by increasing shear strength along the failure surface;

APPENDIX V-1 COUNTERMESURE WORKS

5) Supporting the unstable area of slope by the construction of retaining walls and similar structures;
6) Reducing or preventing the damages from slope disasters by catch works, etc;
7) Avoiding the unstable area by relocating a route or by the construction of bridge and similar structures.

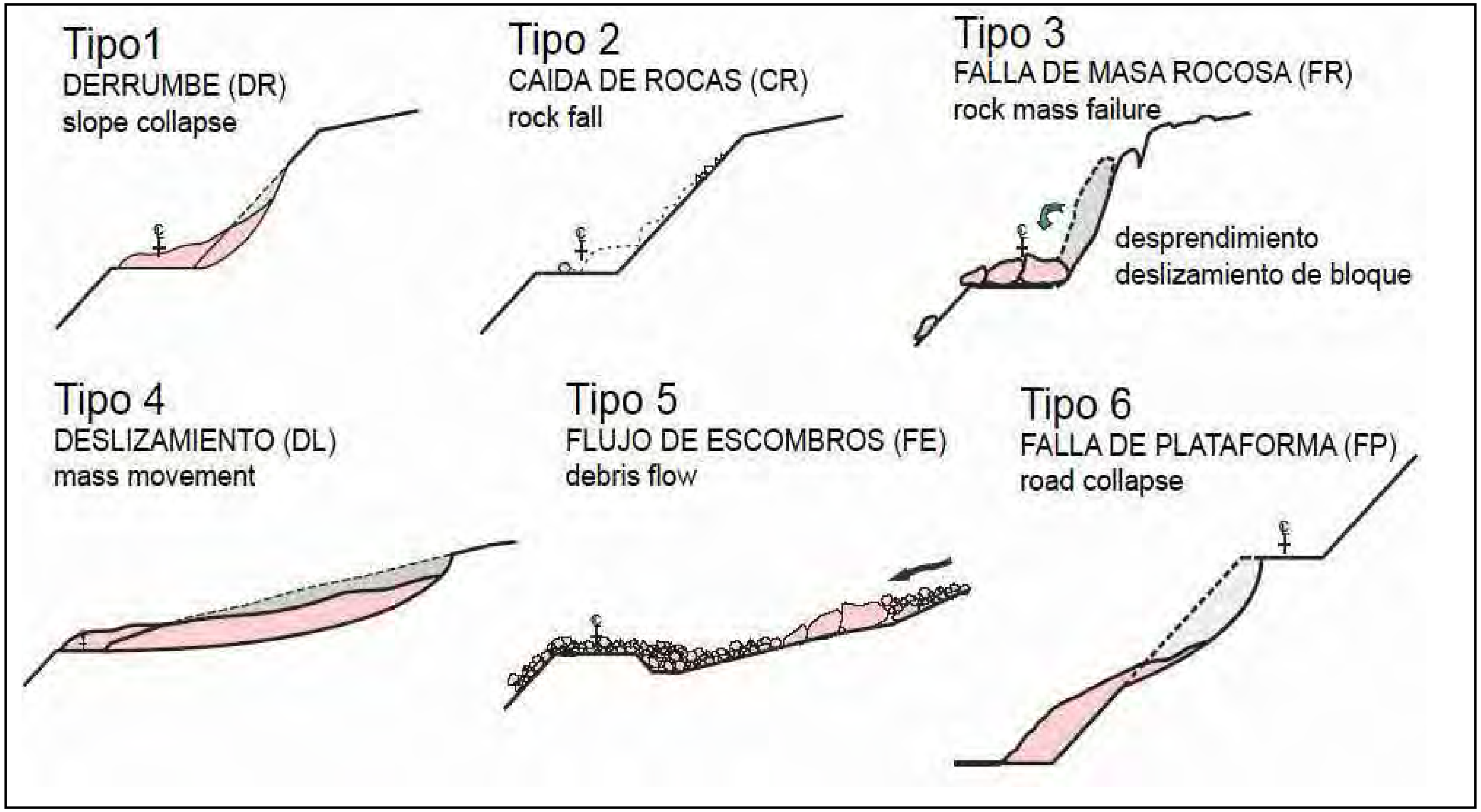


Figure A1-1.1 Disaster Type

APPENDIX V-1 COUNTERMESURE WORKS

Table A1-1.1 Applicability of Countermeasures against Slope disasters

Classification		Measure Works	DR	CR	FR	DL	FE	FP
EARTH WORK	Earth Work	Removal	A	A	A	A	A	-
		Rock cutting	-	A	A	-	-	-
		Rock pre-splitting	-	A	A	-	-	-
		Soil cutting	A	-	-	A	-	-
		Embankment	A	-	-	A	-	A
SURFACE COVER	Vegetation	Hydroseeding	A	L	-	L	-	A
		Vegetation	A	L	-	L	-	A
WATER DRAINAGE	Surface Drainage	Subsoil drainage	L	-	-	A	-	A
		Berm or roadside drain	A	A	A	A	-	A
	Subsurface Drainage	Culverts	-	-	-	L	A	A
		Horizontal drain hole	A	-	L	A	-	A
		Drainage well	-	-	L	A	-	-
		Drainage tunnel	-	-	L	A	-	-
SLOPE WORK	Pitching	Stone pitching	A	L	L	-	-	A
		Block pitching	A	L	L	-	-	A
		Concrete pitching	A	L	L	-	-	A
	Shotcrete	Mortar spraying	A	A	A	-	-	-
		Concrete spraying	A	A	A	-	-	-
	Crib work	Concrete block crib (Precast)	L	L	-	L	-	A
		Cast-in-place concrete crib	A	A	L	L	-	-
		Shotcrete crib	A	A	L	L	-	-
WALL AND RESISTING STRUCTURE	Anchoring	Soil nail	A	L	-	L	-	A
		Rock bolt	-	A	A	-	-	-
		Ground anchor	A	-	A	A	-	A
	Retaining Wall	Gabion wall	A	-	-	L	L	A
		Stone masonry wall	A	-	-	L	-	A
		Gravity type retaining wall	A	-	L	L	-	A
		Concrete block wall	A	-	L	L	-	A
		Supported type retaining wall	A	-	L	L	-	A
	Catch Work	Catch fill	L	A	L	-	-	-
		Catch gabion	A	A	L	-	A	-
		Catch concrete wall	A	A	L	-	A	-
	Pilling	Precast reinforced concrete pile	L	-	-	L	-	L
		Steel pile	L	-	-	A	-	L
		Cast in place reinforced concrete pile	L	-	-	A	-	A
PROTECTION WORK	Protection Work	Rock fall catch net	L	A	L	-	-	-
		Rock fall catch fence	L	A	L	-	-	-
	Rock Shed	Concrete (or Steel) shed	L	A	L	-	L	-
	Sabo (Check) Dam	Concrete (or Stone) dam	-	-	-	-	A	-
		Steel crib dam	-	-	-	-	A	-
		Slit dam	-	-	-	-	A	-
OTHERS	Avoiding Problem Work	Diversion (Shifting)	L	L	A	A	A	L
		Route relocation	L	L	A	A	A	L
		Tunnel, Bridge	L	L	L	A	A	A

Applicability: **A** : Applicable L : Limited case - : Not applicable

DR : Collapse **CR** : Rock Fall **FR** : Rock Mass Failure

DS :Mass movement **FE** : Debris Flow **FP** : Embankment

APPENDIX V-1 COUNTERMESURE WORKS

A1-2 COUNTERMEASURE WORKKS AGAINST SLOPECOLLAPSE (DR)

(1) General

Heavy rainfall and earthquakes frequently cause collapses in natural or cut slopes. Many slopes are stable during normal conditions but become unstable during or after heavy rainfall. To prevent collapse, either the sliding force must be decreased or sufficient resistance to overcome the sliding force must be added by structures. Any prevention plan should be suitable for the field conditions.

An adequate and effective measure for preventing collapse should be selected in consideration of the anticipated causes, shape, mechanism, and scale of collapse, as well as appearance and through discussion. Generally, the following criteria must be used for selection.

1) Wherever possible, cutting work should be selected, especially in the cases of overhanging slopes and highly jointed or weathered rock slopes. In planning cutting work, slope stability and harmony with the surrounding environment should be considered.
2) In principle, surface drainage work should be planned positively. Subsurface drainage works should be adopted if spring water exists during normal time and/or rainfall, or a depression exists near the top of the slope.
3) In most cases, vegetation is low-cost, if it is an available option (gradient and soil). Vegetation should be applied to prevent erosion due to rainfall by growing plants on the face of the slope. Where slopes are unsuited to vegetation, such as jointed or weathered rock slopes, pitching work, shotcrete work, and crib work should be considered.
4) Retaining wall works should be selected if the foot of a slope must be stabilized or if it is to be used as the foundation of other measures.
5) Even though they are costly, anchoring or piling works should be planned if other methods are not expected to control collapses.

Figure A1-2.1 shows a flow chart for the selection of countermeasures to prevent collapse. The success of such collapse countermeasures is influenced greatly by topographical, geological and meteorological conditions. In principle, cutting work, drainage work and vegetation are the preferable choices. Structural methods such as crib work and anchor work are adopted only when soil and gradient conditions are unsuitable for vegetation and slope stability cannot be secured by cutting and/or drainage works alone.

APPENDIX V-1 COUNTERMESURE WORKS

Table A1-2.1 Classification of Countermeasures against Collapse

CLASSIFICATION		TYPE OF WORK
EARTH WORK	Earth Work	Cutting
		Embankment
VEGETATION	Vegetation	Hydroseeding
		Re-Vegetation
DRAINAGE	Surface Drainage	Subsoil Drainage Hole
		Drain Ditch and Cascade
	Subsurface Drainage	Culverts
		Horizontal Drain Hole
SLOPE WORK	Pitching Work	Stone Pitching
	Shotcrete Work	Shotcrete (mortar)
		Shotcrete (concrete)
	Crib Work	Cribwork (Precast)
ANCHORING	Anchoring	Soil Nail
		Rock Bolt
		Ground Anchor
WALL AND RESISTING STRUCTURES	Retaining Wall	Gabion Wall
		Stone Pitching Wall
		Concrete Block Wall
		Retaining Wall (Supported Type)
	Catch Work	Catch Concrete Wall
PILING WORK	Piling Work	Steel Pipe Pile
		H Steel Pile

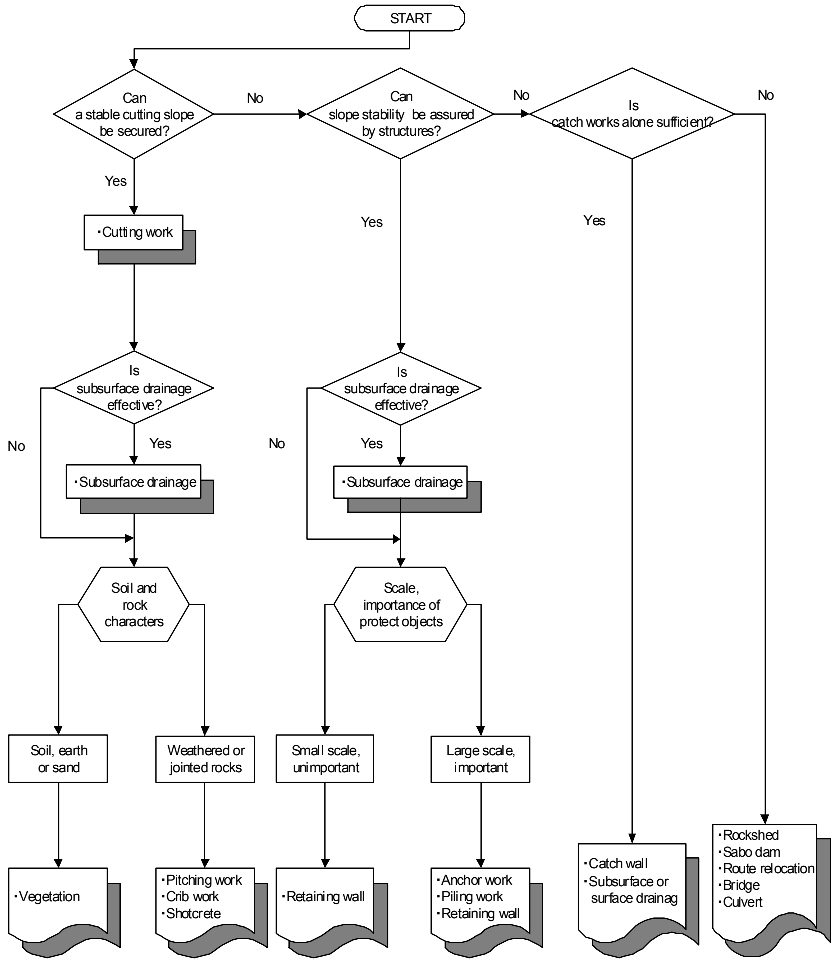


Figure A1-2.1 Flow chart for selection of countermeasures for collapse

(2) Earth Works

1) Purpose

Cutting work is applied to remove unstable soil and rock and to reduce the load, and hence shear force, at the head of an unstable or potentially unstable slope.

2) Design Considerations

The gradient and vertical height of the cutting slope should be determined on the basis of the geological conditions, etc. The gradient should be between 1V to 0.3H and 1V to1.5H depending on subsurface conditions and characteristics. Berms 1 to 4 m wide should be created at intervals of 5 to 10 m in the vertical direction. Careful investigation of the stability of the back slope should be conducted prior to cutting. This suggestion is shown the only normal gradient, therefore applied gradient should be approved by the engineer.

(3) Vegetation

Achieving a dense vegetation cover can prevent the formation of unstable debris on bare hillsides such as failure surfaces and bare slopes. The method is one of the most important countermeasures, and is normally not expensive.

1) Purposes

The main objectives of vegetation are (a) to reduce surface erosion caused by running water and rainfall; (b) to reduce infiltration from rainfall; and (c) to bind subsurface soil with root systems.

2) Design Considerations

Generally, unstable and bare slopes are unsuitable for vegetation, and surface failures are frequent. There is little possibility for successful planting on such a surface without supporting measures. Therefore, vegetation of the slope should in principle be carried out when the slope is stabilized by installation of other countermeasures.

In selecting the type of vegetation to establish, careful attention should be paid to the rainfall, plant growth conditions, and the soil properties of the slope, as well as the timing of construction and the area of protection works. Table A1-2.2 gives general selection criteria for the various vegetation establishment methods in Japan. The table may be applicable in Bolivia,

however it is recommended to revise this table based on the Bolivian condition of vegetation.

Additionally, brushwood and net are usually set on relatively steep slopes to stabilize the surface soil. The slope gradient for vegetation is usually less than 60 degrees.

APPENDIX V-1 COUNTERMESURE WORKS

Table A1-2.2 General selection criteria for vegetation

Soil and rock properties		Methods
Sand		Hydroseeding, seed mud spraying, vegetation mat
Sandy soil, gravel soil, sandy soil containing rocks and cobble stones	Loose	Sodding, hydroseeding, seed mud spraying, vegetation mat, vegetation net.
	Dense	Hydroseeding, seed mud spraying, vegetation bag, vegetation hole, vegetation block, vegetation packet.
Clay, clayey soil, clay or clayey soil containing rocks and cobble stones	Soft	Sodding, hydroseeding, seed mud spraying, vegetation mat.
	Stiff	Hydroseeding, seed mud spraying,, vegetation bag, vegetation hole, vegetation block, vegetation packet
Soft rock		Hydroseeding, seed mud spraying, vegetation bag, vegetation hole.

Closed turfing: This is the conventional method in which sod is directly laid on the face of the slope and is suited to erodable soils. In laying sod, it should tightly contact the face of the slope, which may require it to be hit, and be laid flat without joins to prevent scouring.

Hydroseeding: Mixture of seed, fertilizer, fibres and water, is sprayed over the face of the slope with a pump. This method is suited to relatively gentler slopes or low land.

Seed mud spraying: Similar to hydroseeding, a mud-like mixture of seed, fertilizer, soil and water is sprayed over the face of slope with gum. Therefore, this method is suited to relatively steep slopes and high places. Asphalt emulsion is sprayed to perform the film curing.

Vegetation mat: Fibrous mat containing seed and fertilizer is used to cover the face of slope. This method offers the protection effects of the mats until the establishment of vegetation.

Vegetation bag: Vegetation bags, made of polyethylene net or cotton net filled with seeds and vermiculite, are usually placed on horizontal ditches on the slope.

Vegetation hole: Mixture of seeds, fertilizer and soil is placed in holes that are made in advance in the face of the slope.

Vegetation block: Turf, seeds and mud, are usually placed linearly along contour lines.

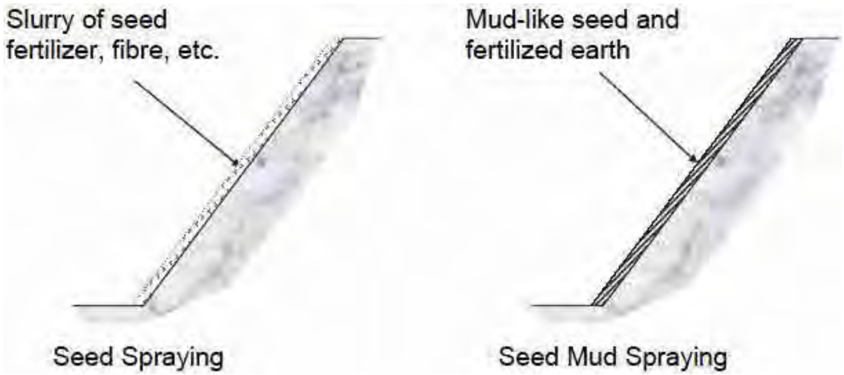


Figure A1-2.2 Typical vegetation works

APPENDIX V-1 COUNTERMESURE WORKS

(4) Pitching

Pitching works include concrete pitching, stone pitching and block pitching. They are commonly used on slopes gentler than 1:1.0. When slope gradient is greater than 1:1.0, these methods are respectively concrete retaining wall, stone masonry retaining wall and block masonry retaining wall.

1) Purposes

Pitching works are applied chiefly to prevent surface weathering, scouring, stripping and erosion and, in some cases, to prevent small-scale collapses.

2) Design Considerations

Stone pitching and block pitching are used for non-cohesive sediments, mudstone and collapsible clayey soils with a slope gradient less than 1:1.0. On the other hand, concrete pitching is employed for jointed rock slope with a possibility of weathering and stripping. For large and/or steep rock slopes, it is desirable to reinforce the concrete with reinforcing bars or wire mesh.

Similar to shotcrete works, drain holes of about 5 centimetres in diameter should be provided every 2 to 4 m^2, regardless of the presence of spring water or seepage water.

Adequate methods should be selected by referring to Table A1-2.3.

Table A1-2.3 Selection of pitching work

Type of pitching	Pitching thickness (cm)	Gradient (V : H)	Height (m)	Geological condition
Stone	25 to 35	1:1.0 to 1:1.5	≤5.0	Sediments, talus, cone mudstone and collapsible clayey soils.
	≤25	1:1.5 to 1:1.8	–	
Block	35	1:1.0 to 1:1.5	≤3.0	
	≤12	1:1.5 to 1:1.8	–	
Concrete	≥20	less than 1:0.5	–	Bedrock with numerous joints and with a possibility of weathering and stripping.
Reinforced Concrete	≥20	Over 1:0.5	–	

Note : This table is only a preliminary suggestion. Further detailed analysis should be carried out by an engineer.

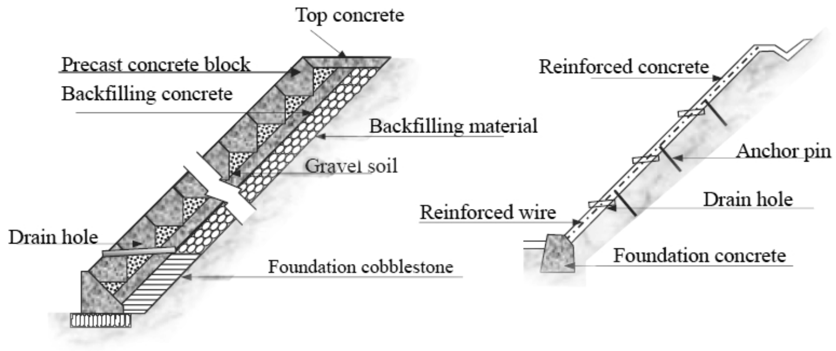


Figure A1-2.3 Examples of pitching works

(5) Crib Works

Crib works include concrete block crib, shotcrete crib and cast-in-place concrete crib works. They are commonly used on steep slopes of highly weathered or heavily jointed rocks accompanied with abundant springs, especially where spalls cannot be fixed with shotcrete works.

1) Purposes

Similar to shotcrete works, crib works are applied (a) to chiefly prevent surface weathering, scouring and erosion and, in some cases, (b) to control both rock fall and small-scale slope disaster.

2) Design Considerations

Concrete block crib work offers little or no resisting force against the driving force of the unstable slopes, while shotcrete crib and cast-in-place concrete crib works have some resistance, depending on the size and space of the cribs.

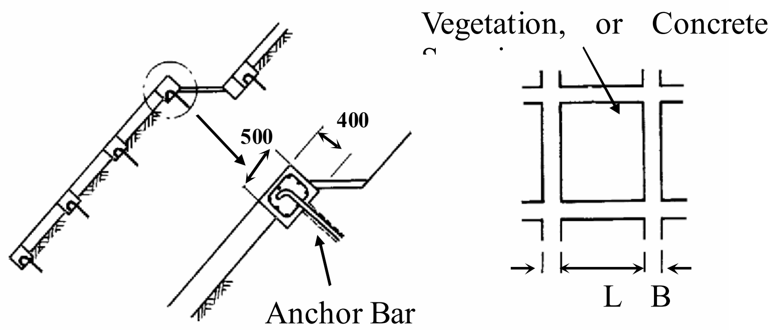
Concrete block crib work is used for slopes with gradients less than 1:1.0 (V:H) and when vegetation is suited to the slopes. Shotcrete crib and cast-in-place concrete crib works are used when the long-term stability of the slope is questionable, or when concrete block crib work is likely to collapse on a large slope or on a slope of weathered and jointed rocks with spring water.

The crib (or frame) usually ranges in size from 200 × 200 millimetres to 800 × 800 millimetres at an interval of 2 to 5 metres. The spaces inside the cribs are filled and protected by stone pitching, mortar spraying, or vegetation, depending on the slope conditions (gradient, spring water, etc). Each intersection of the crib should be anchored with stakes or pre-stressed steel, depending on the conditions of the slope. Table A1-2.4 shows the applications of crib works. Figure A1-2.4 presents details of cast-in-place concrete crib work.

Table A1-2.4 Application of Crib Works

Type of crib works	Gradient (V:H)	Vertical height (m)	Condition of slope
Concrete block	< 1:0.8	≤ 5 m	Flat slope with spring water and large slope of gradient below 1:0.8
Concrete	> 1:0.8	≤ 10 m	Slope of gradient above 1:0.8 and weathered or jointed rocks with spring water lacking in long-term stability
Cast-in-place concrete	> 1:0.8	≤ 10 m	

Note1: This table is only preliminary suggestion. Further detailed analysis and analysis should be carried out by an engineer.



Note: B=300 to 600 mm, L=B×(5

Figure A1-2.4 Details of Cast-in-place Concrete Crib Work

(6) Soil Nails

Soil nails are slender steel rods inserted into the soil layer to provide composite action. There are two different types of soil nails, referred to as flexible nails and stiff nails. Flexible nails are generally drilled and grouted and oriented to mobilize tension. Stiff nailing involves directly insertion without the addition of grout, and nails are oriented to produce both shear and bending in the nail as well as a degree of tension.

1) Purposes

Soil nails are applied to (a) Stabilize small-scale unstable soil slopes and in some cases, (b) to reinforce embankments.

2) Design considerations

The existing design procedures fall into two categories: those that consider shear bending and tension and those that take into account only tension as a restraining action. The latter is recommended as a safer design. The stability analysis of a soil nailed slope is similar to that of an anchored slope (by referring to anchor design).

In planning soil nailing, attention should be paid to soil properties. Soil nail is effective in firm dense low-plasticity soils and is not practical in loose sandy soils and soft clay. Commonly, one nail is used for each 1 to 6 m^2 of soil surface area combined with shotcrete facing (mortar or concrete). Standard nails vary in diameter between 12 mm and 32 mm, and are less than 5 m in length. Figure A1-2.5 shows a diagrammatic example of soil nail.

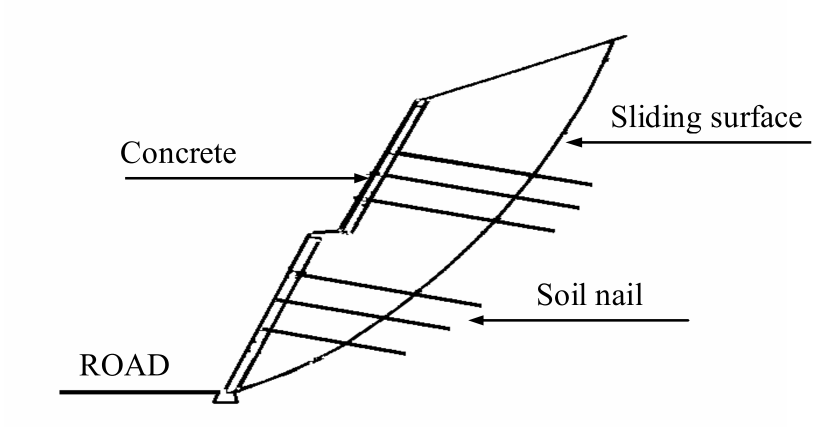


Figure A1-2.5 An example of soil nail

(7) Retaining wall

Frequently, retaining walls are used to support cuttings or embankment and provide restraint against instability. Retaining walls can be generally classified into 5 types in terms of their design criteria, applications, etc. These types are gabion wall, stone masonry wall, crib retaining wall, gravity type retaining wall and supported type retaining wall.

1) Purposes

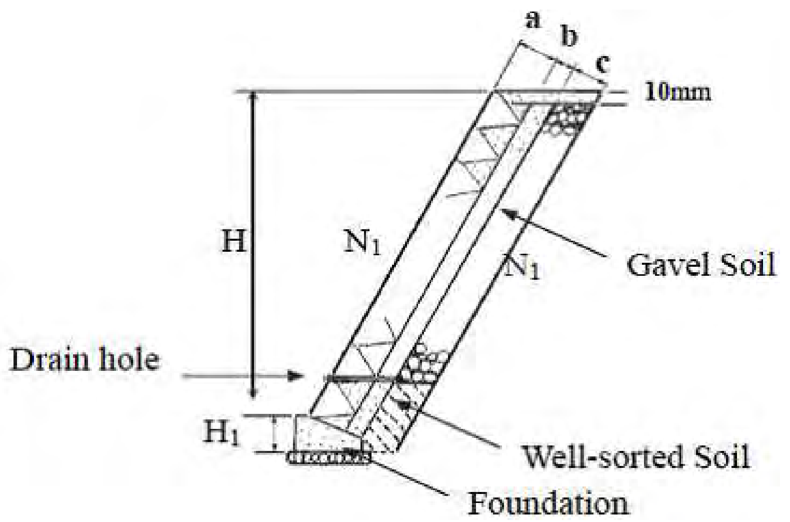
Retaining walls are used (a) to prevent small-scale shallow collapse and toe collapse of large-scale slope disasters, and (b) as a foundation of other slope protection works such as crib works. Typically where the toe of slope has collapsed or the collapse is likely to enlarge upward along the slope, retaining walls are strongly recommended.

2) Design Considerations

In principle, retaining wall design includes analyses of (a) sliding, (b) overturning, typically about the toe of walls, (c) the bearing capacity of the foundation ground, and (d) overall stability. For (d), stability analyses must not only consider the stability of the wall itself, but also the overall slope of which the wall may be a part. Moreover, loads acting on the retaining wall are normally considered to be (e) deadweight, (f) surcharge and (g) earth pressure, for design purposes.

Gabion walls are fabricated from gabion baskets that are typically 1 meter × 1 meter in cross-section and 2 meters to 5 meters in length. The rock fill for gabion is generally graded from a maximum of 250 millimetres diameter down to 100 millimetres size. The gabion structures are flexible and the nature of the gabion filling provides for good drainage conditions in the vicinity of the wall. Therefore, filtration protection between the gabion and the wall backfill should be considered.

Stone (or concrete block) masonry retaining walls must be wet masonry. Wall stability, especially the critical height, should be examined (refer to the depth from the wall top edge to the critical point that protrudes 1/3 outside of the force line centre). In general, the foundation must be embedded at least 30 centimetres. One drain hole (generally φ75 mm) must be installed every 2 to 3 m^2, usually in a zigzag pattern, because of the poor drainage of the walls (Figure A1-2.6).



Note: *Wall thickness* ***a=35 cm***
Backfilling concrete thickness ***b=0 to 20 cm***
Top edge thickness of backfilling ***c=30 to 40 cm***
*Wall height H=**1.5 to 7.0 m***
Foundation height $\boldsymbol{H_1}$***=25 to 40 cm***
Gradient $\boldsymbol{N_1}$***=1V: 0.3H to 1V: 0.5H***

Figure A1-2.6 Detail of stone or concrete block retaining wall

APPENDIX V-1 COUNTERMESURE WORKS

Table A1-2.5 Standard Dimension of Stone or Concrete Block Retaining Wall

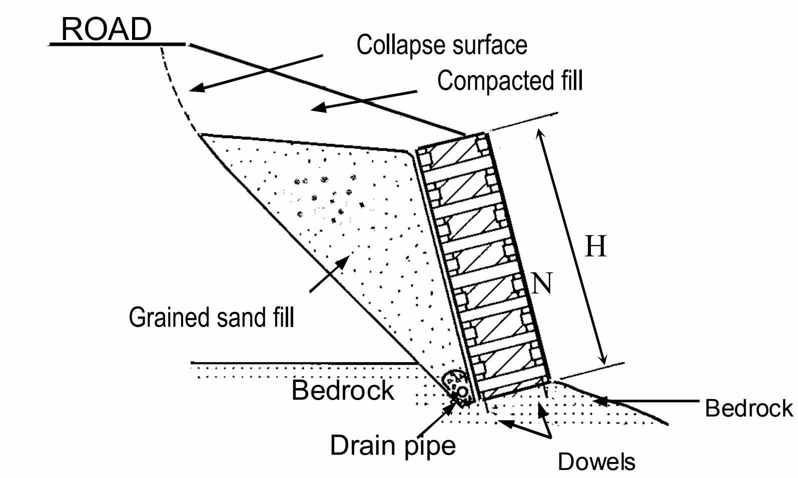
Height (m)	Gradient	Wall thickness (cm)	Backfilling thickness (cm)	Backfilling concrete thickness (cm)
H	**N1**	**a**	**c**	**b**
0 to 1.5	1:0.3	35	30 to 40	0 to 10
1.5 to 3.0	1:0.3	35	30 to 40	10
3.0 to 5.0	1:0.4	35	30 to 40	15
5.0 to 7.0	1:0.5	35	30 to 40	20

Note1: This table is only preliminary suggestion. Further detailed analysis and analysis should be carried out by an engineer.

Crib retaining walls, usually being fabricated from precast reinforced concrete elements, are flexible due to the segmental nature of the elements, and are thus somewhat resistant to differential settlement and deformation. The stability is calculated for the whole structure as well as for several horizontal sections. Slope stability calculations should include the potential failure surface above the toe of the wall. Earth pressure calculations of the walls are similar to that of gravity type retaining wall (Figure A1-2.7).

For gravity type and supported type retaining walls, design considerations mainly involve the above-mentioned analyses of four states, sliding, overturning, bearing capacity and overall stability. In determining the dimension of the wall, it is desirable that the width, B, of the bottom slab is about 0.5 to 0.7 times the height of the retaining wall and that the thickness of the member at the top is greater than 35 cm.

Table A1-2.6 gives some recommended design constants.



*Note: Wall H=**1.5 to 6.0 m**, Gradient **1V: 0.3H to 1V: 0.5H.***

Figure A1-2.7 Detail of crib retaining wall

Table A1-2.6 Recommended Design Constants

Materials	Unit weight (kN/m^3)
Reinforced concrete	25
Concrete	23.5
Gravel, gravely soil, sand	20
Sandy soil	19
Silt, cohesive soil	18

APPENDIX V-1 COUNTERMESURE WORKS

A1-3 COUNTERMEASURE WORKS AGAINST ROCK FALL (CR)

(1) Classification of countermeasures

Countermeasures against rock fall can be classified into works to prevent rock fall and works to provide protection from rock fall. Rock fall prevention concentrates on the rock fall source, such as removal and crib work. Rock fall protection does not attempt to prevent rock fall, but aims at preventing the relevant objects from being damaged by rock fall. There are a variety of methods within the two major approaches shown in Table A1-3.1.

Table A1-3.1 Classification of Countermeasures against Rock Fall

CLASSIFICATION			TYPE OF WORK
Rock Fall Prevention Work	Earth Work	Earth Work	Removal Cutting
	Vegetatioin	Vegetation	Hydroseeding Re-Vegetation
	Water Drainage	Surface Drainage	Subsoil Drainage Hole Drain Ditch and Cascade
	Slope Work	Pitching Work Shotcrete Work Crib Work	Stone Pitching Shotcrete (mortar) Shotcrete (concrete) Cribwork
	Anchoring	Anchoring	Rock Bolt
Rock Fall Protection Work	Wall and Resisting Structures	Catch Work	Catch Fill Catch Gabion Catch Concrete Wall
	Protection Work	Protection Work	Rock Fall Catch Net Rock Fall Catch Fence
		Rock Shed	Rock Shed

(2) Criteria for selection of countermeasures

To select adequate and effective measures for preventing damage from rock fall, one should consider topographical and geological conditions, vegetation, rock fall history, and the effects of the countermeasure by predicting the size and height of any potential rock fall. Figure A1-3.1 shows a procedure for selecting countermeasures against rock fall. The following criteria must be used for selection.

1) If there is a possibility of rock fall, the first priority should be to remove the source of the rock fall. When this is difficult to implement, other methods should be adopted.
2) In selecting a countermeasure, it is essential to consider not only the conditions of the slope and rock fall, but also the road structure, traffic conditions and ground conditions
3) It may be necessary to perform a combination of works because the functions of any single type of countermeasures may be inadequate.

APPENDIX V-1 COUNTERMESURE WORKS

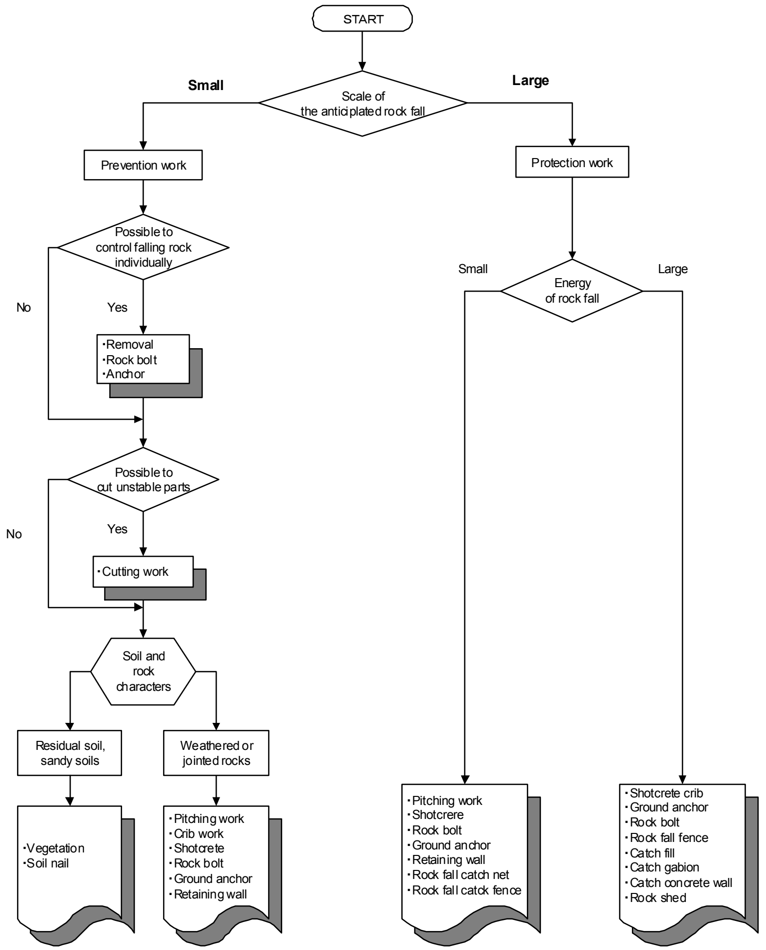


Figure A1-3.1 Flow chart for selection of countermeasures for rock fall

(3) Removal

This method involves the removal of small-scale unstable rock overhangs by trimming and removal of loose individual rock debris by hand scaling. In planning removal, it is important to take account of the rock character. For example, when rocks are highly degradable and strongly susceptible to weathering and jointing, such as shale, the removal of loose rock from the surface will start a new cycle of weathering and instability.

(4) Rock fall catch net

Rock fall catch nets consist of net and wire rope and include two major types, covering type and pocket type.

1) Purposes

Rock fall catch nets are used to cover slopes that show a potential for rock fall in order to protect road traffic from rock fall damage.

2) Design considerations

The design of rock fall catch nets is generally based on the following steps.

a. Determine the size (diameter) of vertical ropes required to support the combined catch net deadweight and weight of falling rocks corresponding to each span of vertical rope.
b. Determine the diameter of horizontal ropes needed to support its own deadweight and the weight of falling rocks assuming that rocks are uniformly distributed in spans in the direction of the slope.
c. To calculate the strength and stability of anchors needed on the assumption that all of the load on the ropes will be transferred to the anchors.

APPENDIX V-1 COUNTERMESURE WORKS

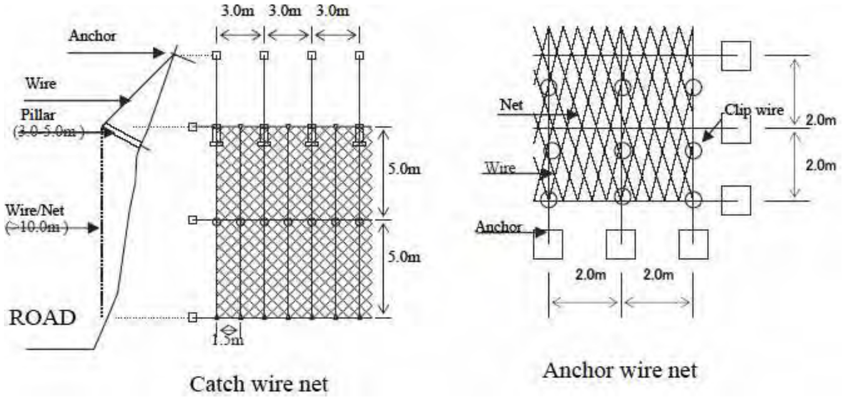


Figure A1-3.2 Example of rock fall catch net

(5) Rock fall catch fence

A rock fall prevention fence consists of a fence made of net and wire rope attached to steel pipe or H-section posts. This type of fence has the capacity to absorb the energy of falling rocks.

1) Purposes

Rock fall catch fences are also designed to protect road traffic from rock fall damage, but differ from rock fall catch nets in that they are installed near the road.

2) Design considerations

The design of a rock fall catch fence mainly involves the energy of falling rock and the absorbable energy by the fence and generally involves the following steps.

a. Determine the yield tension T_y corresponding to the diameter of the wire ropes.
b. Find the force R acting on the post from T_y of the wire ropes. The use of two wire ropes is assumed to be capable of resisting the force of falling rocks.
c. Find the force F_y required for forming a plastic hinge at the bottom of intermediate post.
d. Compare forces R and F_y and calculate the energy that can be absorbed by the fence.

A1-4 COUNTERMEASURE WORKS AGAINST ROCK MASS FAILURE (FR)

(1) Selection of Countermeasures

Because of the larger scale of this kind of failure, it may be more economical to relocate a road route than to prevent rock mass failures. For this reason, route relocation or bridge diversion is the most preferable method of protecting rock mass failure.

Table A1-4.1 gives the general countermeasures for rock mass failures and their classification. In the case of preventing small rock mass failures, countermeasures such as cutting, shotcrete, cast-in-place concrete crib, rock bolt and ground anchor may be the most cost-effective.

Table A1-4.1 Classification of Countermeasures against Rock Mass Failure

CLASSIFICATION		TYPE OF WORK
Earth Work	Earth Work	Removal Rock Cutting
Water Drainage	Subsurface Drainage	Horizontal Drain Hole
Slope Work	Shotcrete Work	Shotcrete (mortar) Shotcrete (concrete)
	Crib Work	Crib Work
Anchoring	Anchoring	Rock Bolt Ground Anchor
Wall and Resisting Structures	Catch Work	Catch Fill Catch Concrete Wall
Protection Work	Protection Work	Rock Fall Catch Net Rock Fall Catch Fence
	Rock Shed	Rock Shed
Others	Avoiding Problem Work	Tunnel, Bridge Route Relocation

(2) Criteria for selection of countermeasures

Rock mass failures generally result from geological structures and mostly occur at a relatively large scale. In selecting and designing the countermeasures, the following points should be considered. Figure A1-4.1 shows a flowchart for selection of countermeasures for rock mass failure.

1) A comprehensive investigation should be conducted on the causes and scale of rock mass failure as well as the regional geological features. Where rock mass failure is closely related to large geological structures such as faults and folds, route relocation is the most cost-effective method because of the large scale involved. Where a rock mass failure threat is a result of geological composition such as limestone and metamorphic rock prone to weathering and jointing, framework and shotcrete work may, in some cases, be cost-effective.
2) Suitable countermeasures should be selected after examination of the economics, effectiveness, maintenance requirements, environment and appearance. In most cases, maintenance is costly, so conservative countermeasures that will require little on-going maintenance should be selected. For example, engineering practice shows that to stabilise strongly jointed rock slopes, mortar shotcrete costs less than cast-in-place concrete crib, but is costly to maintain.
3) If removal work cannot be done by some conditions, protection works should be done to prevent occurrence of rock mass failure. Figure A1-4.5 shows the examples of countermeasures in these cases.

APPENDIX V-1 COUNTERMESURE WORKS

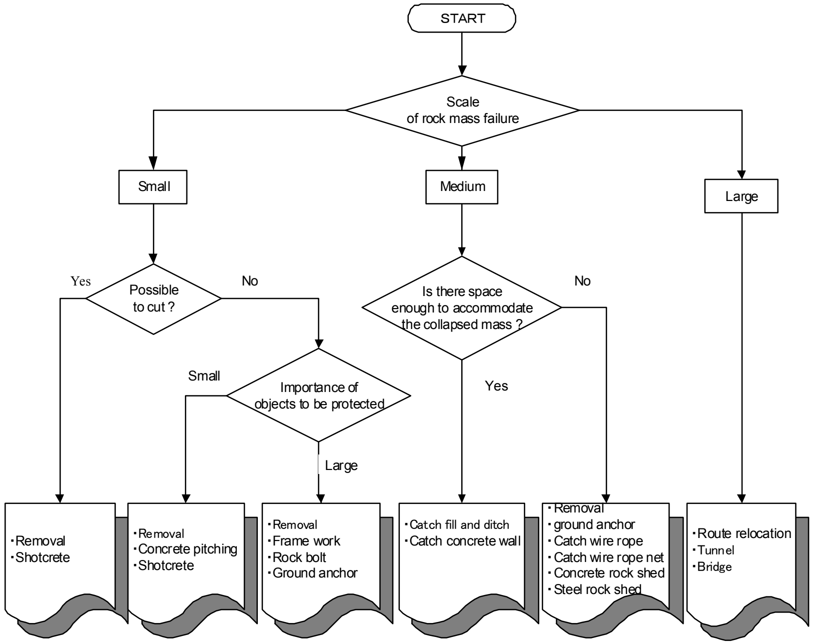


Figure A1-4.1 Flow chart for selection of countermeasures for rock mass failure

(3) Cutting work

The purposes and design considerations for stabilising work are similar to those for collapse. Cutting work is particularly effective to safeguard against rock mass failure and an example is shown in Figure A1-4.2.

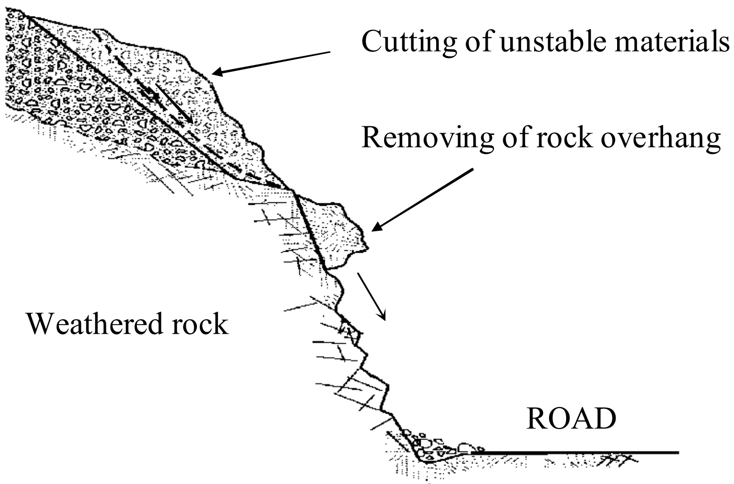


Figure A1-4.2 An example of cutting work to treat rock mass failure

APPENDIX V-1 COUNTERMESURE WORKS

(4) Ground anchor and rock bolt

Where the objects to be protected are very important, and other works cannot provide enough safety, ground anchors and rock bolts should be considered.

Rock bolting is a shallow-fitting method, while ground anchoring is inserted deep into the slope. Therefore, rock bolts are applied to stabilize the slope face by exerting a force that compresses the joints and prevents loosening of the rock mass. Ground anchoring is applied to prevent a rockslide by tension force, generally in association with frame works. Figure A1-4.3 shows diagrammatically how unstable rock above a road can be stabilised by ground anchor and rock bolt.

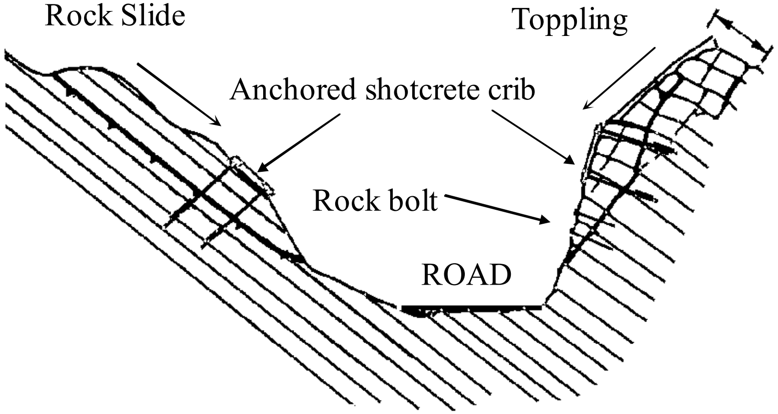


Figure A1-4.3 Stabilization of unstable rock slope above a road

(5) Rock shed

Rock sheds are reinforced concrete or steel structures covering a road and can be subdivided into four types from a structural view; portal (gate) type, retaining wall type, arch type and pocket type (Figure A1-4.4).

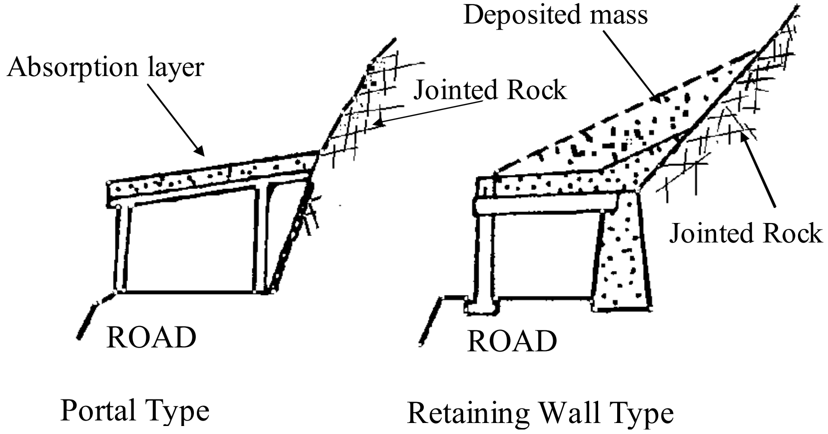


Figure A1-4.4 Types of rock sheds

1) Purposes

This method is applied to reduce road disasters due to rock fall or rock mass failure by absorbing the impact force of a falling rock mass or shifting the movement direction of rock mass failure and rock fall.

2) Design considerations

The most important design consideration should be given to the calculation of the impact force of the falling mass. Generally, rock sheds are designed after converting the impact force into a static force according to the allowable stresses design method. For the purposes of simplifying calculation, the area on which the impact load is calculated is assumed to be rectangular rather than circular.

APPENDIX V-1 COUNTERMESURE WORKS

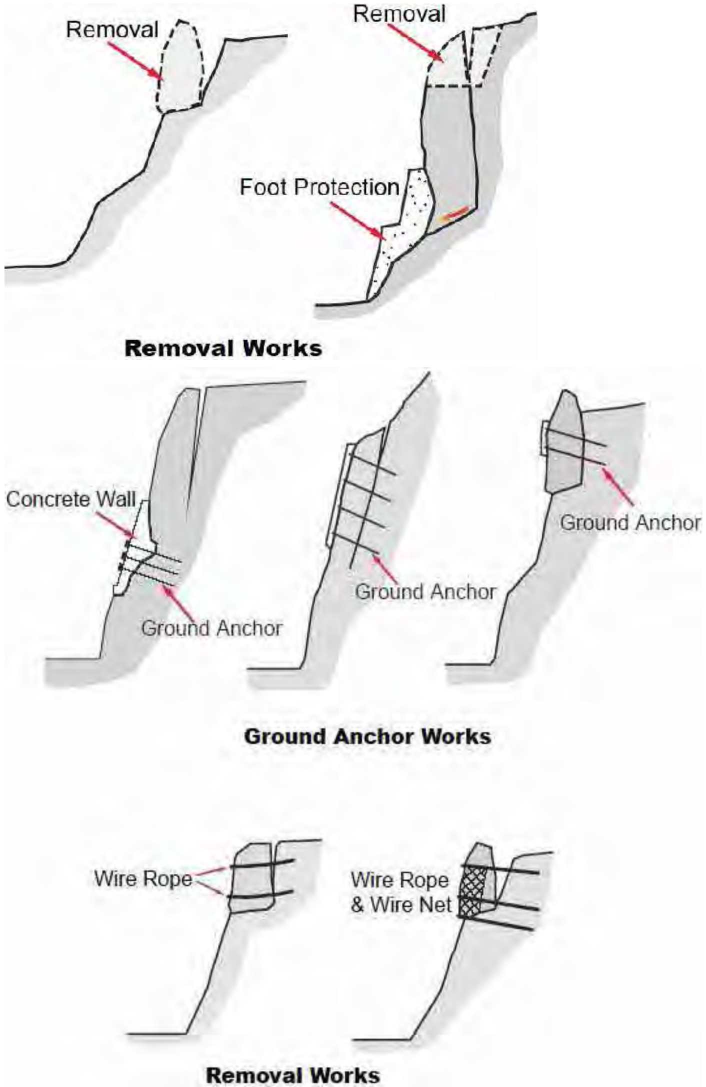


Figure A1-4.5 Examples of countermeasures against rock mass failure

APPENDIX V-1 COUNTERMESURE WORKS

A1-5 COUNTERMEASURE WORKS AGAINST MASS MOVEMENT (DL)

(1) General

Mass movements frequently occur because of particular conditions relating to topography, geology, meteorology, and land utilization. Mass movement disasters can be either direct or indirect disasters. Direct disasters are the damage caused by mass movements to public facilities, houses and cultivated lands, whilst indirect disasters are damage such as the blocking of rivers and secondary collapses as a result of a mass movement. Therefore, the main purpose of a mass movement countermeasure plan is to prevent or reduce disasters due to mass movements.

(2) Classification of Countermeasures

Countermeasures for mass movements belong to one of two broad categories, (A) control works; and (B) restraint works. Control works involve modifications to natural conditions such as, topography, geology, ground water, or other conditions that indirectly control portions of the entire mass movement movement. Restraint methods rely directly on the construction of structural elements. When the potential mass movement is large-scale, it may be more cost-effective to relocate the route or bridge.

Table A1-5.1 Classification of Countermeasures against Mass movements

CLASSIFICATION			TYPE OF WORK
CONTROL WORK	Earth Work	Earth Work	Cutting Embankment
	Vegetation	Vegetation	Hydroseeding Re-Vegetation
	Water Drainage	Surface Drainage	Drain Ditch and Cascade Subsoil Drainage Hole
		Subsurface Drainage	Horizontal Drain Hole Drainage Well Drainage Tunnel
RESTRAINT WORK	Slope Work	Crib Work	Crib Work
	Anchoring	Anchoring	Rock Bolt Ground Anchor
	Wall and Resisting Structures	Retaining Wall	Gabion Wall Retaining Wall
	Piling Work	Piling Work	Steel Pipe Pile Shaft Work
Others		Avoiding Problem Work	Diversion (shifting) Route Relocation Bridge, Tunnel

APPENDIX V-1 COUNTERMESURE WORKS

(3) Criteria for selection of countermeasures

Figure A1-5.1 shows a flowchart for selection of countermeasures against mass movements. Adequate works should be selected in consideration of the following points.

The works selected should address the mechanism(s) of the mass movement, the relationship between precipitation, groundwater and mass movement movement, geological, topographical and soil properties, the scale and type of mass movement and its likely movement velocity.

Control works should be regarded as the main method of mass movement control, while restraint works should be adopted for the stabilization of small mass movements to directly protect public facilities, houses, etc.

Where mass movement movement is closely related to rainfall, surface drainage work should be immediately performed to minimise the infiltration of rainwater.

When a mass movement continues to move, control works should be performed first; restraint works can then be done after reduction or arresting mass movement movement by the control works.

An adequate combination of various works is cost-effective and should be selected.

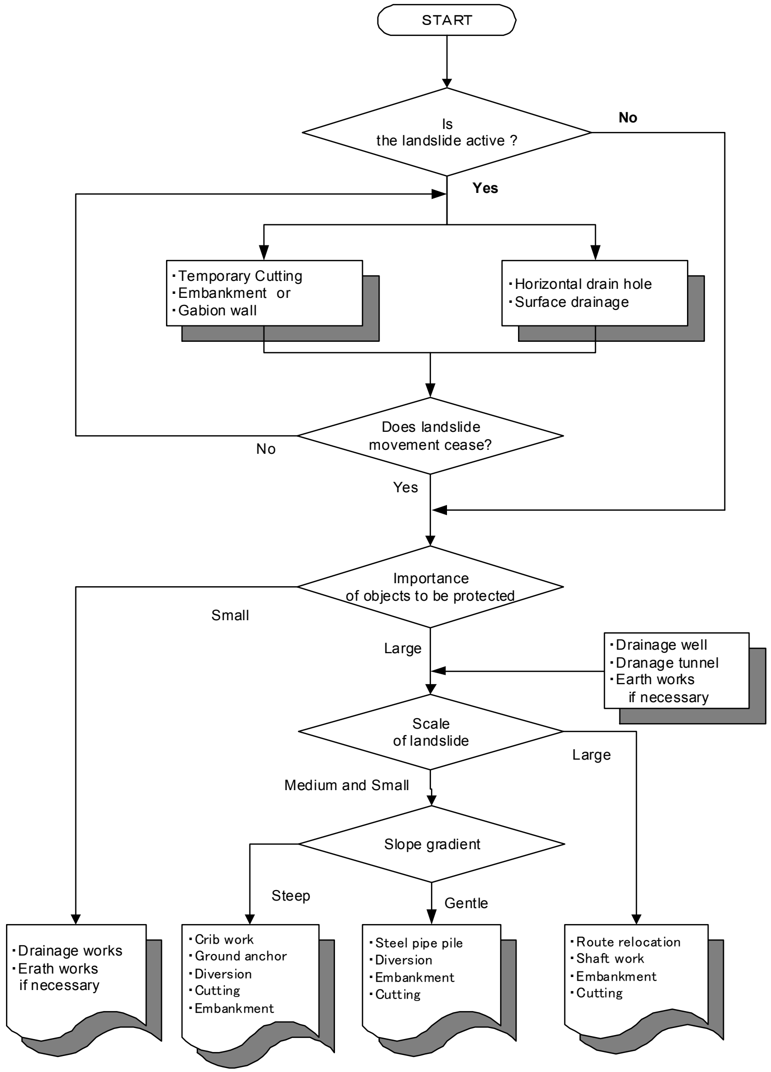


Figure A1-5.1 Flow chart for selection of countermeasures for mass movement

APPENDIX V-1 COUNTERMESURE WORKS

(4) Surface Drainage

Surface drainage can be classified into catch drain, berm drain and toe drain. In most cases, surface water should be prevented from infiltrating the mass movement area to avoid any hydraulic thrusts. Especially where mass movements are closely related to short-term rainfall, the work should be immediately performed regardless of the results of stability analyses. U-shaped gutter, centrifugal reinforced concrete or corrugated pipe may be used to construct the drainage ditch.

1) Purposes

Surface drainage control includes works for drainage collection and drainage channels.

2) Design Considerations

Drainage collection works are designed to collect surface flow by installing corrugated half pipes or lined U-ditches along the slopes, which are then connected to a drainage channel. The drainage channel works are designed to remove the collected water out of the mass movement zone as quickly as possible, and are constructed from the same materials as the drainage collection works. The surface drainage control works are often combined with subsurface control works.

The drainage ditch beds should, in principle, be covered. Collecting boxes should be installed at the confluence with tributaries, curves and points of change in gradient.Where conducted in the active area of a mass movement, drainage ditches should have the required strength and be easy to repair. Bed consolidation should be planned every 20 to 30 m to prevent the drain ditch from sliding.The shoulders and cut slope faces of the ditches must be protected with vegetation, boulder covers, and so on.

(5) Horizontal Drain Hole

Groundwater can generally be divided into two types, shallow and deep. Shallow groundwater, 0 to 5 meters below the ground surface, is due mainly to rainfall received in the short-term. Shallow groundwater frequently causes a shallow failure or the toe failure of a large-scale unstable slope. In such cases, culverts and horizontal drain holes are effective. Deep groundwater is related to rainfall received over the longer term and should be drained by installation of drainage wells or tunnels with horizontal drain holes. The following is a brief presentation of considerations for horizontal drain holes and drainage wells as these are the most effective methods of stabilizing mass movements.

1) Purposes

Horizontal drain holes are used to drain both shallow and deep groundwater to stabilize the mass movement by decreasing the pore water pressure that is responsible for activating the slip surface. It is useful as a temporary countermeasure to decrease the moving speed of a mass movement.

If necessary, the designed reduction in the groundwater level may be determined through stability calculations, aiming at achieving the following values in the case of the standard-scale failure with a failure depth of 20 metres.

Horizontal drain	1 to 3 meters
Drainage well	3 to 5 meters
Drainage tunnel	5 to 8 meters

2) Design Considerations

Horizontal drain holes are constructed for the drainage of shallow groundwater and deep groundwater. If topography prevents the groundwater from being drained on a gentle gradient, then drainage wells or tunnels with horizontal drain holes should achieve drainage.

Horizontal drain holes, usually 20 to 50 meters in length, should be excavated at a gradient of 5 to 10 degrees with a diameter of 50 to 100 millimetres and should be designed to traverse aquifers. A typical location of horizontal drain holes is shown in Figure A1-5.2.

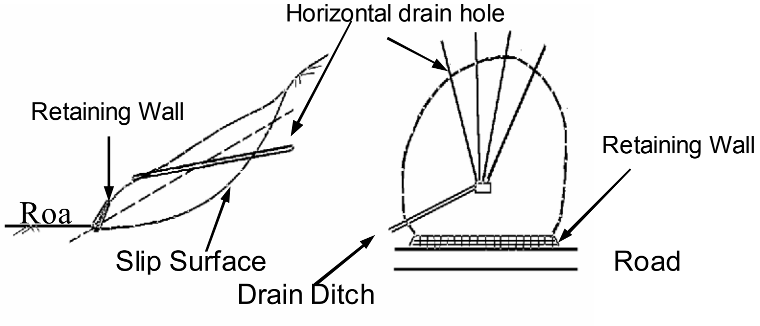


Figure A1-5.2 Typical location of horizontal drain holes

(6) Drainage Wells

Drainage wells consist of wells with horizontally bored collecting drains and relief drains. This method is used when horizontal drains or culverts cannot achieve efficient drainage because of the large scale of the mass movement.

1) Purposes

Similar to horizontal drain holes, drainage wells are used to drain deep groundwater for stabilization of the mass movement.

2) Design considerations

The location of drainage wells should be determined on the basis of the distribution of groundwater and in consideration of the well's safety. In principle, wells should be located in stable ground within an area from which it is possible to effectively collect groundwater. Wells are usually between 2 meters to 4 meters in diameter and 10 to 30 meters in depth. Liner plates, reinforced concrete segments, and other materials generally support the sidewalls of wells.

Collecting drains are similar to horizontal drain holes in terms of design considerations. The safety of drainage wells should be evaluated by checking the earth pressure of the surrounding area. The diameter of drainage holes should be based on catchment quality of groundwater. Figure A1-5.3 shows the details of a drainage well.

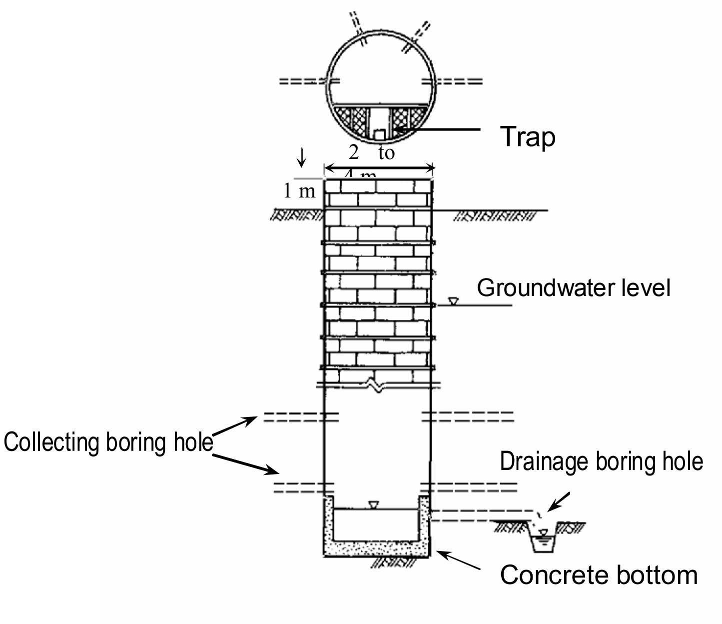


Figure A1-5.3 Details of Drainage Well

APPENDIX V-1 COUNTERMESURE WORKS

(7) Ground Anchor

Compared with other countermeasures, ground anchor works are costly, but reliable. Recently this method has been applied increasingly to artificial mass movements to cut off the toe of the mass movement. Compared with rock bolts and soil nailing, ground anchor work has a relatively large resistance to sliding force and is therefore used to stabilize relatively large-scale slope disasters.

1) Purposes

Ground anchor works are intended to prevent mass movements through the tensile strength of high tensile strength steel wire or bars installed across the slip surface.

2) Design Considerations

Important considerations for ground anchors are the bearing capacity of the groundmass under the bearing plate and the bond strength between the anchor grout and rock at the attachment point. Further, in planning ground anchors, the bond strength test at the attachment should be carried out. Ground anchors are in principle installed at a spacing of at least 2 meters in 2 rows or more.

Fixation length should be 3 meters to 10 meters in length, and the free length should be more than 4 meters. The settlement angle should not be applied from + 10˚ to -10˚.

The direction of anchoring should be parallel to the direction of movement of the mass movement.

Cribs, plates or cross-shaped blocks are used as pressure resisting bearing plates set on the surface of the ground. The most appropriate pressure resisting plate should be selected in consideration of specifications, operation efficiency, cost-effectiveness, maintenance, landscape, etc.

Figure A1-5.4 shows a typical example of a stabilised mass movement with ground anchors and Figure A1-5.5 shows details of an anchor structure.

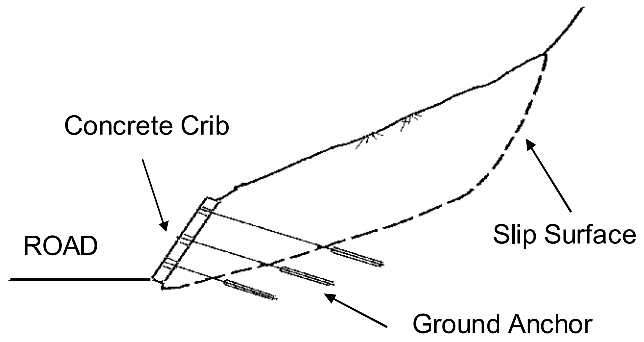


Figure A1-5.4 Mass movement Stabilized with Ground Anchors

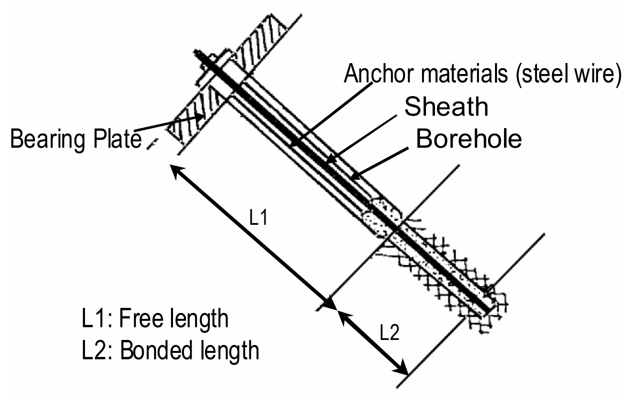


Figure A1-5.5 Outline of Anchor Structure

APPENDIX V-1 COUNTERMESURE WORKS

The following items are decided or calculated for the designing of anchors

- i) Stability analysis
- ii) Calculate the required restraining power
- iii) Selection of anchor works
- iv) Calculate the required anchor power (location, interval, angle)
- v) Determine the type of anchor and steel material
- vi) Calculate the fixation length and diameter of boring
- vii) Design of pressure resisting plate

The design process can be summarised as follows.

1) The design anchor power (Td) is calculated using the following formulas:

$$Td = \frac{Fsp \cdot \Sigma W \cdot \sin\alpha - \Sigma c \cdot l - \Sigma(W - u \cdot b)\cos\alpha \cdot \tan\varphi}{Fsp \cdot \cos(\alpha+\varphi) + \sin(\alpha+\varphi) \cdot \tan\varphi} \times \frac{B}{N} \quad \cdots\cdots\cdots (1.6)$$

Po: the required resisting power (kN/m^2)

Td : *Anchor power*

Fsp : *Design safety factor*

c : *Cohesion*

l : *Length of sliding surface*

b : *Width of slice*

W : Weight of slice

u : *Pore water pressure*

α : *Angle of slope of sliding surface*

φ : *Internal frictional angle of sliding surface (degree)*

B: *Interval between anchors in horizontal direction (m)*

N: *Number of anchor setting in vertical direction*

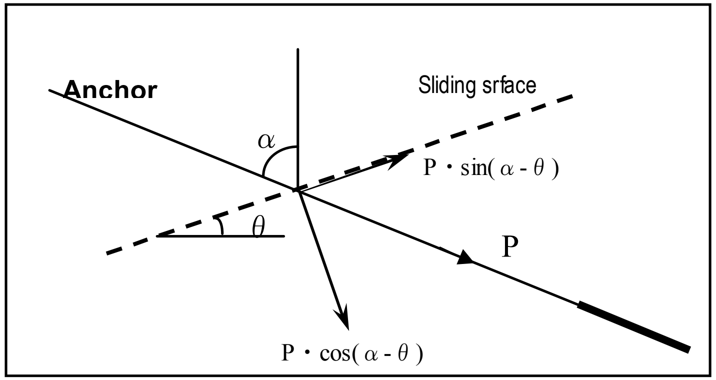


Figure A1-5.6 Functional description of an anchor

2) Determination of the type of anchor and steel material

Generally, the type of anchor is determined by comparing the tension strength of steel material with the skin frictional resistance between the ground and grout as well as the allowable adhesive stress between a tendon and grout.

3) Calculation of the fixed length of an anchor

For the design anchor power to meet the allowable anchor pullout force, the length of contact between the ground and

APPENDIX V-1 COUNTERMESURE WORKS

grout must be compared with that between the tendon and grout. Whichever is longer should be used as the fixed length.

$$Tab = \pi D \cdot \tau ab \quad \cdots\cdots\cdots\cdots\cdots\cdots \quad (1.7)$$

Tab : allowable adhesive force (kN/m)

D : diameter of tendon (m)

τ ab : allowable adhesive stress between tendon and grout (kN/m)

$$Tag = \frac{1}{f} \cdot \pi D \cdot \tau ag \quad \cdots\cdots\cdots\cdots \quad (1.8)$$

Tag : skin friction force (kN/m)

f : safety factor

D : diameter of anchor (m)

τ ag : skin frictional resistance (kN/m²)

$$ls = Td \;/\; \tau ab \quad (ls < lsa) \quad \cdots\cdots\cdots\cdots \quad (1.9)$$

ls : required length of tendon (m)

lsa : standard length of tendon

Td : design anchor power (kN/m)

τ ab : allowable adhesive stress between tendon and grout (kN/m)

In the preliminary design stage, the locations, directions, intervals and angles of anchors should be considered. Corrosion countermeasures should be taken to give protection under the most unfavourable possible conditions that might be expected over the period of the anchor's useful life.

APPENDIX V-1 COUNTERMESURE WORKS

A1-6 COUNTEMEASURES WORKS AGAINST ROAD COLLAPSE (FP)

(1) General

Generally, road collapse results from (1) the toe failure of an embankment slope, (2) scouring of the surface of an embankment slope, (3) rising pore water pressure within an embankment, (4) a gradient steeper than the standard gradient, or, in some cases, (5) settlement of an embankment's ground foundation. Therefore, countermeasures for road collapses consist mainly of slope protection and drainage works.

(2) Classification of Countermeasures

Table A1-6.1 shows the classification of countermeasures for road collapses

Table A1-6.1 Classification of Countermeasures against road collapses

CLASSIFICATION		TYPE OF WORK
Earth Work	Earth Work	Embankment
Vegetation	Vegetation	Hydroseeding Re-Vegetation
Water Drainage	Surface Drainage	Drain Ditch and Cascade
	Subsurface Drainage	Horizontal Drain Hole Culverts
Slope Work	Pitching Work	Stone Pitching
	Crib Work	Crib Work
Anchoring	Anchoring	Soil Nail Ground Anchor
Wall and Resisting Structures	Retaining Wall	Gabion Wall Stone Pitching Wall Concrete Block Wall Retaining Wall (Gravity Type) Retaining Wall (Supported Type) Crib Wall Pile Wall

(3) Criteria for selection of countermeasures

Adequate measures for preventing road collapse should be selected in consideration of the causes, mechanism and scale of the anticipated road collapse, embankment materials, and foundation conditions. Generally, the following guidelines should be followed for selection.

1) In principle, a standard embankment slope (gradient and height) should be designed, especially where sufficient land is available to meet the full width of the base of the embankment. If sufficient space is not available, a retaining structure such as a retaining wall should be considered.

2) The surface of an embankment should, in principle, be protected by closed turf. Selection of a type should take into account the susceptibility of embankment materials to weathering or erosion.

3) Separate drainage work to deal with surface water runoff and groundwater inside the embankment is essential, for both construction effectiveness and the long-term stability of the embankment.

APPENDIX V-1 COUNTERMESURE WORKS

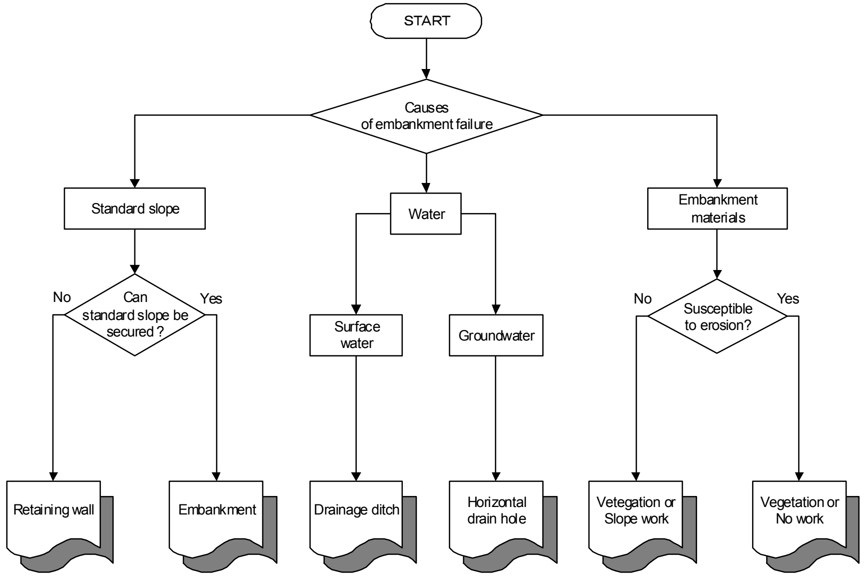


Figure A1-6.1 Flow chart for selection of countermeasures for road collapse

(4) Embankment

1) Purpose

Embankments are used at the toe of unstable or potentially unstable slopes to balance the driving force of additional loading.

2) Design considerations

The main considerations for embankments chiefly concern stability analysis as well as the selection of slope gradient in proportion to embankment materials. In selecting embankment materials, their strength and deformation characteristics should be considered. Table A1-6.2 gives the recommended standard embankment slope for different embankment materials. These can only be applied where the foundation ground has sufficient bearing capacity.

Furthermore, for high embankments consisting of different kinds of materials, a standard gradient suitable to each material should be applied to each slope. The stability of the foundation ground of the embankment should be reviewed prior to construction.

Table A1-6.2 Recommended Standard Embankment Slopes

Embankment Materials	Height (m)	Gradient (V:H)
Well graded sand, gravels and sand or silt mixed with gravels (GW, GP, GM, GC)	< 5 m	1:1.5 ~ 1:1.8
	5 ~ 15 m	1:1.8 ~ 1:2.0
Poorly graded sand (SP).	< 10 m	1:1.8 ~ 1:2.0
Rock masses (including muck).	< 10 m	1:1.5 ~ 1:1.8
	10 ~ 20 m	1:1.8 ~ 1:2.0
Sandy soils (SM, SC), hard clayey soil and clays (CL, ML).	< 5 m	1:1.5 ~ 1:1.8
	5 ~ 10 m	1:1.8 ~ 1:2.0
Soft clayey soils	< 5 m	1:1.8 ~ 1:2.0

Note) Height of embankment is the vertical height from the toe to the top of the embankment.

The insertion of a sand layer at an embankment at certain intervals for drainage purposes as shown in Figure A1-6.2 is sometimes conducted to prevent the failure of an embankment slope.

APPENDIX V-1 COUNTERMESURE WORKS

Embankments with Sandy Soil Liable to Erosion by Rainwater

As this type of soil is characterised by poor water retention as well as poor nutrition, protection of the slope surface with top soil, etc. as part of planting is necessary. Meanwhile, facilities with a sufficient drainage function are required to prevent slope erosion by rainwater during construction. For general embankment work, the introduction of a higher cross grade at the central part during construction to create a downward inclination towards the top of the slope and the introduction of a drainage ditch at the top of the slope is recommended.

Embankments on Inclined Ground

In regard to embankments on inclined ground, embankments filling a valley, half-bank and half-cut and boundary of cut and embankments, spring water from the ground often infiltrate the embankment, destabilising the embankment slopes. In such cases, the introduction of a drainage layers inside the embankment is recommended to reduce the water pressure in the embankment in addition to the introduction of sub-surface drainage to prevent the infiltration of groundwater to the embankment (Figure A1-6.2).

As some inclined ground has a soft layer(s) which makes an embankment vulnerable to failure, it may be necessary to conduct investigations on the foundation ground and to design an embankment which is similar to Mass movement.

The shear strength of soil near the ground surface is often low because of weathering and other reasons and, therefore, it is preferable for the ground to be excavated in the form of bench cutting as deep as possible prior to the construction of an embankment. The minimum width and minimum height of bench cutting should be 1 m and 0.5 m respectively.

Lowering of the groundwater level inside an embankment is effective to not only reduce rain-induced disasters but also as an earthquake-proof measure.

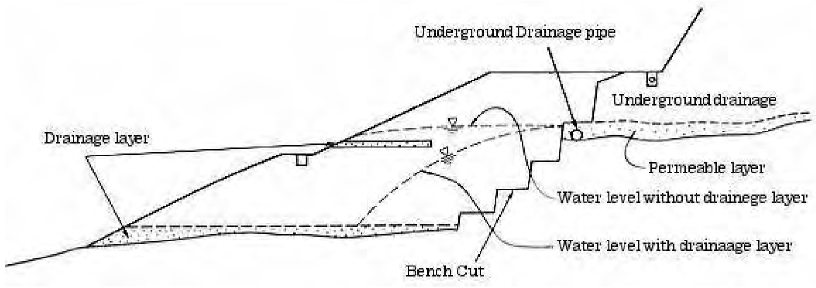


Figure A1-6.2 Groundwater Drainage Facilities and Drainage Layer for the Embankment on Inclined Ground

Widening of Embankments

When the widening of an existing road is planned by constructing an additional embankment(s) at the side(s) of the road, the construction of the new embankment(s) by the bench cutting of the existing embankment slope(s) as shown in Figure A1-6.3 (a) is preferable.

There are many examples of road collapse due to rain or an earthquake at those sites where a narrow embankment has been added to inclined ground. When the slope stability of the ground is secured, much cutting volume should be introduced as shown in Figure A1-6.3 (b). If possible, the bottom parts of these cut slopes should be made into a horizontal surface above which an embankment is constructed. The widening of an embankment with long-term stability can be successfully achieved in this manner.

APPENDIX V-1 COUNTERMESURE WORKS

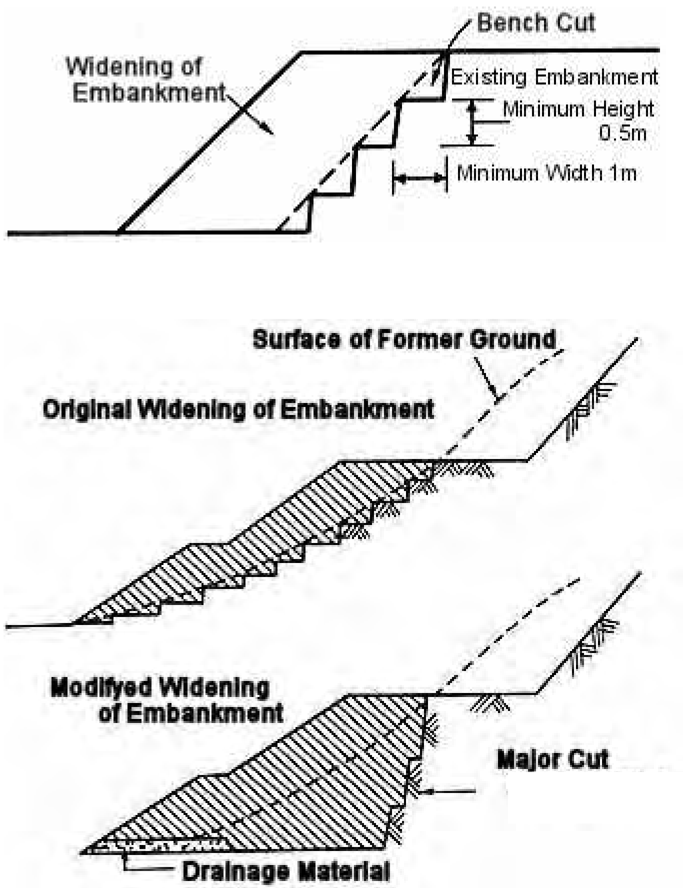


Figure A1-6.3 Widening of Embankment

APPENDIX V-2

INVESTIGATION

APPENDIX V-2 INVESTIGATION

A2-1 BASIC CONCEPT OF INVESTIGATION

Appendix V-2 Investigation describes the standard method for investigation and monitoring through instrumentation for each of six classified disasters. The locations where abnormal condition were found and prevention measure works required by Disaster Inventory Inspection or Regular Inspection shall be investigated in detail or monitored.

The investigation shall be to know the Primary Factor and the Contributory Factor.

In the course of a series of procedure as above described, selection of the investigation method and establishment of the investigation plan are made, taking into account generally the objectives, scale of failure, geological conditions, surface and topographic conditions, access to the site, overall countermeasure policy, restriction in terms of budget and time, etc. Engineers concerned are expected to draw flexible and appropriate judgments concerning the urgency and safety, since conditions of actual sites vary widely,

The site reconnaissance is the basic investigation to know the primary factors and the contributory factors.

The mass movements are normally large scale and moving slow, therefore detailed investigation other than the site reconnaissance may be important.

The sauces of debris flows are normally far from the road, therefore detailed investigation other than the site reconnaissance may be important.

APPENDIX V-2 INVESTIGATION

Table A2-1.1 Check Points of Site Investigation

Type of Disasters	Primary / Contributory Factors	Detailed Study
Collapse (CL)	Primary Factor: highly weathered surface, colluviums, rock conditions of fissures having certain regularity, daylight, erosion weak soil, weak rock when dip in water (slaking), trace of collapse Contributory Factor: rainfall, earthquake, cut off at the base of slope	Confirm depth of highly weathered zone or lose layer covers slope
Rock Fall (RF)	Primary Factor: rock conditions of fissures having certain regularity Contributory Factor: earthquake, rainfall, vibration by construction works	Confirm number and size of loose rocks, if necessary.
Rock Mass Failure (RM)	Primary Factor : hard rock conditions of fissures having certain regularity, daylight structure, vertical fissures Contributory Factor: earthquake, opening of fissures, vibration by construction works, freeze / fusion of water in fissures	Confirm width and opening speed of crack, if necessary.
Mass movement (LS)	Primary Factor : thick weathering zone, colluvium on slope, daylight Contributory Factor: ascent of groundwater in sliding mass, cut off at the toe of sliding mass, embankment on the top of sliding mass	Preliminary Study is made to estimate the scale and mechanism of landslide, followed by establishment of the necessary investigation and monitoring plan. To confirm depth, volume, speed of landslide for designing of the countermeasure
Debris Flow (DF)	Primary Factor : debris deposit on stream, insufficiency of section of cross stream, collapses on upper stream Contributory Factor: rainfall	Check if there is any drawing around the road concerned. If necessary, to confirm thickness of sediments and gradient along stream.
Embankment (EB)	Primary Factor : rainwater overflow on road surface, erosion at the end of embankment toe, Contributory Factor: rainfall, earthquake, cut off at the base of slope	Check if there is any data and record during construction. If the embankment is critical stage, detailed study is made for designing of the countermeasure.

APPENDIX V-2 INVESTIGATION

Table A2-1.2 Outline of Preliminary Study and Detailed Study

Item	Item	Description	Application
Preliminary Study	Interpretation of topography	Interpretation of wide area around the slope concerned. Large-scale topographic map and stereoscopic aerial photos	Implemented always
	Collection of existing data	Past disaster history, boring log, geological map, groundwater	
	Site reconnaissance	In-depth survey of the slope concerned and its surrounding area Range from the ridge to channel in certain cases	
	Simplified measurement	Simplified measurement with marking and batten plate	
	Survey	Made when no existing survey drawings exist or are available.	
Detailed Study	Geophysical survey	Seismic refraction survey, resistivity imaging method, etc. Applicability and profile line length are reviewed with reference to the transverse direction.	Implemented if judged necessary as a result of detailed survey
	Boring investigation	Basically, all-core boring is made, including sampling. Survey to be made to a point below the estimated slide surface, collapse surface, and bed rock.	
	Sounding	Dynamic probing, Swedish sounding, etc.	
	Borehole logging	Borehole television, electrical method, PS logging, etc. depending on geological condition	
	In-situ test	Standard penetration and borehole horizontal loading tests in boreholes depending on geological condition, including sampling in test pit, adit, and shaft	
	Laboratory test	Rock and soil tests to be made as required	
	Instrumentation and Monitoring	Measurement of ground surface slide movement (ground surface extensometer), measurement of borehole movement (probe-inclinometer), groundwater survey (piezometer, Casagrande type), precipitation survey (rain gauge), periodical ground Site reconnaissance	

APPENDIX V-2 INVESTIGATION

A2-2 SITE RECONAISSANCE

(1) Basic Concept of Site Reconnaissance

Site reconnaissance consists fundamentally of visual and careful confirmation of any deformation of the ground surface in addition to geological, topographical, vegetative, and hydraulic condition by engineering geologists or geotechnical engineers with the information such as sketch and photos.

Main purpose of the site reconnaissance is to find the primary factors.

The primary factors of landslides are shown on Table A2-2.1

Table A2-2.1 Ground Condition and Primary Factors of Disasters

Ground Condition	Primary Factors
Topographic Conditions	1 Over hung 2 Water channel 3 Trace of landslides 4 Existence of clacks on the ground surface 5 Damage of cut slopes and natural slopes
Geological Conditions	1 Weathering 2 Conditions of fissures having certain regularity, such as bedding stratification, foliation and joints 3 Existing of colluviums 4 Boulder stones which is not firmly embedded in the ground
Water Conditions	1 Water Spring 2 Erosion 3 Channels

(2) Site Reconnaissance

Following items shall be investigated, estimated and examined at the site. Also the site reconnaissance results shall be entered in plan and cross-sectional views of the scale of about 1/100～1/500 if available.

1) The geology and its structure of the slope. Observation is made while paying attention to the hardness of geology, separation surface, weathering, and looseness of rock mass. With attention paid to discontinuity of joint, etc., and its type, direction, spacing, continuity, and nature, determination is made on whether the ground is excavated or dip slope.
2) Microtopography on the slope. Slope height, slope length, gradient, position of the knick line, small steps, presence of open cracks or faulting, etc.
3) Presence of seepage location, water-holding condition of surface soil, vegetation, etc and drainage facilities.
4) Range and depth of unstable matter through the site reconnaissance by surface deformation with fracture and elevation, faulting and cave-in, distribution of grooved topography, etc.
5) Mechanism of the disaster.
6) Existing countermeasure condition. Fracture and squeezing, peeling and deterioration of concrete, cut and corrosion of net, rope, and wire, loosened anchor.
7) Positional relationship between the disaster 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.
8) Any other anomaly or deformation surrounding area.

APPENDIX V-2 INVESTIGATION

When there is any deformation that may indicate possible collapse, simplified measurements are made. They include the measurement of a distance between marked pins and nails provided on both sides of fracture and step, observation of mortar provided to repair fracture for any deformation, etc as shown on Figure A2-2.1.

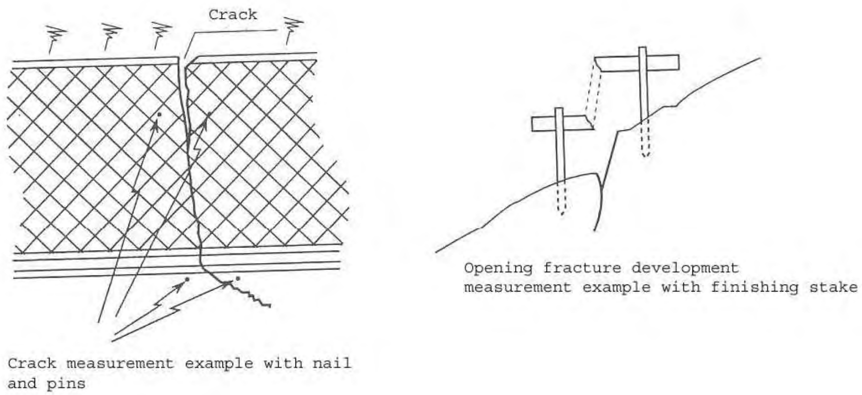


Figure A2-2.1 Example of Simplified Measurement

APPENDIX V-2 INVESTIGATION

A2-3 INVESTIGATION FRO MASS MOVEMET

(1) Checkpoints of Survey

Mass movements tend to occur frequently in areas with specific geology or geological formations such as Tertiary mudstone or tuff zones or Mesozoic and Palaeozoic metamorphic rocks zones, and such areas frequently indicates unique topographic features due to past successive mass movement activity. The relation between the topographical features of mass movements and the properties of sliding mass in the process of mass movement movement have been generally recognized. Mass movements are also frequently induced by small-scale earthworks in areas where the topographical features of mass movements are apparent. Such mass movement zones can be frequently determined by aerial photographs.

A survey on mass movements is conducted to obtain the following types of information when a road is crossing at a mass movement site or at a site where the possibility of a mass movement is recognised.

i) Extent and scale of sliding
ii) Direction and velocity of sliding and presence of a scarp
iii) Stability of a mass movement and changes of the safety factor due to earthwork and other causes
iv) Mutual relationship between a mass movement and contributory factors
v) Location of installed measuring instruments

The entire picture of a mass movement is clarified based on the above information and a suitable route is selected or adequate countermeasures are implemented by investigating the causes and mechanism of the mass movement. There will be a high potential of mass movement occurrence requiring detailed surveys if the following symptoms are found in the survey areas after reading the topographic maps and aerial photographs.

i) Irregular arrangement of contour lines
ii) Presence of horse-shoe shaped type cliffs or plateau type slopes, or presence of dense contour lines below gentle slopes
iii) Regularly arranged ponds, swamps and marshes
iv) Presence of irregular contour lines in front of steep cliffs, or presence of separate small hills
v) Abnormal curves of such as gorges, streams, abnormal curves and changes in the grade of road
vi) Presence of terrace paddy field, debris flow deposit

(2) Survey on Stability of Mass movement

Surveys are mainly performed by borings and sometimes the excavation of test pits is also performed to study the mass movement mechanism from the viewpoint of soil mechanics and to examine the soil mechanical characteristics in detail of sliding surface clay.

For soil and geological survey, at least four borings should be made and three of these should be on and across the sliding block and one should be on the upper slope of a block. It is important to plan and actually make a boring at least 5 m into the bedrock in order to distinguish the sliding mass from the bedrock. Also, where the mass movement area is wide and the distribution of bedrock is quite irregular, it is also important to perform elastic wave exploration and to provide an auxiliary course of traverse to allow a review in the traverse direction.

From the mechanical point of view, this survey is performed to determine the hardness of the landslide mass and the soil texture, and also to determine the strength of soil mass required for the stability analysis of the slope in the mass movement area and for designing countermeasures with the results of sounding, standard penetration tests, in-situ tests, and tests for physical and mechanical properties.

The survey results are then compared to the results of the field survey and topographic and geologic map readings, and then the characteristics and extent of mass movement activity are examined.

(3) Survey on Contributory Factors of Mass movement

It is well known that mass movements frequently occur during periods of heavy rain and that mass movement movement becomes active as the groundwater level rises. Information concerning the mechanism and possibility of mass movements can be obtained by determining the groundwater conditions in the mass movement area (fluctuation in ground water level, flow of groundwater, runoff path, current speed, quality and temperature of groundwater, etc.) to make it possible to examine the quantity and location of effective drainage work as countermeasures based upon the state of groundwater. Groundwater surveys can be generally classified into groundwater distribution surveys and groundwater pressure surveys. The contents of the survey are as shown in Figure A2-3.1, and the scope of survey should be determined according to the purpose.

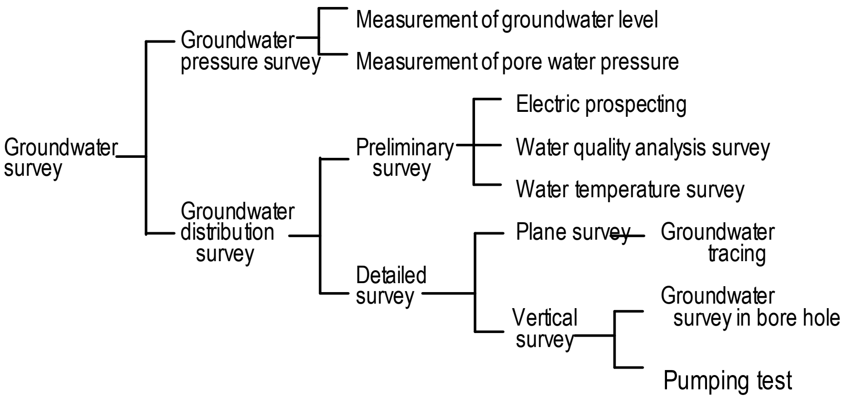


Figure A2-3.1 Groundwater Survey

Groundwater should be surveyed by continuous observation since it often has seasonal fluctuations. In addition, vegetation in the mass movement area is closely related to the distribution of the groundwater zone and, this, must be compared to the results of field survey.

2.3.4 Survey on Extent and Movement of Mass movement

This survey is performed to examine the extent, direction of movement, and the mechanism of mass movements in detail when any sign of mass movement motion such as slide scarps or cracks are found or when there is any possibility of the occurrence of mass movements in the future.

Measurement or monitoring survey may involve monitoring of movement or survey on sliding surface. Monitoring of movement is undertaken in order to confirm the extent of sliding and to obtain material for forecasting future activation of mass movements and measures the amount of fluctuation of inclination and expansion or contraction of the slope surface. The method of measurement involves the use of such devices as invar wire extensometer (Figure A2-3.2) and ground inclinometer or a simplified method using displacement stake or displacement plate (Figure A2-3.3).

APPENDIX V-2 INVESTIGATION

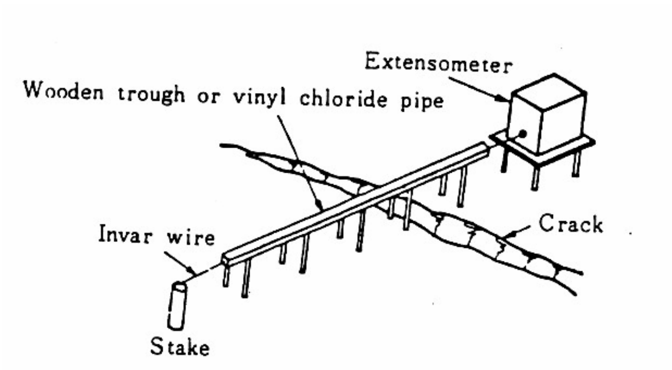


Figure A2-3.2 Schematic Diagram of Invar Wire Extensometer

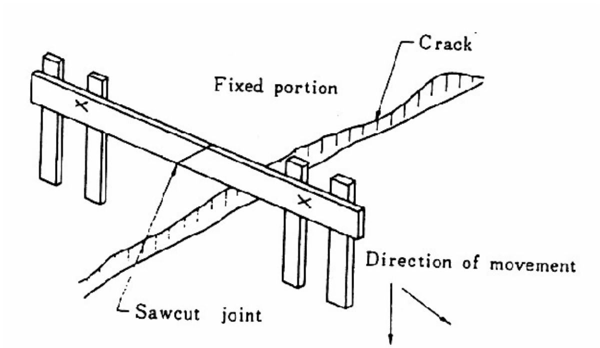


Figure A2-3.3 Simple Displacement Plate

Sliding surfaces may be investigated through examination of the boring core or measurement of the sliding surface. Core examination is employed to verify evaluation through measurement or when the sliding surface cannot be evaluated through measurement survey. Survey through measurement of the sliding surface is undertaken by embedding rigid polyvinyl chloride pipe equipped with strain gauge (pipe strain gauge type inclinometer) or an insertion type underground inclinometer (Figure A2-3.4) in the bore hole to measure changes in the internal stress in a ground or bore hole incline angle in order to grasp the condition of the sliding surface. The point at which the pipe strain gauge type or insertion type underground inclinometer is embedded is, in principle, all bore holes but in some cases, this may be limited to the bore holes along the main measurement line.

Survey of the sliding surface is undertaken when it is clear that the mass movement block has been moving from the results of the site reconnaissance or measurement of ground movement.

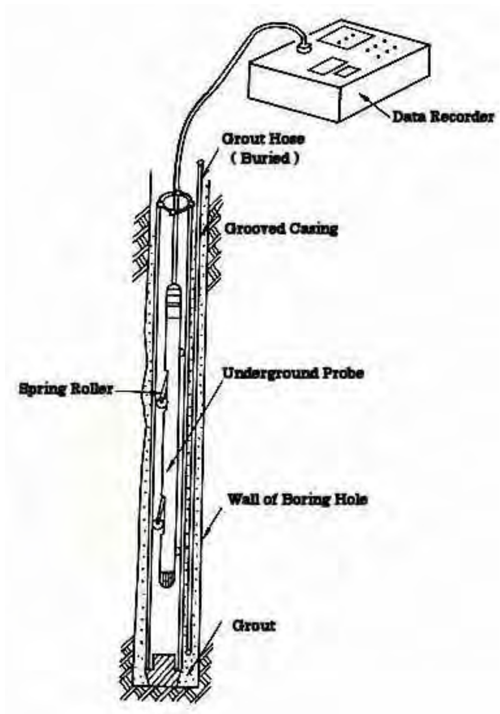


Figure A2-3.4 Underground inclinometer

A2-4 INVESTIGATION FOR DEBRIS FLOW

A2-4.1 Checkpoints of Survey

A debris flow is a phenomenon in which soil at the bottom of a valley or upstream moves as a result of heavy rain or earthquake and flows in hydraulic bores out of the valley. There are 4 main types of debris flows as shown in Table A2-4.1.

Survey on debris flow is focused on the following points and involves investigation of materials on past damage, site reconnaissance and interpretation of aerial photographs.

i) Possibility of a debris flow occurrence
(frequency of occurrence, weather conditions, etc.)

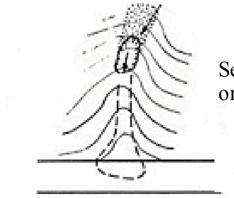
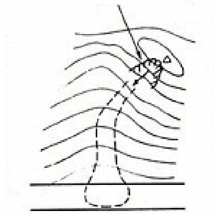
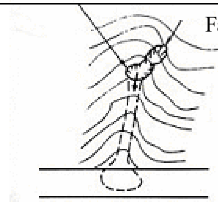
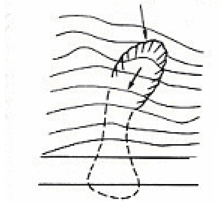
ii) Scale and characteristics of the debris flow
(peak amount of discharge, the flow velocity, wave height, volume of soil, maximum gravel diameter, etc.)

iii) Area likely to be inundated by the debris flow

iv) Presence of existing facilities for erosion control or forestry protection and its configuration and size.

In the event a planned road would cross over a mountain stream by bridge or culvert where the occurrence of debris flow is expected, the peak amount of discharge, the flow velocity, maximum wave height and maximum gravel diameter of the debris flow should be investigated as material for reviewing whether or not the debris flow will pass without damaging the bridge or culvert.

Table A2-4.1 Classification of Debris Flow

Category	Description	Schematic Drawing
Fluidisation of deposited sediment and gravel on the riverbed	Fluidisation of sediment and gravel deposited on the bed of a steep stream due to the supply of a large quantity of water due to a downpour or rapid thawing	
Fluidisation of sediment produced by a hillside failure	Fluidisation of sediment produced by a hillside failure as the structure is broken up while sliding down the slope and mixed with water	
Collapse by natural check dam	Fluidisation of sediment forming a natural check dam(s) which is created by the blockage of a mountain stream by failed sediment and which is then eroded by overflow or which collapses	
Fluidisation of mass movement soil mass	Fluidisation of a cohesive soil mass with a high water content originally produced by a landslide	

APPENDIX V-2 INVESTIGATION

A2-4.2 Survey on Occurrence of Debris Flow

(1) Identification of Locations where Debris Flow may occur

In depressed topography to which rain water gathers, in mountain streams where water flow exists during rainfall, for mountain streams with 15 degrees or more gradient of the river bed and more than 5 ha of catchment area upstream from the point at which the gradient of the river bed is 15 degrees, with consideration focused on cases in which there is sediment at the river bed that could become debris flow, locations at which such debris flow may occur need to be investigated.

Moreover, catchment areas of less than 5ha upstream from a point at which the gradient of the river bed is 15 degrees where relatively large failure at a mountainside can be expected due to the soil properties, spring water or history of failure may be considered as areas where debris flow can be expected. The above survey should be undertaken through rough interpretation of topographic map and aerial photographs firstly and should be revised through site reconnaissance.

(2) Estimation of Frequency of Debris Flow

Existing materials on disaster records, hearings and site reconnaissance should be utilized to determine the times and frequency of occurrence of recent debris flow in the relevant mountain stream.

(3) Estimation of Rainfall Conditions Causing Debris Flow

Areas should be divided based on similarity of rainfall conditions, and materials on rainfall that caused debris flow in the past, heavy rains that did not lead to such occurrence should be collected in order to determine the distinction between rainfall conditions that lead to such debris flow and those that do not lead to such debris flow.

In the event there has been no rainfall that has caused debris flow in the relevant area, the maximum amount of rainfall at which such debris flow did not occur shall be used as the temporary rainfall conditions on the occurrence of debris flow, and other information such as topography and soil properties should also be used in the determination.

APPENDIX V-2 INVESTIGATION

A2-4.3 Survey on Estimation of Scale, Character and Inundation Area of Debris Flow

(1) Estimation of Scale and Character of Debris Flow

In order to review the scale and positioning of countermeasures for debris flow, the scale of the debris flow (discharged soil volume), peak amount of discharge, the flow velocity and other such factors need to be estimated.

Estimation of the discharged soil volume and the maximum grain size of debris flow may be undertaken by investigating the volume of river bed sedimentation and grain size distribution through site reconnaissance, but the peak discharge, the flow velocity and unit weight of debris flow are estimated with reference given to experimental and theoretical research on debris flow and empirical formulae obtained from field observation of debris flow.

The flow velocity of a debris flow ranges from several meters to 10 meters per second in the case of flow having large gravel content (gravel type debris flow). In debris flow in volcanic areas (mud flow type debris flow), depending on water content, the velocity may range from small up to 15 to 20 meters per second. Moreover, with respect to the wave height of a debris flow, the height is generally 3 meters or less. If there are records of debris flow that have occurred close to the targeted mountain stream, such materials should be used as reference in making estimations after confirming the similarity of the topography and geology.

(2) Estimation of Inundation Area of Debris Flow

The debris flow area and its inundated area downstream from the point at which such flow may occur are estimated. Debris flows are assumed to become sedimentation covering the flat land at the bottom of valleys and alluvial fans in the present topography. While in general, the point at which sedimentation begins is assumed to be the exit of the valley, partial sedimentation may also begin where the width of the flow suddenly increases and the gradient of a river bed is 15 degrees or less, where the width of the flow becomes narrower or where the gradient of river bed suddenly becomes gentle.

In general, most mountain stream has experienced debris flow in the past. For this reason, when the exit of a valley is investigated, it is possible to know what scale of debris flow with what diameter of gravels and what extent of discharge and sedimentation have occurred in the past.

APPENDIX V-2 INVESTIGATION

A2-5 OTHER INVESTIGATION

Based on the site reconnaissance, plan of the detailed study shall be determined.

Boring investigation is effective for clarification of the geology and geological structure. Boreholes can also be used as survey holes for observation of groundwater and as dynamic observation hole to estimate the collapse depth. On the other hand, geophysical survey proves effective for investigation of the degree of weathering and looseness of rock mass and, when used together with boring investigation, enables understanding of the sectional structure of unstable slope. In any case, transfer or temporary set up of the machinery in the site of steep slope with possibility to collapse is mostly not easy. Therefore, the study plan must be developed taking into account the applicability of investigation methods to the site concerned and investigation costs. As described above, the necessity to implement Detailed Study should be determined after thorough review of above factors.

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

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

A2-5.1 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.

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.

(1) Seismic Refraction Survey

<u>Considerations for operation of seismic refraction survey on the road slope</u>

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.

<u>Cautions for application of seismic refraction survey on slope stability</u>

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.

(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.

APPENDIX V-2 INVESTIGATION

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.

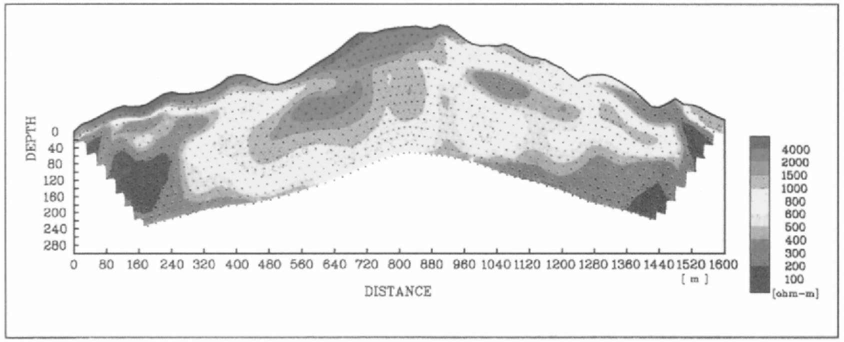


Figure A2-5.1 Example of analytical results of the resistivity imaging method

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.

A2-5.2 Other Site Investigations

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.

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.

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.

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.

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.

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.

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.

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.