Republic of Mauritius
Landslide Management Unit: LMU, Ministry of Public
Infrastructure and Land Transport: MPI

TECHNICAL COOPERATION PROJECT : LANDSLIDE ADVISER FOR MAURITIUS

MANUAL

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Japan International Cooperation Agency (JICA)
Kokusai Kogyo Co., Ltd.

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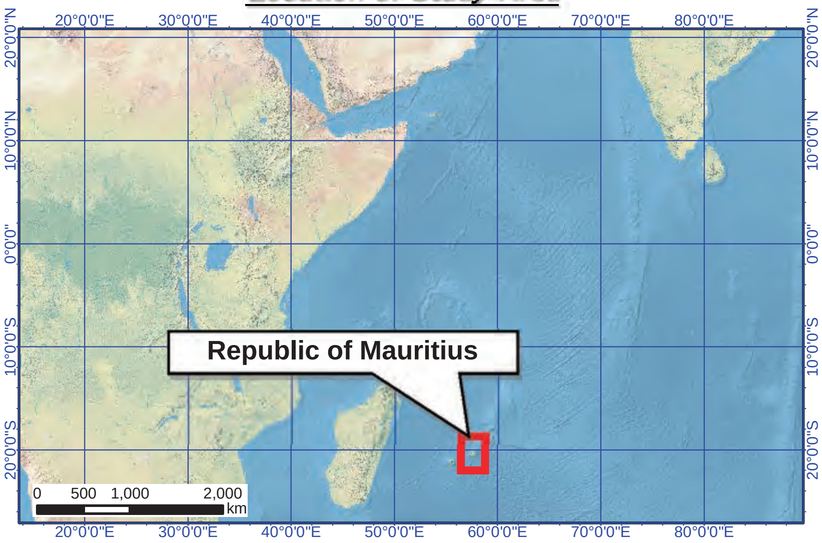
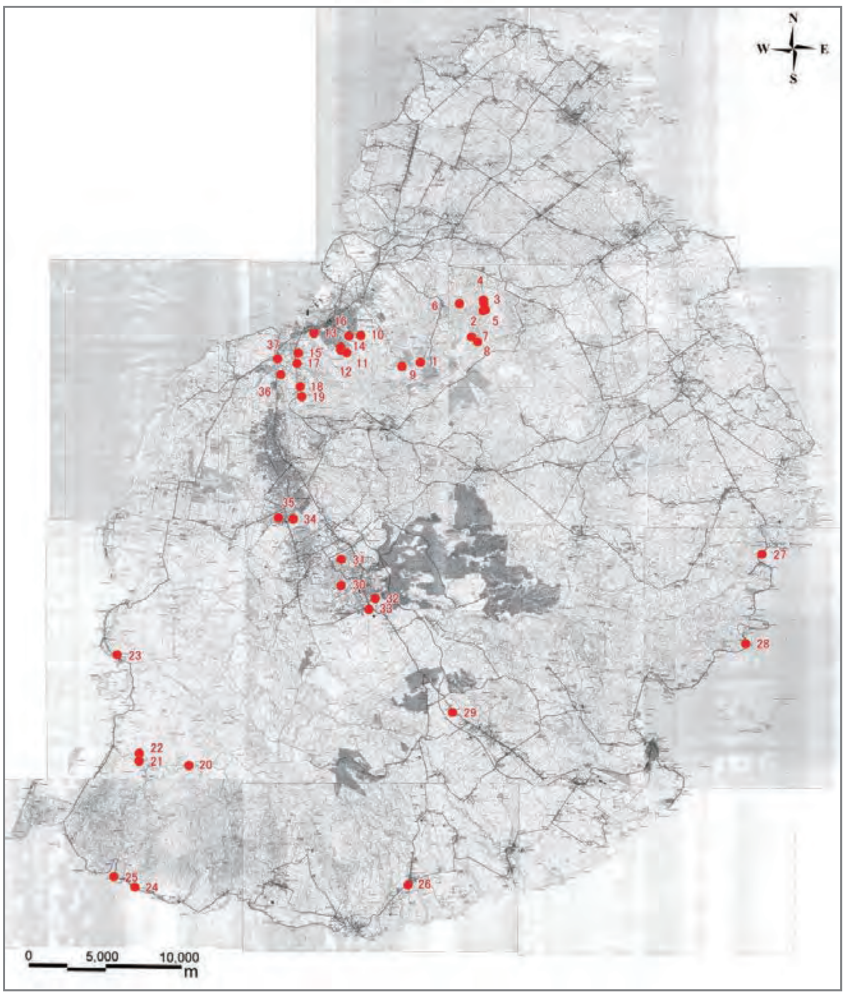
CONTENTS

Location of Study Area



Detail Map



Rate of Currency Translation

1 USD	= 32.1306 MUR
	= 110.69 JPY
100 MUR	= 2.95035 USD
	= 326.57 JPY

MUR: Mauritius Rupee

As of 17 January 2018

JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)
MINISTRY OF PUBLIC INFRASTRUCTURE AND LAND TRANSPORT (MPI)

Manual for Survey and Countermeasure of Slope Failure, Rock Fall and Debris Flow

September 2017

Landslide Management Unit, Ministry of Public Infrastructure and Land Transport and

KOKUSAI KOGYO CO., LTD.

Preface

Japan International Cooperation Agency (hereinafter JICA) has implemented the ‘Project of landslide management in Mauritius’ (hereinafter the Previous Project) from April 2012 to March 2015 as a part of the climatic change adaptation and disaster mitigation program for Small Island Developing States (SIDS). “Technical guideline for initial survey” and “Procedure manual for landslide” were prepared during the Previous Project in 2015.

Technical Cooperation Project: Landslide Advisor for Mauritius (hereinafter the Following Project) is planned to be implemented as a successor of the Previous Project. The Following Project is focused on the phenomena of slope failures, Rock Falls and debris flows, which were not dealt as main phenomena in the Previous Project.

Furthermore, the technical transfer planned in the Following Project has to be implemented by sharing information and cooperating with the ongoing and planned projects by other donors to suit the development capacity of the administration of Mauritius.

One of the products of the Following Project is the manual for slope failures, Rock Falls and debris flows. This manual is based on the experience and knowledge gained from the activities carried out by JICA Expert Team (JET) in the Following Project, and technical guidelines and manuals of the Ministry of Land, Infrastructure, Transport and Tourism, Japan (MLIT), mainly by Public Works Research Institute in Japan (PWRI).

This manual is a technical guidance for preliminary survey, design of the structural countermeasures, execution, work management and inspection, and maintenance of the structures. By using this manual, basic knowledge and procedure of survey and countermeasure can be obtained. Depending on the limitations of the site condition, period and budget of investigation and construction, etc., methods and type of countermeasures might vary to suit each site.

It is expected that the engineers of MPI and District Councils will carry out survey and countermeasure planning for slope failures, Rock Falls and debris flows through their experience and ideas in Mauritius and revise this manual.

JICA Expert Team (JET)
Chief Advisor: Kensuke Ichikawa,
Kokusai Kogyo Co., Ltd.

This manual was prepared by JICA Expert Team based on the “Manual for Highway Earthworks in Japan, January 2004”, by Public Works Research Institute in Japan (PWRI). Some information and examples were included from the experience of the Projects in Mauritius on slope countermeasures. The JICA Expert Team expresses their appreciation to PWRI Japan for the permission of usage.

Permission No. （国研）土研業第9号（平成28年9月15日）

Contents

page

Annex

List of Figures

List of Tables

Page

1 Introduction

1.1 What is a Landslide?

1.1.1 Definition of Landslide

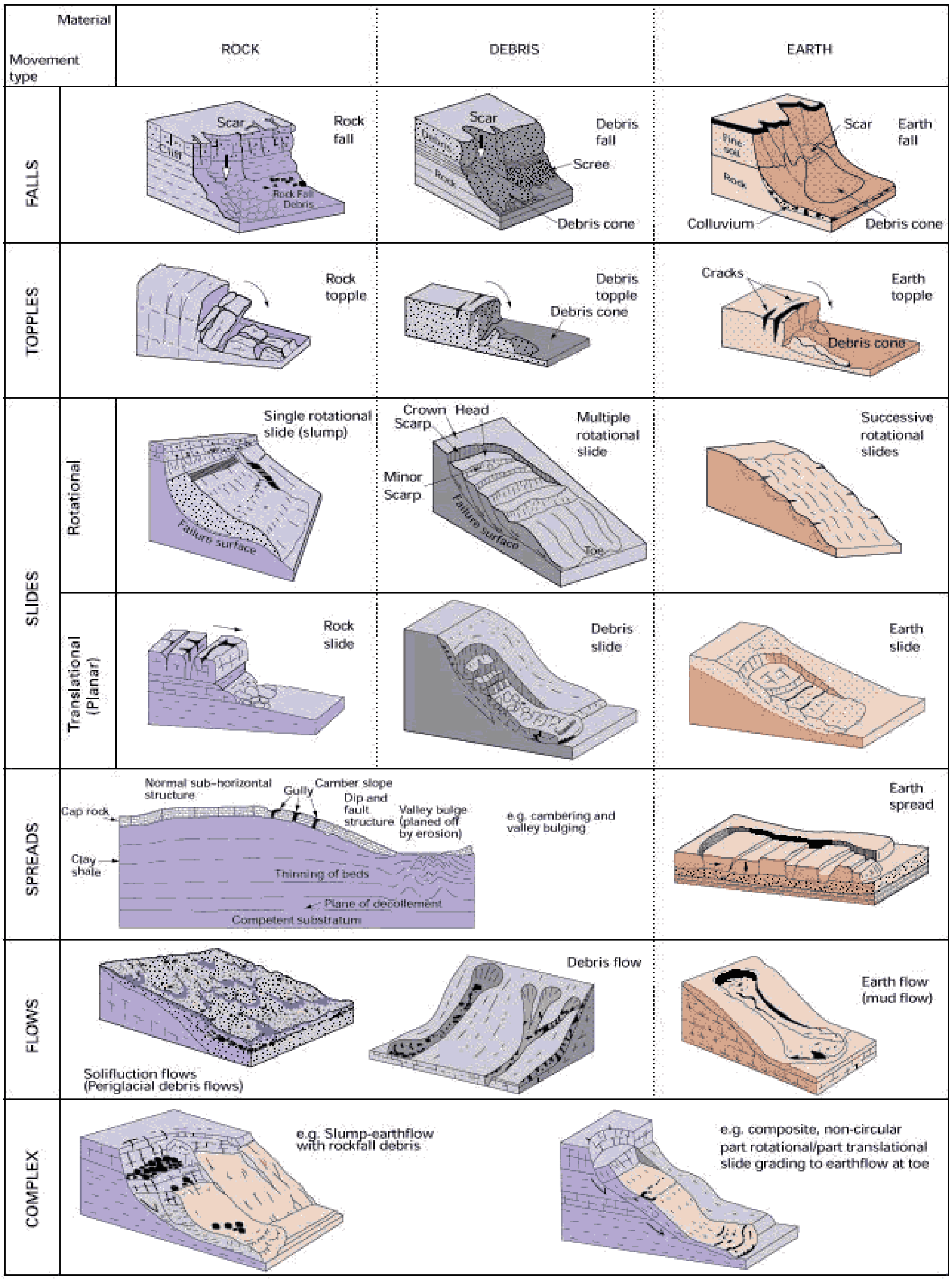
The term “Landslide” is defined as "the movement of a mass of rock, debris, or earth down a slope" (Cruden, 1991). Landslides are a type of "mass wasting" which denotes any down slope movement of soil and rock under the direct influence of gravity. The term "landslide" encompasses events such as Rock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

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

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

The classification by Varnes (1978) through USGS is widely adopted worldwide. Table 1.1 presents the updated classification.

Table 1.1: Classification of Types of Landslides (modified after Varnes, 1978 and DoE,1990)



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

Generally speaking, a landslide is classified as follows:

(1) Landslide

A landslide is mainly equivalent to the “SLIDES” mentioned in the Table 1.1. A landslide is a phenomenon where the soil mass on one or more failure (slip) surfaces deep in the ground gradually shifts downwards, triggered by heavy rain, river erosion, and earthworks. Landslide sites tend to be concentrated in areas with specific geology or geological structure. Compared to slope failures, gentler slopes move on a large-scale, forming specific topography (landslide topography), the inclination angle of the landslides slope is relatively low (about 5-20 degrees).

(2) Slope failure

A slope failure is equivalent to the “FALLS” of debris and earth material in the Table 1.1, however it does not include “Rock Fall”. The slope failure mass detaches from a steep slope/cliff along a surface with little or no shear displacement. It may be called a “Surface Failure”. Compared to landslides, the slope failure moves quickly on a small-scale and the inclination angle is relatively high (over 20 degrees).

(3) Rock Fall

A Rock Fall is equivalent to the “FALLS” and the “TOPPLES” in Table 1.1. A Rock Fall is a phenomenon where foliated rocks and gravel start to fall down a slope, due to enlarged cracks in the bedrock or outcropped rocks.

(4) Debris flow

A debris flow is equivalent to the “FLOWS” of debris and earth material in the Table 1.1. A debris flow is a phenomenon where soil and boulders are liquefied by surface water or groundwater and tend to flow downwards rapidly through a mountain torrent. It usually has huge energy and destructive force. Debris flows tend to occur in places where there is massive amount of unstable sediment along a steep torrent, or a large risk of slope failure due to heavy rain in the catchment basin.

Slope failures, Rock Falls and debris flows are described in this manual.

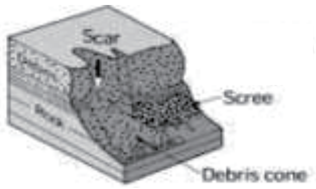
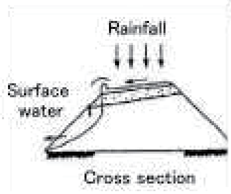
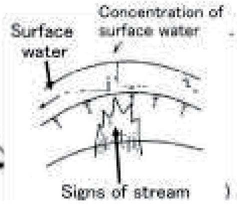
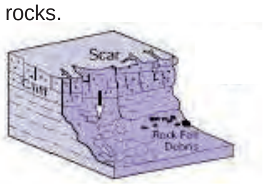
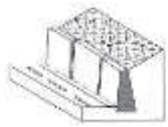
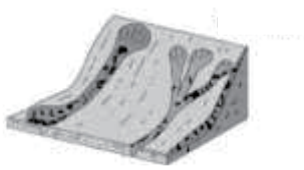
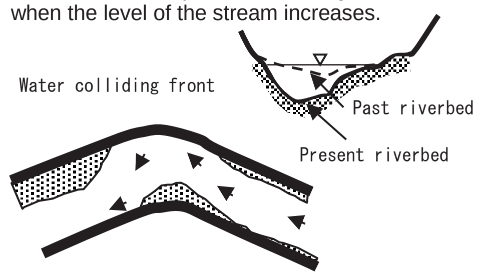
1.1.2 Type of slope disasters in Mauritius

Landslide hazard areas, based on the "Cyclone and Other Natural Disasters Scheme 2011-2012", include several disaster forms besides landslides. Therefore landslide hazard areas are classified into six (6) types of disasters, given in Table 1.2.

General classification: Landslide hazard areas, based on the "Cyclone and Other Natural Disasters Scheme 2011-2012", are classified into two kinds of disaster, Slope disasters and other disasters.

Sub classification: Slope disasters are classified into slope failure, Rock Fall and debris flow. Other disasters occurred in Mauritius are classified as damage of embankment, damage of wall and stream erosion.

Table 1.2 Description of the Slope Disaster Types in Mauritius (source: JET)

Slope disasters		Other disasters	
Slope failure	A slope failure is a mass detaching from a steep slope/cliff along surface with little or no shear displacement. Compared to landslides, slope failure is rapid and small-scaled, the inclination angle is relatively high (over 30 degrees).  	Damage of embankment	Collapse of road embankment is often triggered by rainfall, infiltration of underground water, erosion by surface water, or a partial catchment. It can be caused by weak embankment material or by lack of soil compaction.  
Rock Fall	A Rock Fall is a phenomenon where foliated rocks and gravel start to fall down a slope as a result of enlarged cracks in the bedrock or outcropped rocks.  	Damage of wall	The disaster of a retaining wall doesn't occur suddenly as with Rock Falls etc., the deformation rather occurs over a comparatively long time. The survey should investigate: ・ condition around the retaining wall ・ main body of the retaining wall ・ history of the retaining wall  
Debris flow	A debris flow is a phenomenon where soil and boulders are liquefied by surface water or groundwater and tend to flow downwards rapidly through a mountain torrent. 	Stream erosion	Stream erosion is the phenomenon where the soil of the bank is removed by the flow of the river. It occurs in riverbanks where the flow of the river hits with the most power. Water might overflow when the level of the stream increases. 

In this manual, there are three types of slope disasters within the six slope disaster types described in the previous project (Table 1.2). Those which are most serious in Mauritius have been focused and selected (Table 1.3).

Table 1.3 Description of slope failure, Rock Fall and debris flow in Mauritius (source: JET)

Items	Slope failure	Rock Fall	Debris flow
Image			
Photograph	 Peille's, cut slope along the motorway	 Maconde	 Baie du Cap
Points of the characteristics and the mechanism	・Failure of slope surface material ・Prone area: Slopes with slope angle from 30 to 50 degrees and cut slopes ・Higher velocity than landslide ・Close relationship with rainfall and subsurface water	・Fall of rocks from steep slope ・Prone area: Rock cliffs, cut rock slopes and steep slopes ・Very high velocity: rom bouncing to free fall ・Instability and weak contact with the ground by weathering and erosion	・Flow of debris from slopes and valleys with water ・Prone area: Stream and valley in mountain slope and piedmont ・High velocity: 5m/sec to 10m/sec at maximum ・Close relationship with short term rainfall and surface water
Effectiveness of the structural countermeasure works	・Planting (Vegetation) works: Seeding, Hydro seeding, Planting , etc. ・Slope failure prevention by structure construction: Wire netting, Retaining walls, Reinforced earth, etc.	・Rock Fall prevention works, Removal works, Gluing works, Retaining wall, etc. ・Rock Fall protection works: Protection net, Protection fence, Protection wall, etc.	・Source countermeasures: Check dam, Mountainside reinforcement, ground sill, etc. ・Countermeasures in the flowing/sedimentation area: Sabo dam, channel work, training dike, etc.
Recognized issues from both technical side and administrative side	・Because there are many target dangerous slopes, it is difficult to carry out a countermeasure for all ・Land use control by slope angle map based on PPG ・The construction of all countermeasures will not be possible in Mauritius. ・Enforcement of regular check and maintenance ・Administrative organizations in charge of natural slopes, road slopes and land-development slopes are different. ・There are differences between measures taken in public land and private land	・Because there are many target dangerous slopes, it is difficult to carry out countermeasures for all ・Hazard map of Rock Falls ・Construction of all countermeasures will not be possible in Mauritius. ・Enforcement of regular check and maintenance ・Administrative organizations in charge of natural slopes, road slopes and land-development slopes are different. ・Balance between landscape and countermeasure constructions (most of the Rock Fall site are in scenic spots)	・Debris flow is the slope disaster that is less recognized in Mauritius. ・Hazard maps of debris flows ・Construction of all countermeasures will not be possible in Mauritius. ・Enforcement of regular check and maintenance ・Administrative organizations in charge of mountains and rivers (mountain stream) are probably different. ・There are differences between measures taken in public land and private land

1.1.3 Location map and inventory

The project area is the Island of Mauritius, and the JET prioritized 37 high risk areas designated in the "Cyclone and Other Natural Disasters Scheme" (hereinafter the Disasters Scheme).

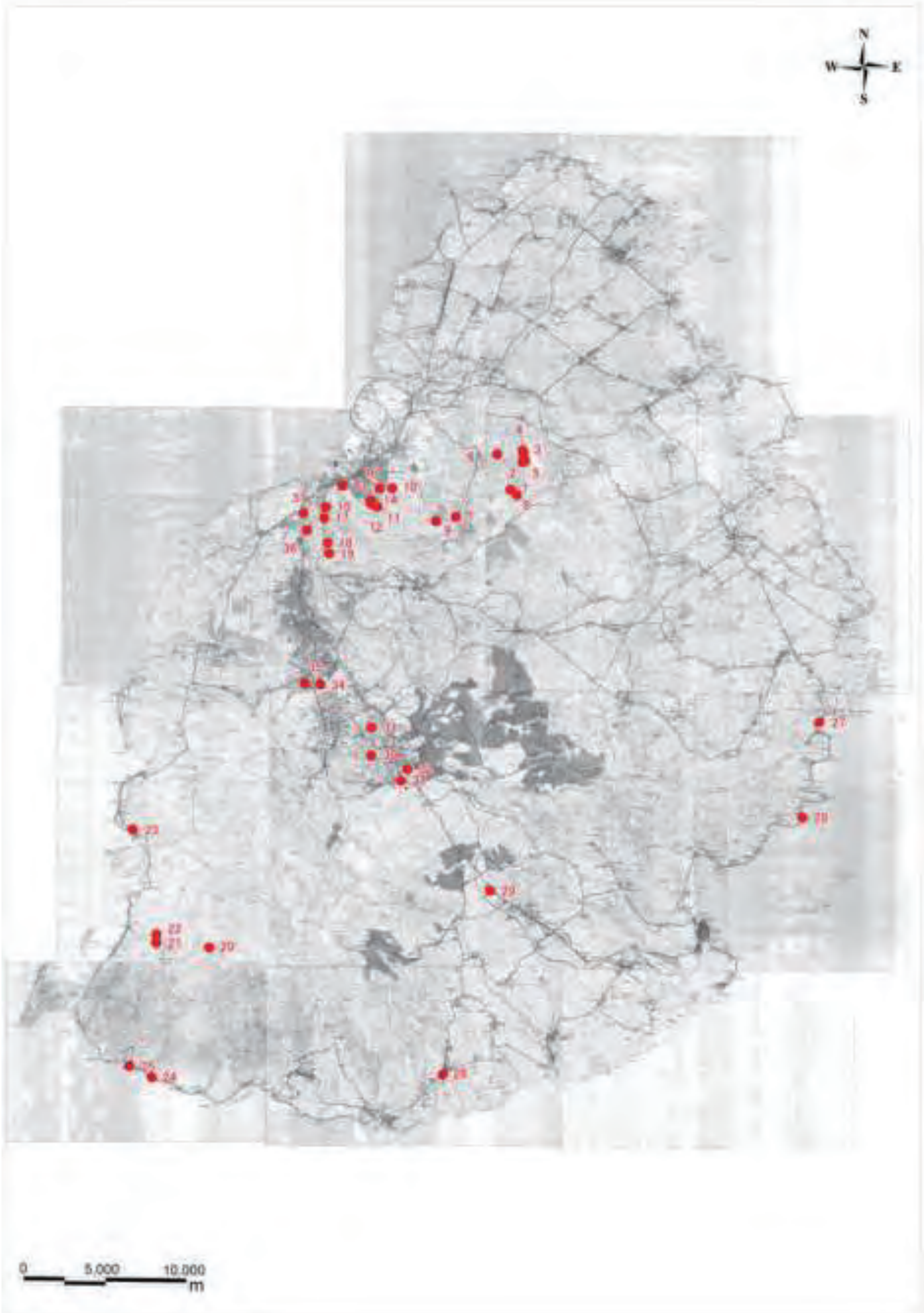


Figure 1.1 Location of the Slope failures, Rock Falls and Debris flows sites (source: JET)

Table 1.4 Inventory of the Slope failures, Rock Falls and Debris flows sites (source: JET)

(1): Landslide landforms and characteristic, (2): Damage on constructions and houses, (3): Existing record of Landslide

no.	Area name	Summary of the field investigation and interview	Kind of the disaster		Score of landslide hazard evaluation			
			General classification	Sub classification	(1)	(2)	(3)	Total
1	Temple Road, Creve Coeur	Deformation on a concrete block wall and a house caused by embankment deformation at the front yard (parking area) was confirmed. Another problem was the inadequate surface drainage causing surface water to flow directly from mountains to houses during heavy rain.	Other	Damage of wall	–	–	–	–
2	Congomah Village Council (Ramlakhan)	A small stream flows under the road through a concrete pipe culvert. However, it causes flooding and bank erosion during heavy rain because it is too small.	Other	Stream erosion	–	–	–	–
3	Congomah Village Council (Leekraj)	A 1m high retaining wall that was constructed to build the road was reported to be leaning, but it was found to be stable and no slope failure was observed.	Other	Damage of wall	–	–	–	–
4	Congomah Village Council (Frederick)	The 1m high retaining wall along the road was found to have collapsed due to erosion by surface water flow during the rainy season.	Other	Damage of wall	–	–	–	–
5	Congomah Village Council (Blackburn Lanes)	A slope failure was confirmed on the side of the road.	Other	Damage of Embankment	–	–	–	–
6	Les Mariannes Community Centre (Road area)	There are a few slope failures and a landslide in this site. The slope at the roadside collapsed during heavy rain in 2010 and a section of the road was washed away. Since then, a retaining wall has been constructed and the site is currently stable.	Slope	Slope failure	–	–	–	–
7	Les Mariannes Community Centre (Resident area)	There appeared to be bank erosion on the left bank above the bridge.	Other	Stream erosion	–	–	–	–
8	L'Eau Bouillie	Some cracks have been spotted on the road surface due to the deterioration of the bearing capacity of the roadbed. However, the cracks have been repaired.	Other	Damage of Embankment	–	–	–	–
9	Chitrakoot, Vallee des Pretres	A clear landslide was confirmed. A landslide was reported to have damaged houses and a school after heavy rain in 2005. Drilling investigation and monitoring have been carried out, but not sufficiently. No countermeasures have been implemented. Therefore, a detailed investigation and monitoring are necessary while the countermeasures are expected in the future.	Slope	Landslide	2	2	2	6
10	Vallee Pitot (near Eidgah)	Lately, housing developments are growing rapidly in this area. A landslide boundary of 35m x 20m was clearly detected. Several houses have been damaged and some cracks were observed. The situation of the damage was also reported in the newspaper.	Slope	Landslide	2	2	2	6
11	Le Pouce Street	An insufficient surface drainage leads rain water to concentrate in a low area and erode roads and houses in its path. Damage is negligible at present, although maintenance of the surface drainage will be necessary.	Other	Stream erosion	–	–	–	–
12	Justice Street (near Kalimata Mandir)	An embankment has been constructed to build up the road, which caused an adjacent retaining wall to be pushed out and deformed. An insufficient surface drainage causing accumulation of groundwater could also be a factor inducing this deformation.	Other	Damage of wall	–	–	–	–
13	Mgr. Lean Street and nearby vicinity, La Butte	The landslide of La Butte occurred in 1986, and many houses and a school were damaged. As for this landslide, countermeasures were carried out in 1998, therefore further investigation of the landslide is unnecessary. However, Port Louis City wants to continue the monitoring on this landslide in the future.	Slope	Landslide	2	1	2	5
14	Pouce Stream	Both sides of the channel are covered by concrete. The water level rises over the upper edge of the channel and erodes	Other	Stream erosion	–	–	–	–

		beyond this point in the rainy season. Gabions have been set at the lower part of the slope at the channel, and no damage has been reported yet. However, the deterioration of the concrete wall is remarkable and an extension of the wall height will be necessary. Therefore, further investigation and countermeasures are advisable.						
15	Old Moka Road, Camp Chapelon	The landslide topography is not clear, but five houses and two retaining walls were damaged and spring water was spotted in two places. There are two possible causes of this, creep transformation of weak surface soil or a shallow landslide. Therefore, landslide investigation and monitoring are necessary as countermeasures are expected in future.	Slope	Landslide	2	1	0	3
16	Boulevard Victoria, Montague Coupe	Gabions were installed on the cut-slope when the road was constructed. There is no record of damage for this site but the angle of the wall is steep. Therefore, the monitoring of this wall is advisable.	Other	Damage of wall	–	–	–	–
17	Pailles: (i) access road to Les Guibies, and along the motorway, near flyover bridge	The slope failure has been spotted along a cut-slope (5m height) at the roadside of the highway. The surface of the cut-slope is weathered, and it is being eroded by rain.	Slope	Slope failure	–	–	–	–
18	Pailles: (ii) access road Morcellement des Aloes from Avenue M.Leal (on hillside)	Insufficient drainage is causing erosion at the base of the water tank. An immediate remedial work is needed.	Other	Stream erosion	–	–	–	–
19	Pailles: (iii) Soreze region	Falling rocks at the upper slope and shallow slope failure at the middle and lower slope occurred in an area of housing. There is only slight damage for the time being, although shallow slope failure and cracks have been confirmed.	Slope	Slope failure	–	–	–	–
20	Plaine Champagne Road, opposite "Musee Touche Dubois"	Retaining walls have been constructed as countermeasures where slope failure has been confirmed. Slope failure is currently stable, although there were a few cracks spotted in the retaining walls which are believed to be due to substandard construction.	Slope	Slope failure	–	–	–	–
21	Chamarel: (i) near Restaurant Le Chamarel	Cracks in the road shoulder have occurred due to a lack of bearing capacity. It is caused by insufficient soil compaction.	Other	Damage of Embankment	–	–	–	–
22	Chamarel: (ii) Roadside	Deformation of the road has been confirmed at the shoulder of the road due to a lack of bearing capacity. The embankment was protected with stone masonry walls and retaining walls but they are insufficient.	Other	Damage of Embankment	–	–	–	–
23	Grande Riviere Noire Village Hall	A crack at the base of the Village Hall area and the edge of the concrete basketball court has been confirmed. However, the surrounding structures are not affected. Therefore, it is considered unlikely this damage was caused by landslides. It is rather likely to be caused by a lack of bearing capacity of the ground or a problem with the structure itself.	Other	Damage of house	–	–	–	–
24	Baie du Cap: (i) Near St Francois d'Assise Church	A debris flow has occurred in the past and a block wall has been constructed since then. Also, small surface failures have been observed frequently in this area.	Slope	Debris flow	–	–	–	–
25	Baie du Cap :(ii) Maconde Region	A new road was built to reduce the damage from Rock Falls. However, Rock Falls and small rock failures are also a frequent occurrence along the new road. The rocks are weathered, and there is a high possibility of Rock Fall in future.	Slope	Rock Fall	–	–	–	–
26	Riviere des Anguillans, near the bridge	There are many houses built on the cliff in this area. The cliff is weathered severely and stream erosion occurs frequently. Therefore, the houses will need to be relocated.	Other	Stream erosion	–	–	–	–
27	Quatre Soeurs, Marie Jeanne, Jhummah Street, Old Grand Port	Landslide activity has been confirmed at the Quatre Soeurs area where many houses have been damaged. The groundwater level at the lower part of the landslide is high and is causing instability in the landslide. Drilling investigation and monitoring have been carried out, but not sufficiently. Further investigation and	Slope	Landslide	2	2	2	6

		monitoring are necessary while countermeasures are expected in future.						
28	Bambous Virieux, Rajiv Gandhi Street (near Bhavauy House), Impasse Bholoa	Slope failure was confirmed in the backyard of the house. No damage on the house was reported although the soil of the slope failure reached near the house. A retaining wall has been constructed independently.	Slope	Slope failure	–	–	–	–
29	Cave in Union Park, Rose Belle	A cavity (4m x 4m x 3m depth) due to land subsidence was observed in the residential area. No damage was caused to the houses and the cavity was filled in with soil. A similar situation was confirmed nearby.	Other	cavern	–	–	–	–
30	Trou-Aux-Cerfs	A slope failure in the crater of the volcano occurred during heavy rainfall in 2005. The possibility of slope failure in the rear side of the crater is low. However, slope failure on both sides can be expected.	Slope	Slope failure	–	–	–	–
31	River Bank at Cite L'Oiseau	Bank erosion and floods are common during the rainy season when the river water level rises. There is more damage on the left side of the riverbank because water collides stronger on that side. However, damage suffered in the past has been restored by constructing a retaining wall.	Other	Stream erosion	–	–	–	–
32	Louis de Rochecouste (Riviere Seche)	Bank erosion and floods are common during the rainy season. The foundations of the houses have been eroded and the retaining walls of the houses are inclined.	Other	Stream erosion	–	–	–	–
33	Piper Morcellement Piat	Bank erosion and floods are common during the rainy season. However, the damage suffered in the past has been restored by constructing a retaining wall.	Other	Stream erosion	–	–	–	–
34	Candos Hill at LallBahadoor Shastri and Mahatma Gandhi Avenues	A clear landslide was confirmed in the backyard of the house. The landslide topography and slope are clear and spring water has been observed. The scale of this landslide is small (40m x 35m) and there are no houses on the landslide area. Only slight cracks have been confirmed on the retaining wall.	Slope	Landslide	2	1	0	3
35	Cavernous Area at Mgr Leen Avenue and Bassin	A cavity was reported during the house construction but it was filled with concrete. There is no further danger in this site.	Other	cavern	–	–	–	–
36	Morcellement Hermitage, Coromandel	A slope failure occurred in 2010, and a road was destroyed. After that, a retaining wall was made as a countermeasure, and large-scale slope failures have not been found. However, the stone blocks from the top of the retaining wall have fallen down. This is likely to be caused by the ground behind the retaining wall, which is sinking due to a lack of compaction of the backfilling soil.	Slope	Slope failure	–	–	–	–
37	Montee S, GRNW	Weathered outcrops were detected on both sides of a river bank. Erosion of the river bank is considerable during the rainy season.	Other	Stream erosion	–	–	–	–

1.2 Procedure Manual of Slope Failures, Rock Falls and Debris Flows

1.2.1 Basic Procedures and Contents

This procedure manual for slope failures, Rock Falls and debris flows has been prepared for the implementation of surveys and countermeasures from the structural point of view and non-structural aspects as well.

This manual covers what type and how to implement countermeasures to mitigate the disaster risk of slope failures, Rock Falls and debris flows, and also provides the MPI, National Disaster Risk Reduction and Management Centre (NDRRMC) and District Offices guidelines to carry out surveys/analysis and planning/design/construction of countermeasures for slope failures, Rock Falls and debris flows by themselves. It is also formulated based on the review of the early warning/evacuation procedures and the Planning Policy Guidance (PPG).

The scope of application of this manual is indicated in the following figure (Figure 1.2) and the detailed contents of it are in the table on the following page.

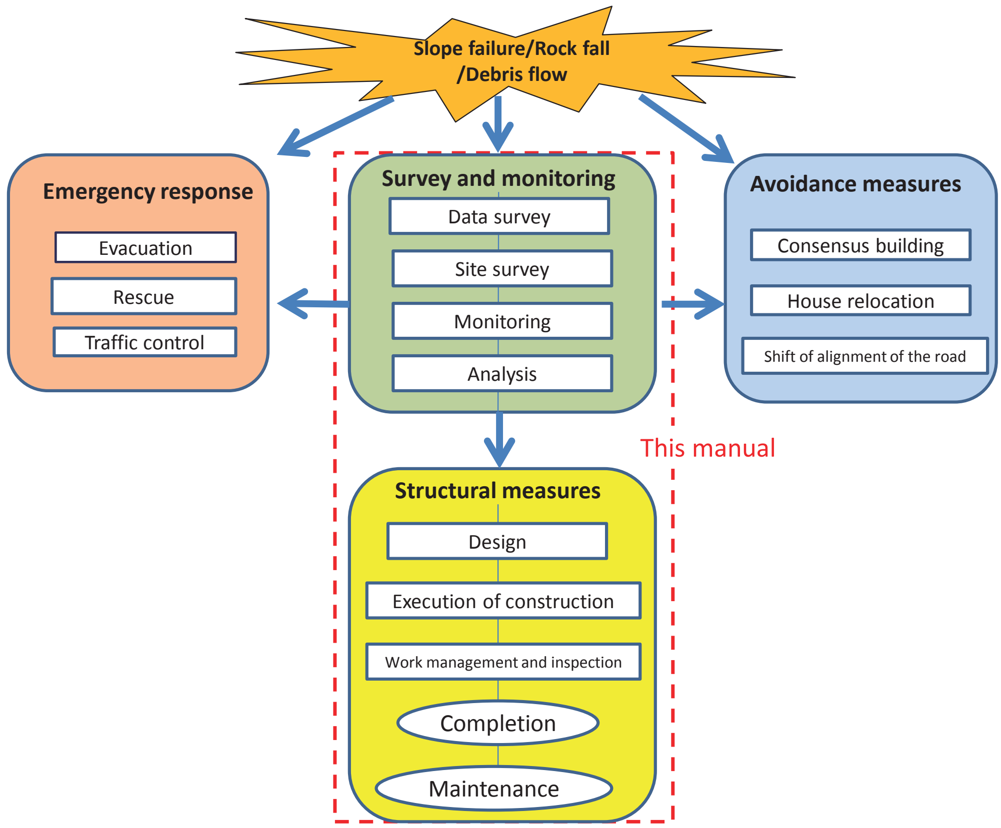


Figure 1.2: Scope of Application of the Manual for Slope Failures, Rock Falls and Debris Flows (source: JET)

Table 1.5 Contents of the Manual for Slope Failures, Rock Falls, and Debris Flows (source: JET)

Cp.	Title	Contents
1	Introduction	- Definition of landslides - Outline of landslides in Mauritius - Technical terms
2	Surveys, monitoring and analysis	- Introduction - Survey on slope failures - Survey on Rock Fall - Survey on debris flow - Survey on drainage system - Survey on retaining wall
3	Design	- Introduction - Cut slopes - Slope protection - Countermeasures for Rock Fall - Countermeasures for debris flow - Drainage - Retaining wall - Culvert
4	Execution	- Introduction - Slope work - Countermeasures for Rock Fall and debris flow - Construction of retaining wall and culvert, etc.
5	Work management and inspection	- Introduction - Execution management - Work inspection
6	Maintenance of structures	- Introduction - Maintenance of slopes - Maintenance of drainage facilities - Maintenance of retaining walls and culverts

The Landslide Management Unit (LMU) of MPI should renew appropriately the contents of the Manual after the Project for including more adequate and rational case studies based on the issues in Mauritius.

1.2.2 Proceedings of Slope Earthworks

The proceedings of slope earthworks have been discussed so far in terms of the stages involved. In this section, the actual proceedings are analysed in further detail and their connection with earthworks are described. Needless to say, there is no set formula for the proceedings of slope earthworks and the actual proceedings vary depending on the owner, type of project, scale of project and area.

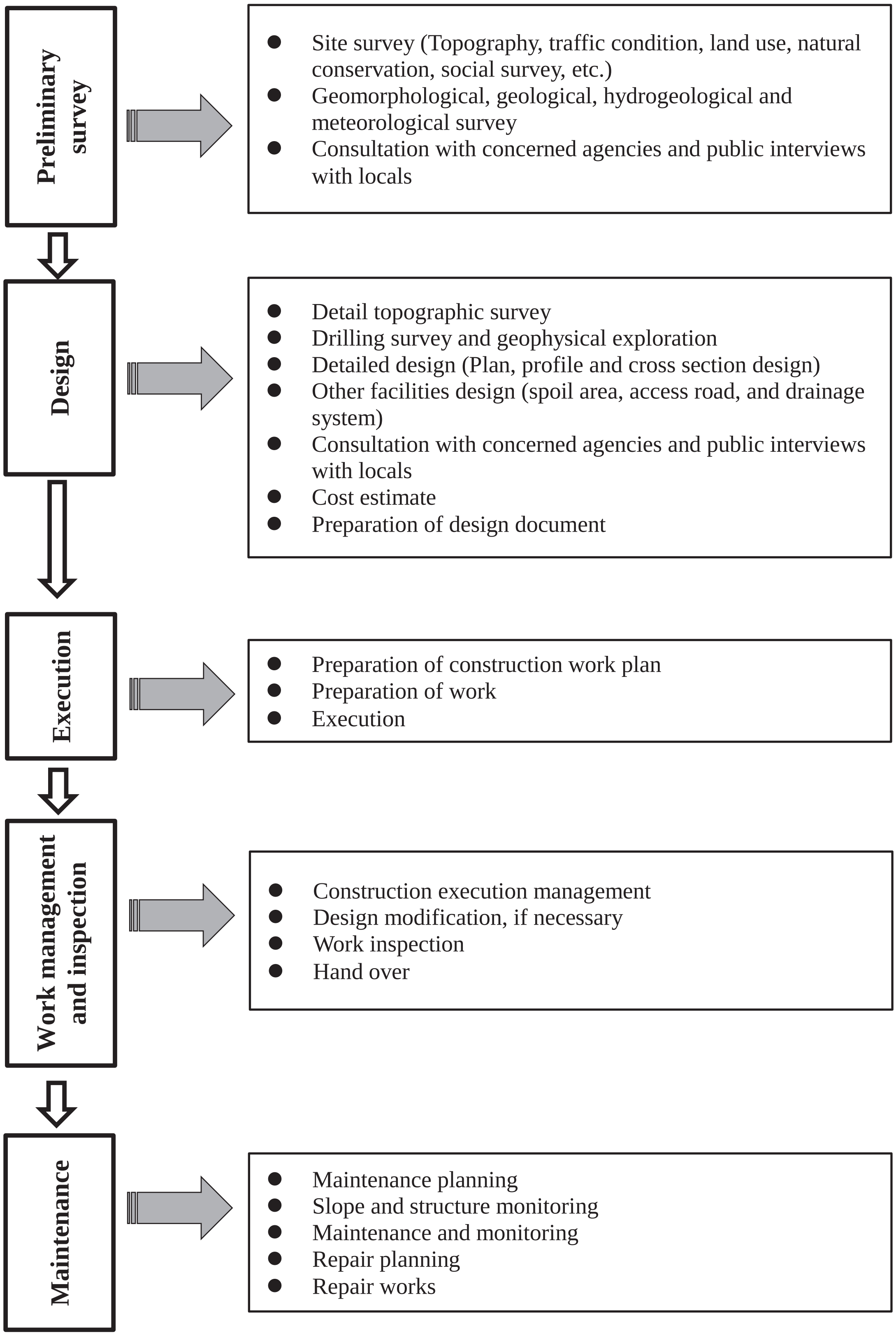


Figure 1.3 Flow Diagram of Slope Earthworks (source: JET)

(1) Preliminary Survey

Preliminary survey is carried out to consider many alternative countermeasures to suit the target slope condition. Multifaceted examination is carried out in view of natural aspects, such as topography, geomorphology, geology, vegetation and fauna, and in view of the social aspects, such as land use, communities and culture of the surrounding area. Therefore, it is necessary to survey the situation of related public works in progress and environmental issues, together with a full interview about the opinions of the district offices, as well as local residents and consultations to bodies related to the planned slope earthworks.

Slope earthworks planning at this stage outlines the slope profiles, basic geological cross-sections, appropriate cutting, banking volumes and the basic cross sections for slope earthworks. Accordingly, problems related to the topography or geology are identified. What is important here is to identify the places where slope earthworks are necessary.

(2) Execution Survey

An execution survey is intended to give concrete form to the plan and to transform the survey findings into actual project components. These are the most important works during the execution survey stage. However, it often happens that the topographical and geological data required for slope earthworks design are difficult to obtain by means of surveying on site. This is because of the circumstances surrounding the local communities which will be affected by the slope earthworks.

In order to produce a preliminary design in which the accuracy is higher than the Preliminary Survey stage, for the Execution Survey, existing materials, maps and aerial photographs, etc. are used, together with efforts to obtain as much detailed information as possible, including site reconnaissance results. At this stage, it is still not possible to formulate a detailed slope earthworks plan and the main activity is the examination of the work difficulty, the level of stability during the work, and the engineering and environmental conservation after completion of the construction works. One essential task for this examination is to ensure that the problems identified during the examination will not become fatal shortcomings which hamper the progress of slope earthworks. Even if measures to rectify these problems are available, they must be economically viable.

Special attention should be paid to the following items during the examination:

(i) Suitable cross-section for major cut slope and embankment,
(ii) Drainage system, including waste water disposal,
(iii) Stability of large-scale slopes and the suitability of slope protection works

The Execution Survey is followed by the announcement of the proposed countermeasures based on the findings of this survey and interviews with local people’s opinions.

(3) Survey for Detailed Design

Announcement of the proposed countermeasures are usually followed by consultations with local communities and the commencement of surveys and geological investigations in the countermeasure site.

At this stage, longitudinal levelling and cross-sectional surveys are conducted and geological investigations involving on-site drilling, soil sampling and in-situ tests are also carried out. The detailed design is then carried out based on the findings of these activities and concrete data on the countermeasure sites, borrow pits and spoil heaps. Since the detailed design is required to have sufficient accuracy as the basis for placing construction survey stakes, land acquisition, or order placement for construction works (cost estimation), it is essential to obtain all of the necessary data and reference materials in advance. Given the fact that slope earthworks planning is often severely restricted because spoil heaps cannot be secured, careful examination in this regard is essential at this stage.

(4) Detailed Design

At the Detailed Design stage, countermeasures for the cross sectional configuration of cut slopes, such as retaining walls, culverts and slope protection structures, etc., are designed based on the geological investigation results. In regard to slope earthworks, an appropriate design involves balance between the cutting volume and examination of the stability and workability of the cut slope, in view of the site topography and geology. As slope earthworks are strongly affected by surface water and groundwater, a plan for drainage during and after the works should be carefully prepared. One important point is to give transverse channels a sufficiently large cross-sectional area to avoid insufficiency in the future due to an increase of the water discharge when the drainage basin is further developed. It is also necessary to examine suitable temporary construction roads that connect with borrow pits and spoil heaps, during the works for slope earthworks.

Another important point for the design works at the Detailed Design stage is to make all of the structures easy to inspect and repair, in order to ensure easy maintenance of the slope structures.

(5) Cost Estimation

At the Cost Estimation stage, the countermeasure work areas are divided into work sections, and Cost Estimation is carried out for each work section, based on the Detailed Design for the order placement of construction works. Firstly, the schedule for each type of work is determined based on the geological investigation results and other relevant information. During this stage, the contents of the construction plan should also be outlined, including transportation plan, selection of the construction machinery to be used, calculation of the work capacity and preparatory works. The cost for each type of work is then estimated and totalised.

(6) Construction Work

As slope earthworks involve many factors, such as the geological conditions, which are uncertain and difficult to establish in advance, it is important to introduce a regime under which the site conditions are constantly monitored, with a view to conducting a survey or analysis of any problem which is encountered. Thereby, an appropriate judgement can be made and remedial measures can be quickly implemented before a problem is beyond remedy.

Prior to the commencement of the Construction Work, the design documents, drawings and specifications should be carefully examined, and the site conditions should be accurately identified. In addition, the relevant data and information produced during the surveys implemented so far and the local situation, etc., should be carefully analysed to build up a precise understanding of the concepts harboured by the designers.

For slope cutting works or embankment works, it is essential to fully investigate the relationship between groundwater/surface water and the soil properties. The workability and work quality can be significantly affected by the season when the works are carried out, due to a substantial rise of the groundwater level and rainfall. Therefore, the timing of order placement for construction works and the construction period must be properly arranged. In the case of slope earthworks on mountainous and hilly areas, the actual geological features of the cut slopes and the ground of the foundation of the structures, such as retaining walls, may not necessarily be previously anticipated. The encountering of problematic geological features is not a rare occurrence. A flexible system to deal with these problems as they arise is required, as well as the implementation of a geological investigation, including drilling and test pitting, with a view to examining possible countermeasures. This is particularly important to ensure a safe progress of the construction work.

(7) Inspection

Inspection is carried out to check whether or not an entirely or partially completed work meets the contract conditions, for the purpose of ascertaining the degree of completion of the target work. Inspection may also be carried out after a certain stage of the work, in order to determine whether or not it is justifiable to advance to the next stage, likewise in the case where verification of the work quality after completion is thought to be difficult. Inspection is carried out for evaluating both, the quality of finished work and the quality of completed structures. In this manual, the finished work quality means the location, dimensions and quantities of the slope earthwork structure(s) created for the target work, while the quality of the completed structures means the degree of compaction and strength of the soil of which the target slope earthwork is made.

Inspection usually consists of sampling, supplemented by visual observations and other means. The inspection method to be adopted must be simple, effective and highly accurate, taking into consideration the work contents, required time and cost of execution. For example, the number of inspections for the finished work quality must be increased in places where the cross-section pattern/characteristics significantly changes. When points where the continuity of the work is poor is identified through visual observation, appropriate measures, including additional measuring, should be implemented. In regards to the test on the degree of compaction, which is a part of the quality inspection, special attention should be paid to those places which are possibly weak points of the slope earthworks to ensure effective inspection, such as slopes near to slopes of embankment or slopes near to other slope structures.

(8) Maintenance

Once the Construction Work is completed, a slope earthwork with its structures is handed over to the structure owner. Adequate maintenance is required for these slope protection works in order to extend its specific functions for a longer time.

The monitoring regime and method to constantly maintain the slope protection works in good condition are described in this manual.

Heavy rain may cause slope failure, soil outflow (due to clogging of the drain ditches), collapse of an embankment or retaining wall (due to poor drainage), scouring of the wing walls at the intake or outfall sections of a transverse drainage channel, and/or settlement on the slope earthwork sections of a road and slope area. Moreover, scouring of a road often takes place due to the massive overflow of rainwater from drainage ditches or the inflow of a large volume of water from an access road, etc., in a very short period of time. This is caused by an insufficient capacity of the drainage system.

Connecting sections between cut slopes and embankments tend to suffer from faulting or differential settlement after some time, even if the work is carefully executed, creating maintenance problems for a long period of time. At weak ground sections where residual settlement often occurs, it may be necessary to change the composition of the surface, including the introduction of provisional paving materials, and to readjust the timing of the paving works.

While some of the problems mentioned above cannot be predicted in advance, others may be prevented with the implementation of appropriate measures during the Construction Work. Consideration of the long-term maintenance requirements during the Survey, Planning and Design stages, are the key points to achieve preventing the problems. Work records, design drawings for Construction Works, geological survey data, etc., must be routinely filed and kept as they are useful for the maintenance and reparation of earth structures, and also for the planning of post-disaster rehabilitation measures.

1.3 Explanation of Technical Terms

The names and definitions of the components of slope earthworks and the main technical terms used in this manual are given below (see Figure 1.4).

(1) Slope

A slope may include a natural slope or an artificially created slope by earthworks, i.e. a cut slope or an embankment slope. In normal circumstances, in this manual, a slope will refer to a cut slope or an embankment slope. Meanwhile, slope protection works mean covering a slope with vegetation or structures for the prevention of erosion, weathering or slope failure.

(2) Embankment Slope

The slope section of a structure made of compacted soil, usually constructed for river embankments, residential development, road construction, etc., is called Embankment Slope.

(3) Cut Slope

The slope section of cut/excavated ground, usually made for residential development, road construction, etc., is called Cut Slope.

(4) Retaining Wall

A retaining wall is a type of structure that supports earth materials from collapsing. It is constructed when soil of earthworks cannot achieve the required stability on its own, because of sight conditions, topographic factors, etc. There are several different types of retaining walls, including masonry retaining walls, concrete block retaining walls, gravity retaining walls, cantilever retaining walls and reinforcement walls.

(5) Culvert

A culvert is a type of structure created through an embankment or the original ground, to secure the space for a road or water channel crossing under another road constructed beneath the target embankment or target original ground. Based on their mechanical characteristics, culverts are classified as either rigid culverts or flexible culverts. There are many types of rigid culverts, including box culverts, portal culverts, arch culverts and pipe culverts, while the types of flexible culverts include corrugated metal culverts and rigid polyvinyl chloride (PVC) pipe culverts.

(6) Temporary Structures

Temporary structures are the structures which are temporarily built to construct the permanent structures and include earth retaining cofferdams and temporary piers.

(7) Drainage

Drainage from slopes and artificial areas, such as reclaimed lands and roads have many forms, including surface drainage, sub-surface drainage, slope drainage, drainage from the backfill of a structure or from inside a structure, and transverse drainage of a road, such as a culvert, depending on the amount of water, etc. that needs to be drained.

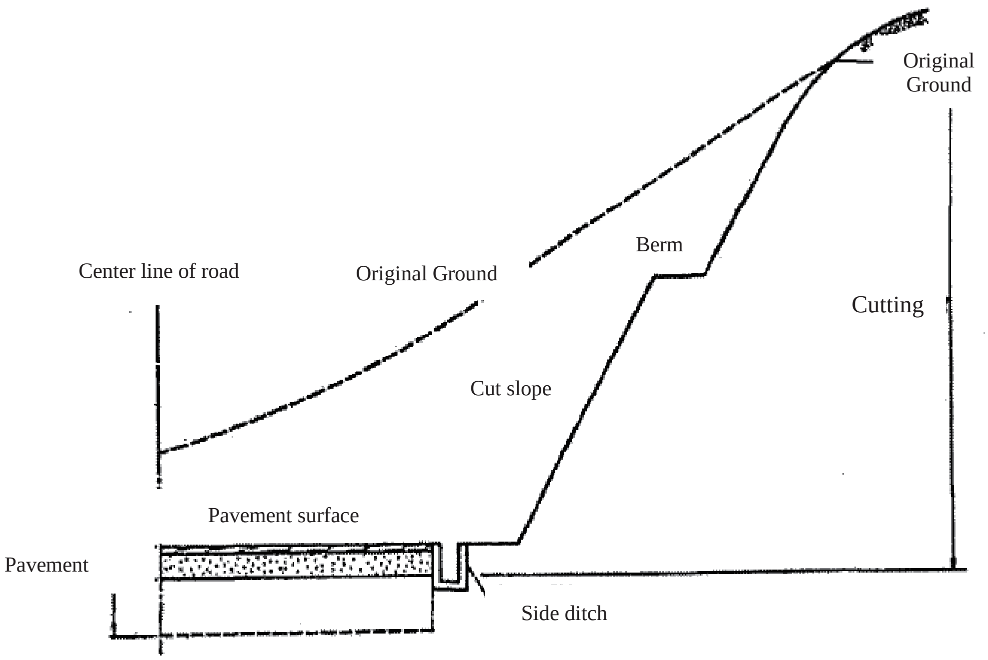


Figure 1.4 Cross Section of Cut Slope of Road (source: PWRI, 2004)

2 Surveys

2.1 Introduction

2.1.1 Relationship between Procedure of Slope Earthwork and Soil Investigation

Figure 1.3 indicates the flow of slope earthwork and the survey required at the various stages of such construction. As it can be seen from the figure, the types and the required accuracy of the survey differ by the stage of the construction and it is necessary to undertake appropriate surveys using appropriate methods with consideration given to the local conditions and characteristics of the site in question.

Surveys that are considered closely linked to slope earthworks may be categorized into site investigation (including topographic survey and geological survey) and other surveys (survey of the weather, environment, etc.), and the site investigation is the most important from the engineering point of view. For this reason, the basic policies in undertaking such surveys will be detailed including points and matters, such-as cut slope, embankment, drainage, soft ground, Rock Fall, landslides, debris flow, retaining wall and culvert. Only simple explanation is provided on surveys other than soil investigation.

Details of the method of investigation and test are addressed according to related standards.

2.1.2 Survey Method

(1) Preliminary Survey

Collection of relevant existing data (topographic maps, geologic maps, geological and soil investigation reports of other construction works in the vicinity, construction records, disaster records, etc.), interpretation of aerial photographs and site reconnaissance are the principal activities undertaken as preliminary survey.

However, for areas that may exert significant impact on the land development planning, road route planning, the slope protection structure, road structure and construction cost, preliminary survey is ought to be undertaken as far as possible. Special attention should be given to factors such as failure and landslide prone areas, and/or areas where large scale ground cutting, geophysical exploration, sounding or drilling is expected.

(2) Main Survey

The main survey is undertaken prior to the detailed design. In addition to performing an overall survey of the soil and geological conditions of the entire area, the purpose of the survey is to clearly identify the soil and geological conditions of areas where problems may arise during the construction works on the slopes. The main survey is undertaken for the entire area as well as the surrounding area of the slopes.

When selecting concrete points at which the survey is implemented, it is desirable to prioritise sections that need particular review from the perspective of topography and structures, such as infrastructures and buildings. However, since it is difficult to obtain all the information concerning soil and geological properties through a single survey, and since the structure to be constructed is not clearly determined at the time the survey is undertaken, the soil and geological conditions should be identified in a general manner by first carrying out soundings, drillings, sampling and testing of soil and rock properties with appropriate intervals in the study area. Moreover, in the event that the structure to be constructed is changed, as the detailed design of the construction progresses, further specific survey should be undertaken with respect to places where the soil and geological conditions or the geomorphological conditions are complex, and places where large or special structures are expected to be constructed.

The main survey generally involves drilling as the primary method. In theory, the depth of the drilling survey is up to a depth where the bearing stratum is identified to a thickness of five meters in normal locations. However, in locations where ground cutting is to be implemented, drilling is performed to a depth of two meters below the ground surface and in locations prone to landslides, drilling is performed deeper than the assumed slip surface. Moreover, for the foundations of structures other than bridges, the Standard Penetration Test (SPT) value shall be 15 or more, and for the foundation of large structures, drilling shall be performed until adequate deepness where the bearing stratum required for the assumed structure’s foundation is confirmed.

2.2 Survey on Slope Failures

2.2.1 Checkpoints of Survey

Generally, the geological structure and properties of soils change considerably for grounds which have been cut to form the cut slopes. Therefore, it is extremely difficult to determine the detailed properties and characteristics prior to the execution of slope earthworks, and it is especially difficult to theoretically preview the stability of planned cut slopes from the results of the soil and geological surveys. Nevertheless, it is required to determine the properties of the soil and rocks of the ground, the presence or absence of slope failure hysteresis, and the influence of groundwater, by performing soil investigation and geological surveys at some typical points in the sections where the works will be carried out.

Especially, the design of a large cut slope greatly affects not only the construction cost but may cause slope troubles during the period of construction and maintenance. Therefore, appropriate surveys suited to the purpose must be selected and performed. It is required to survey and test the excavated soil if it is to be used as filling materials.

The main checkpoints of surveys for cut slope are:

- ✓ Stability of cut slope
- ✓ Stability of adjacent natural slope (see 2.3 for Rock Fall and 2.4 for debris flow)
- ✓ Difficulty in excavation
- ✓ Change of groundwater level in adjacent ground due to excavation (see 2.5 for drainage system)

2.2.2 Cut Slope and Natural Slope Failures

Cut slope and natural slope failures have different shapes based on their principal conditions, i.e. soil, geological structure and groundwater conditions, etc., and the secondary conditions, i.e. width of the cutting, shape of the slope, rainfall, etc.

Slope failures can be roughly classified into the following types as shown in Figure 2.1.

2.2.3 Survey on Cut Slope Stability

In the case of cut slopes, an ordinary survey should begin with the preliminary survey described in 2.1.2. This preliminary survey is performed to study the actual condition of the existing slopes, to judge the presence or absence of slope failure, debris flow and Rock Fall hysteresis, and also to determine the groundwater conditions, based upon a rough survey on geology, soils and their structures. The results of the survey are used for determining the rational survey plan for the main survey to be performed in the next stage.

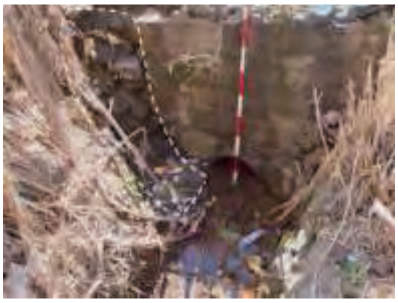
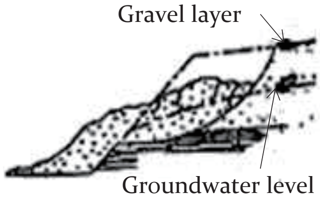
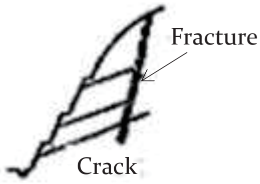
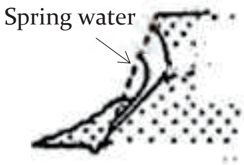
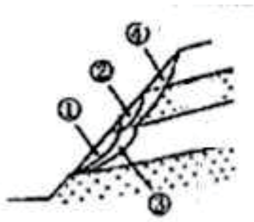
Category 1 Erosion/fall	 
Category 2 Surface Failure	 
Category 3 Large-Scale Failure/ Landslide Type Failure	 

Figure 2.1 Classification of Slope Failures (source: JET)

Table 2.1 Classification of Cut Slope and Slope Failures (source: PWRI, 2004)

	Description	Type of Failure		Description	Type of Failure
1. Erosion/fall	1) Separation of the surface or production of gullies by repeated drying and wetting, and rain could conduct to a deep failure	 Gully erosion by surface water	3. Large-Scale Failure/ Landslide Type Failure	1) Large-scale sliding of a slope consisting of a loose layer with a low angle of consolidation, or a slope with unstable factors in terms of the geological structure when the ground water level rises	 Slipping along surface of discontinuity in terms of permeability
	2) Fall of overhanging parts on a slope			2) Large-scale slipping of a rock body which has a geological structure such as a dip slope, a fault or a fracture zone	 Sliding along fault fracture zone
	3) Fall of rocks with plenty of cracks and joints	 Loose stone type Rock Fall		3) Toppling of a dip slope or rocky slope with developed cracks	 Toppling of dip slope
2. Surface Failure	1) Sliding of the highly weathered rock layer due to the slipping of top soil, often induced by spring water	 Failure caused by piping			
	2) Sliding of the surface layer as a result of weathering, etc.	 Surface failure with weathering advancing, etc.			
	3) Sliding of rocks along a dip slope structure or cracks in the bedrock with joints, a small fault and/or a thin layer	 Failure along cracks of rock			

The main survey is performed for detailed design of the slope and may be made in two or more steps if required. The main survey is to be performed in addition to the results of the preliminary survey to find the detailed condition of geology, and various parameters and information required for designing and reviewing the places that may be prone to or have stability problems.

The survey on the natural slope above the cut slope is also performed in accordance with the survey procedure for cut slope.

Table 2.2 indicates the relationship between the main points of the survey and the survey method at the cut slopes.

Table 2.2 Focal Points of Survey at Cut Slopes and Survey Methods (source: PWRI, 2004)

Survey method / Main focal points of survey		Site reconnaissanc	Geophysical exploration					Drilling survey	Test pit	Sounding	Borehole TV	Soil test	Rock test	Ground water survey	On-site measurement
			Elastic wave exploration	Elastic survey	Underground radar	Elastic logging	Velocity logging								
Soil properties and lithology		◎	○	△			△	◎	△	△	△	◎	◎		
Geological structure	Geological structure	◎	○	△		△	△	○	△		△				
	Fissures and cracks	◎	△		△		△	◎	△		○		○		
	Weathering	○	○	△		△	△	◎	△	○	△		△		
	Soil	○	○	△	△		△	◎	△	○	△				
Ground strength			△				△	○	△	○		◎	◎		△
Deformation		◎													○
Ground water condition		○		○				○	△					◎	
Fluctuation of groundwater level								○	△					◎	

Note:

1) Soil properties means the type of the soil, state of stratification, change of strength in the depth, degree of hardness and state of compaction, while lithology means the name of the rock, state of stratification, degree of vulnerability to weathering and degree of cracking etc.
2) ◎:most frequently used method, ○:frequently used method, △:supplementary method

Careful thought is required to determine the drilling sites. Drilling should be carried out at problematic sites from the viewpoint of slope stability wherever found during the site reconnaissance. In the main survey, drilling should be carried out along the middle line of the slope at sites where the topographical or geological features change. It is desirable to carry out several additional drillings at sites which are found to be problematic in terms of slope stability, or at sites with a large-scale slope according to the results of the preliminary and main survey. At sites where elastic wave exploration is carried out, it is desirable to carry out drilling surveys at the crossing points of the lines.

2.2.4 Survey on Slope Failures Requiring Extra Precautions

(1) Cuts in Colluvial Deposits and Highly-Weathered Rock Slopes

In the case of cutting unstable ground such as talus which has a low degree of solidification, weathered rock slope, volcanic mudflow deposit, and zones where slope failure has occurred previously, the site reconnaissance should be performed in the first place. It is required to determine the groundwater level and the SPT values from the results of drilling, the grain size distribution (condition of matrix) from the results of soil test, and the state of stratification from the elastic wave exploration. In addition, it is required to fully survey the main factors which may control the stability of slope such as the relation between the depth of cutting and groundwater level, the state of solidification of the matrix and the grading, dip of bedrock, and the presence or absence of hysteresis of slope failures in the past. The results of this survey should be reflected in the design.

(2) Cuts in Erodible Soils

Sandy soils are easily eroded by the surface water, and sometimes resulting in Rock Falls, slope failures or outflow of soil. In order to determine the slope gradients for such soils or to design slope protection works, it is necessary to make a comprehensive review of the degree of solidification and the erosion resistance by considering the SPT value, and the sand and silt content by grain size analysis. It is also necessary to analyse the results of the erosion resistance testing and the survey of the actual condition on the existing slopes.

(3) Cuts in Easily Weathered Rock such as Mudstone

For slopes cut in rocks with a low endurance against weathering, the appropriate gradient of slope cut should be determined after comprehensively evaluating the velocity of elastic waves through the ground, the unconfined compressive strength of sampled cores, and the relation between the thickness of weathered zone of existing slopes. Also the period of time which has elapsed after the cut was made as well as the results of the dry-wet repeating test should be evaluated.

(4) Cuts in Rocks with Numerous Fissures

The stability of slopes cut into rock is mainly controlled by faults or the degree of fracture, as well as by conditions of fissures having certain regularity, such as bedding stratification, foliation and joints. The properties of rocks and the conditions of fissures should be fully studied through the detailed observation of the existing slopes and outcrops, and a comprehensive engineering evaluation should be made based upon the core recovery (R.Q.D.), and calculations of index of degree of fissuring, in addition to the elastic wave exploration. If the direction of the fissure inclination has a regularity in a certain direction and coincides with the direction of the slope inclination (that is, if there is dip slope), then an extremely unstable slope may have formed, which requires a careful survey performance.

(5) Cuts in Ground with a Large Amount of Groundwater

It can be said that most causes of slope failures are related directly or indirectly to groundwater. The groundwater can be evaluated by various methods such as drillings, electric prospecting and pumping tests. An appropriate type of survey should be selected and performed taking account of the field conditions.

(6) Cuts with Large Slope

Large slopes are rarely composed of uniform and rigid soil, and are more often composed of weak layers such as weathered layers, faults and fractured layers. In particular, when cutting through cols, since cols (saddlebacks) are often fault fractured zones, the degree and direction of the fracture should be confirmed through drilling or elastic wave exploration.

Moreover, rocks containing a large amount of montmorillonite that is said to be expansive rock may often be judged to be relatively hard rock through in situ tests (SPT, elastic wave exploration) at points where the depth of the soil covering the rock is large. However, in large slopes, a large amount of stress is relieved and significant secondary decline of strength occurs after the ground cutting.

In particular, for large slopes, since changes of configuration of slope (re-cutting) during the cutting is disadvantageous from the perspective of construction cost and efficiency of work, detailed survey of the soil property and condition of ground water is required.

(7) Rock Falls and Slope Failures from Area above the Cut Slope

In order to prevent the Rock Fall and slope failure from the area above the cut slope, it is required to investigate the stratum, unembedded rocks and boulder stones with the potential of slope failure or Rock Fall. The history of such incidence should be understood from site reconnaissance, topographic map or aerial photograph interpretation, and appropriate countermeasures to be taken against possible incidence should be studied in advance.

2.2.5 Surveys for Planting

The following surveys should be carried out to meet the preconditions for the completion of planting.

1) Observation of the local environment and vegetation

When a planting target area has been established, the possible impacts of planting work and the planned species on nearby plants are examined to achieve continuity and harmony between the slope of construction and its surrounding environment.

2) Survey on the weather

The temperature, rainfall, wind and sunshine, etc. are surveyed to examine the suitable selection of plants, timing of planting and planting method.

3) Survey on the slope at the time of cutting

4)

(a) Survey on the slope shape and others

The shape, size, height, bearing, gradient, location of spring water, degree of undulation and locations of drainage ditches and structures are surveyed at the slope of construction work for the selection of suitable plants and the examination of workability.

(b) Investigation on the soil characteristics
The soil hardness, soil texture and soil acidity, etc. are investigated for the selection of suitable plans and the examination of other relevant matters.

5) Utilisation of the survey results

As planting involves live materials, the site conditions significantly affect the success of the work. Important points for utilisation of the survey results for the design and execution of planting are listed in Table 2.3 and Table 2.4.

Table 2.3 Gradient and State of Plant Growth (source: PWRI, 2004)

Gradient	State of Plant Growth
Gentler than 1:1.7 (less than 30°)	▪ Restoration of the vegetation dominated by trees is possible. ▪ Local species find it easy to invade from the surrounding area. ▪ Plants grow very well. Once vegetation is covered, surface erosion virtually disappears.
1:1.7 — 1:1.4 (30° — 35°)	▪ A gradient of less than 35° is required to allow natural invasion from the surrounding area to form plant communities* when the site is recovered to nature.
1:1.4 — 1:1 (35° — 45°)	▪ Medium high trees and shrubs are dominant and the creation of plant communities where herbaceous plants cover the ground surface is possible.
1:1 — 1:0.8 (45° — 50°)	▪ The creation of low height plant communities consisting of shrubs and herbaceous plants is possible. ▪ The introduction of trees may destabilize the foundations.
Steeper than 1:08 (more than 50°)	▪ Slope protection works other than planting are required.

* Plant Community: A group of plants with a virtually uniform appearance and species, such as forest or grassland, and used as a classification unit for vegetation. The planting targets are expressed as such community types as grassland type and shrub land type, etc.

Table 2.4 Soil Hardness and State of Plant Growth (source: PWRI, 2004)

Soil Hardness Test	State of Plant Growth
Less than 10 mm	▪ Germination is poor because of dryness. ▪ The land is vulnerable to failure if the gradient exceeds the angle of repose.
Clayey Soil: 10 — 23 mm Sandy Soil: 10 — 27 mm	▪ Growth of the root system is good (in the case of herbaceous plants, the soil should be fertile). ▪ The soil is suitable for tree planting.
Clayey Soil: 23 — 30 mm Sandy Soil: 27 — 30 mm	▪ Growth of the root system is hampered except for some woody species.
Higher than 30 mm	▪ Growth of the root system is almost impossible.
Soft Rock/Hard Rock	▪ Growth of the root system of woody plants is possible where the rock has cracks.

2.3 Survey on Rock Fall

2.3.1 Checkpoints of Survey

The types of Rock Falls are, as shown in Table 2.5, “uprooting type (boulder type)” and “flaking type”. These differ in their mechanism of occurrence and this categorization is fundamental to evaluating the possibility of Rock Fall occurrence or planning countermeasures for Rock Falls.

Survey on Rock Falls needs to be divided into 'survey for planning and design' and 'survey for undertaking countermeasures', and implemented taking into consideration the following points:

1) Possibility of Rock Fall (frequency of occurrence, weather conditions, etc.);

2) Extent and type of Rock Fall (size and location of objects that originate Rock Falls, categorisation into the uprooting type or flaking type);

3) Dynamics and path of the Rock Fall (sliding, rolling, bouncing, etc.);

4) Margin at the sides of the road or houses;

5) Extent and range of Rock Falls reaching the road and houses; and

6) Condition of the ground at locations where preventive countermeasures need to be undertaken.

Table 2.5 Classification of Rock Fall (source: PWRI, 2004)

Category	Description	Schematic Drawing	Typical Geological Features	Remarks
(1) Uprooting Type	1) Dropping of gravel located on a sandy slope containing gravel		Terrace and pyroclastic material, etc.	
	2) Sliding down of gravel contained in the sediment above the bedrock		Heavily weathered rock on talus, colluvial soil, hillside slope or cut slope	Loose stone type rock fall may occur depending on the relative positions of the bedrock and sediment.
(2) Flaking Type	1) Exfoliation along the surface of discontinuity in the bedrock		Bedrock with many cracks or continual cracks	Different forms, such as sliding, falling over and falling, take place depending on the directions of the slope and cracks; special attention is required in regard to the degree of looseness.
	2) Exfoliation of the surface of a highly weatherable or erodsible bedrock		Weatherable soft rock or alternation of soft and hard rock layers from the Neogene onwards	The scale is generally small but the falling of large rocks may occur at an overhang section of alternated soft and hard rock layers.
(3) Others	1) Increased instability of residual boulders, etc. on a ridge due to weathering or erosion		Weathered granite, etc.	Not frequent but tends to be on a large scale.

Based on the above points, site surveys shall be undertaken using the following methods and considering the following factors.

1) Survey of existing materials: Survey of literature and records of past Rock Falls, survey of the weather upon occurrence of Rock Falls in the past;

2) Interpretation of aerial photographs: Size and location of objects that originate Rock Falls, condition of the path of Rock Falls, positional relationship of slopes where rocks falls occur and the road and houses, roughness of the slope, vegetation, etc.;

3) Site reconnaissance: Size and position (coordination by GPS) of objects that originate Rock Falls, possibility, status of plants, detailed topography of slopes, stability and influence to the road and houses etc.; See the Rock Fall Inventory Instruction in the Appendix.

4) Weathering condition of the slope, density of fissures in the slope, depth of base rocks, strength of ground, etc.

2.3.2 Survey on Rock Fall Requiring Extra Precautions

(1) Steep Slope with Protrusions in the Cross Section

Slopes that have protrusions in the cross section profile (perpendicular to the contour lines) or in the plane section may result in fallen rocks hitting the protrusions and rising or jumping to an abnormal height. The topology of such slopes needs to be investigated in detail.

In particular, slopes with overhangs are prone to Rock Falls and geological conditions need to be surveyed in detail.

(2) Steep Valley Shaped Slopes adjacent to Roads or High Natural Slopes above Cut Slopes

When rocks fall on plane surface slopes, the fall trajectories are macroscopically perpendicular to the contour lines. Accordingly, Rock Falls at slopes with protrusions (ridge shaped) as shown by the arrows (a) in Figure 2.2 are prone to have fall trajectories falling in various directions, while at slopes with indentations (valley type), the fallen rocks generally concentrate along the valley lines. In the case of steep and high slopes such as the one shown in Figure 2.2 (c), the probability of the occurrence of Rock Falls is high, and when such Rock Falls occur, it is highly possible fallen hit roads and houses with a considerable amount of energy. For this reason, caution needs to be taken with this kind of slope.

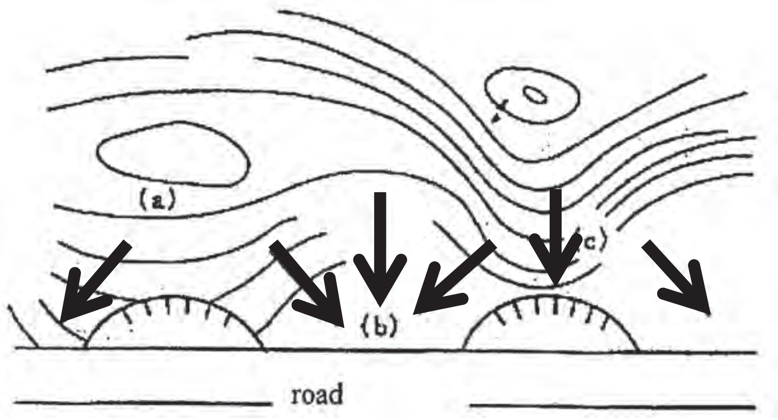


Figure 2.2 Plane view of slope and Rock Fall trajectory (source: PWRI, 2004)

(3) Slopes with Rock Types and Rock Properties that Require Special Care

Among rock types and rock properties that comprise slope surface or slopes, particular care is necessary for alteration of strata with mud stone and sandstone, lava and pyroclastic materials. Moreover, highly welded tuff and regular tuff generate fissures that can cause Rock Falls.

(4) Slopes with History of Disaster due to Rock Falls

Rock Falls tend to occur relatively in the same place successively, therefore it is said that in those places such phenomena are frequent. For this reason, past damage from slopes and in particular slopes that have history of Rock Fall occurrence need to be investigated to the extent of what was the weather condition and how was the Rock Fall generated.

(5) Slopes where Changes with time are identified in their Shapes

With respect to slopes where localized changes in their shapes with the passage of time is identified, such as slopes where the probability of uprooting type Rock Falls is increasing with the progressive exposure of rock masses, boulder or cobble due to matrix erosion, or where the probability of flaking type Rock Fall is increasing, due to enlargement or loosing of rock fissures causing instability in rock blocks surrounded by fissures, particularly detailed survey needs to be undertaken. In such cases, the current state of the change and its progress forecast needs to be estimated to evaluate the probability of Rock Fall.

2.4 Survey on Debris Flow

2.4.1 Checkpoints of Survey

A debris flow is a phenomenon in which soil, weathered base rock, valley deposit and colluvial deposit at the bottom of a valley or upstream moves as a result of heavy rain and flows in hydraulic jump out of the valley. There are four main types of debris flows as shown in Table 2.6.

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.

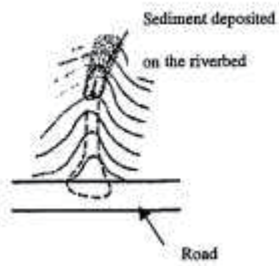
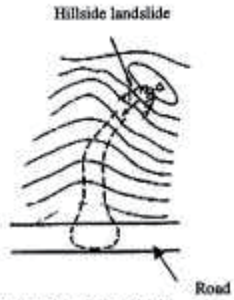
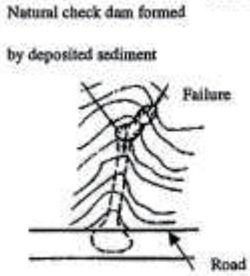
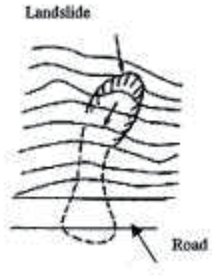
1) Possibility of a debris flow occurrence (frequency of occurrence, weather conditions, etc.)

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

3) Area likely to be inundated by the debris flow

4) Presence of existing facilities for debris flow control and its configuration and size.

Table 2.6 Classification of Debris Flow (source: PWRI, 2004)

Category	Description	Schematic Drawing
(1) 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	
(2) 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	
(3) 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	
(4) Fluidisation of landslide soil mass	Fluidisation of a cohesive soil mass with a high water content originally produced by a landslide	

In the event that a planned road or development area would cross over a mountain stream, where the occurrence of debris flow is anticipated, by a bridge, a culvert and/or a channel, the peak amount of discharge, the flow velocity, the maximum wave height and the maximum gravel diameter of the estimated debris flow should be investigated, in order to provide a benchmark for reviewing whether or not the debris flow will cause damage to the bridge, culvert and/or channel.

2.4.2 Survey on Occurrence of Debris Flow

(1) Identification of Locations where Debris Flow may occur

In lowland topography to which rain water gathers, in mountain streams where water flow exist during rainfall, in mountain streams with 15 degrees or more gradient in the valley bed with more than 5 ha of catchment area upstream, from the point at which the gradient of the valley bed is superior to 15 degrees, and where there is sediment in the valley that could become debris flow, debris flow may occur, therefore, these areas need to be investigated.

Moreover, catchment areas of less than 5 ha upstream, where the gradient of the valley bed is more than 15 degrees and relatively large slope failures at the mountainside can be expected due to the soil properties, areas with spring water, and/or areas with history of slope failure may be considered as areas where debris flow may occur. The above investigation should be undertaken through rough interpretation of topographic maps and aerial photographs firstly, and should be revised through site reconnaissance.

(2) Estimation of Frequency of Debris Flow

Existing materials on disaster records, interviewing, and site reconnaissance should be utilized to determine the times and frequency of occurrence of recent debris flow in the target 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. Also, heavy rains that did not lead to debris flow occurrence should be collected in order to determine the distinction between rainfall conditions that lead to debris flow and those that do not.

In the event there has been no rainfall that has caused debris flow in the target 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. Other information such as topography and soil properties should also be used in the determination of the threshold for debris flow occurrence.

2.4.3 Survey on Estimation of Scale, Character and Inundation Area of Debris Flow

(1) Estimation of Scale and Characteristic of Debris Flow

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

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

The velocity of a debris flow ranges from several meters to ten meters per second, in the case of large gravel content flows (gravel type debris flow). The height of a debris flow is generally three meters or less. If there are records of debris flow that have occurred close to the target 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 inundation area downstream is estimated from the point at which such flow may occur. Debris flows deposit the sediment they carry covering the flat land at the bottom of the valleys and alluvial cones of the streams they go over. 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 the river/stream bed is 15 degrees or less.

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

2.5 Slope Disaster Related Structures (Drainage, Retaining Wall and Culvert)

2.5.1 Survey on Drainage Systems

(1) Checkpoints of survey

A drainage facility may be constructed for the purpose of ensuring the stability of an earth structure such as an embankment or a cut slope, for ensuring an efficient construction work or protection from floods.

A survey on drainage facilities is undertaken taking into consideration the above mentioned purposes and the items shown in Table 2.7. The following points need to be noted during the performance of the actual survey.

1) Locations where the surface water flows in a locally concentrated manner

2) Locations with a large amount of spring water or seepage water

3) Ground water condition

4) Condition downstream for discharge of the collected water

Since the stratum structure of the foundation ground, soil properties and other such factors are related to the flow of seepage water in the ground in a complex manner, it is difficult to ensure accurate understanding only through the preliminary survey. For this reason, in many cases the existence of ground water or seepage water is discovered during the construction works. Therefore, it is always important to observe surface water and seepage water during the construction works.

Moreover, special attention is also required to observe the decrease of groundwater level due to the impact of cutting works.

Table 2.7 Survey for Drainage System (source: PWRI, 2004)

	Item of Survey	Purpose of Survey
1	Meteorology	Determination of run-off Design for drainage during execution of countermeasure works
2	Topography and coverage of ground surface	Determination of run-off Groundwater flow calculation
3	Soil and geological structure, groundwater etc.	Design for drainage during execution of countermeasure works Determination of groundwater drainage Determination of slope drainage
4	The condition and drainage capacity of the existing drainage canals, which belong to the same drainage area and drainage system	Determination of run-off Plan of new drainage system

(2) Survey on Drainage System for Surface Water

In the case of drainage facilities that target surface water resulting of rainfall or water that flows from the vicinity areas, the major factors to be investigated are the meteorological conditions and the catchment areas. Investigating the meteorology, the last ten years of records should be collected at least from the meteorological observatory, or reference should be made to other construction works undertaken in the vicinities of the construction site. With respect to the catchment area, the area should be calculated for each type of surface, both the construction site and the adjacent area. In particular, since mountainous areas have numerous slopes and in many cases the catchment area is not clear, it is desirable to use aerial photographs to determine the catchment area.

In the case of drainage on slopes, as the objective is to prevent erosion and scouring of the slope due to the flow of surface water, in addition to adding materials for strengthening the top soil, adequate survey of the topography, the slope condition, soil properties, ground water condition, existing drainage systems and other factors is required. In particular, locations that are prone to concentration of surface water, such as valleys, hollows, remains of caverns, remains of small scale landslides etc. need to be investigated carefully. Moreover, slopes of sandy soil, such as fine sand, volcanic ash or terrace deposits are prone to erosion by surface water, thus they must be investigated carefully.

(3) Survey on Drainage System for Seepage Water

For the planning of subsurface drainage facilities targeting seepage water, the stratum structure of the foundation ground and the ground water condition should be carefully investigated regarding the slope earthworks.

First, existing data should be collected, aerial photographs interpreted, site reconnaissance undertaken, interviews to the related engineers implemented to obtain comprehensive information on the ground water at the planned site. Based on such information, the ground water system and water balance shall be considered to determine whether or not the ground water will affect the site as an impediment. When the target area is composed of landform units such as slopes, pediments, terraces, alluvial cones, coastal plains, other lowlands, these guidelines should be referenced to undertake preliminary survey, since ground water has specific properties for each type of landform, Moreover, in general, where ground water seeps to the surface, there is a permeable layer, such as a gravel bed or pyroclastic deposits, beneath an impermeable stratum, and the plants on the surface differ from those in the vicinities. These points should be carefully noted during site reconnaissance for discovering springs and wet spots.

If lowering the ground water level or draining the ground water is deemed necessary as a result of the preliminary survey, the main survey for ground water should be undertaken.

In the main survey, detailed review is made on the soil composition of the ground and the ground water conditions, through identifying changes in the water quality and volume. These changes are generally checked in wells and springs, and consist in measuring water flow at major valleys and other water channels, investigating geology through drilling at ideal locations, electric prospecting and in-situ permeability tests. These investigations must be carried out in accordance with the situation and characteristic of the site. In particular, slopes consisting of talus deposits, faults, fracture zones, and combination of hard and soft soils often have highly permeable strata, such as those composed of gravel or sand bed. These strata comprise aquifers providing seepage water or ground water and thus favouring failure of the slope surface. For this reason, adequate survey of the composition of the strata, permeability and changes in the ground water condition is required.

2.5.2 Survey on Retaining Wall and Culvert

(1) Checkpoints of Survey

Structures constructed for slope earth works include retaining walls and culverts.

The original ground that forms the foundation of a structure is generally complex and in recent years the complexity has increased due to the construction of structures placed in unfavourable conditions, such as slope areas and cut slope sections. Moreover, in construction works in urban areas, impact on the surrounding ground or adjacent structures, and the issue of vibration needs to be taken into consideration.

For this reason, before and during the construction of structures, investigation needs to be undertaken on the impact to the surrounding areas in addition to survey of soil and geology, in order to ensure that the design and construction of the target structures are in conformity to the conditions of the site.

The following represent the areas that need to be investigated with respect to the design and construction of structures and their major checkpoints.

a) Survey on Topography and Geology

Data on geological surveys and drilling undertaken in the vicinity of the construction site should be collected, site reconnaissance should be undertaken, and the dip of the geological stratum and surface, difference in elevation, undulation, the existence of spring water, system, direction and volume of runoff water need to be reviewed.

b) Investigation on Soil Properties

The composition of the strata, soil properties and conditions of the ground water at the construction site need to be understood, and in order to obtain materials required for determining the type of foundation to be used for the structure, soil tests need to be performed with respect to the following factors depending on the type of structure.

1) Investigation for soil parameters required for calculating external forces (earth pressure, unconfined compression and tri-axial compression tests, unit weight test, etc.)

2) Investigation for soil parameters required for stability analysis (unconfined compression and tri-axial compression tests, unit weight test, standard penetration test, etc.)

3) Investigation for soil parameters required for calculating the bearing capacity of shallow foundation and design of pile foundation (tri-axial compression test, standard penetration test, plate loading test, etc.)

4) Investigation for soil parameters required for calculating consolidation settlement (natural water content test, consolidation test, etc.)

5) Investigation concerning the ground water (drilling survey, in-situ permeability test, etc.)

The above investigation items should be adapted to general structures and in the event of large scale structures or where special constructions are involved, or where the ground is extremely soft, other tests should be added to obtain soil parameters required for the design works.

(2) Survey on Retaining Wall

The structural design of a retaining wall differs by the topography, soil, geological properties, impact on structures in the surroundings, construction conditions, and height of the retaining wall. For retaining walls in mountainous areas, retaining walls built on weak grounds or retaining walls built in confined spaces, etc. there are cases in which special structural design needs to be adopted. For this reason, concerning the survey on retaining walls, it is important to give consideration to the cases above.

Moreover, in the event a retaining wall is constructed on weak grounds or inclined grounds, it is necessary to take into consideration lateral movements, displacement, or overturning of the retaining wall, due to overloading on embankments. Also, it is necessary to care for the uplift of U-shaped retaining walls used in open-cut roads. In such cases, adequate investigations need to be undertaken with respect to the soil properties, geological structure, inclination of bedrock, condition of the ground water and the backfill soil. Posteriorly, the stability of the retaining wall needs to be studied based on such results.

(3) Survey on Culvert

For the design and construction of a culvert, it is necessary to take into consideration not only aspects of the culvert itself, but also the impact it may cause on the flatness of the land and/or the road surface on both sides of the culvert.

In the event of common grounds, in very rare cases the culvert is damaged or has a large differential settlement at the adjoining point with the embankment as a result of the settlement and deformation of the ground. However, in the event of weak grounds or in locations where the soil properties differ significantly, differential settlement due to the loads on the embankment may occur, causing differences in land and road levels, cracks and/or damage of the culvert. For this reason, with this type of ground, it is necessary to investigate the soil properties and the geological composition in order to design the culvert foundation.

In the event the foundation or backfill material of a culvert is inappropriate or the construction work of a culvert is poor, the culvert may settle locally or the backfill in the vicinity of the culvert may settle, thus negatively affect the flatness of the land and road surface. For this reason, the quality of the backfill materials to be used need to be evaluated through tests for categorising the soil, for example through compaction test.

3 Design

3.1 Introduction

3.1.1 Basic Principles

A slope earthwork section must be capable of safely preserving the space required for land use and traffic. Slope earthworks consists of the construction of cut slopes by excavating the ground and of embankments by transporting and compacting excavated soil so that a cutting and a banking area and section will have the important functions mentioned above. Construction of structures such-as retaining walls introduced as auxiliary structures in cut slope to reinforce an earth structure and culverts buried in the ground to provide a passageway or water channel are usually included in the category of earthwork.

As the existing ground subject to cutting or excavation and the foundation ground above which an embankment is constructed, the soil and rocks used as materials for an embankment are all naturally generated, their properties are very complicated and diverse. As earthwork is carried out under natural weather conditions, it is strongly affected by the seasonal characteristics of the weather, rainfall and seepage water, etc. Accordingly, appropriate measures are required to ensure the sufficient bearing capacity of the foundation, to maintain the stability of slopes and to control the settlement of embankments so that cut slopes and embankments forming the main body of a flat land and road and auxiliary structures of earthwork can be constructed to meet their objectives and to perform their expected functions for many years. As soil is liable to erosion by running water and also to a significant decline of its strength by water infiltration, it is essential to properly deal with surface water and groundwater.

The design of slope earthwork generally proceeds as described below in correspondence with the slope earthwork stages shown in Figure 1.3.

(1) Outline Design

The outline design is carried out at the planning survey stage and the rough design of such structures as cut slopes, embankments, slope protections, retaining walls and culverts as well as various control/prevention works relating to earthwork for the planned land development. Also, the new route (and alternative routes, if necessary) is carried out and the rough construction cost is estimated. At this stage, the design work is generally based on existing drawings and reference materials and also on the site reconnaissance results.

(2) Preliminary Design

The preliminary design is carried out at the execution survey stage and the design work is carried out for the planned land development and along the selected route for road, featuring almost the same items as the outline design. However, as more detailed analysis of each item is required, topographic maps based on aerial photographs and the results of surface geological reconnaissance and sounding, which are carried out at main spots, are used and incorporated in this design. In addition, appropriate design modifications based on a wide consensus are made through consultations with related organizations as needed.

(3) Detailed Design and Cost Estimation

Based on the basic conditions determined by the preliminary design, the detailed structural design is firstly carried out for structures such-as cut slopes, embankments, retaining walls and culverts, etc. and also for various control/prevention works. This is followed by decisions on the work execution plan (transportation plan, determination of borrow pits and spoil areas, calculation of work capacities and scheduling, etc.) following a decision on the work sections. The general design, including temporary structures required for each permanent structure, is then carried out to estimate the construction cost.

3.1.2 Important Points for Design

(1) Verification of Developing Area and Formation Level

The skeleton of the earthwork design, including the heights of cut slopes and embankments and the volume of soil to be handled, is determined by the position of the developing area and the formation level. As these elements are almost decided at the planning survey and execution survey stages, there is little room for modification in the subsequent stages. However, the necessary modifications must be made to the extent permitted by examining the following issues.

1) In a mountain area where the large-scale excavation of rocks or high retaining walls are required or at a steeply sloping site where large-scale slopes are formed, area of development and the position of the road centre line and the formation level should be modified as much as possible to reduce the cutting height.

2) In the case of a high embankment planned above weak ground, efforts must be made to reduce the banking height as much as possible in view of the stability of the embankment and the settlement of the embankment over a long period of time. In the case of a low embankment above weak ground with a high groundwater level, it is desirable for the level of the embankment surface to be at least 50 cm above the highest groundwater level.

3) Careful attention should be paid to compatibility between such structures as retaining walls or culverts and slope earthwork related to cut slopes or embankments, and the suitability of approach works to existing facilities should be carefully analysed.

(2) Temporary Structures

The construction of structures generally requires the construction of temporary structures, including earth retaining and construction of access roads. As temporary structures are only used during construction work, after which they are removed, they do not attract much attention sometimes. However, temporary structures play an extremely important role in construction work near densely populated areas or construction work in slope areas with considerable differences in levels. It must be recognised that temporary structures demand careful attention in regard to safety management, including the prevention of accidents and labour accidents, and also in regard to environmental conservation.

(3) Transportation plan

Earthwork involves different types of work, including excavation, transportation, compaction and surface finishing, and the appropriate transportation plan focusing on construction machinery, transportation distance and soil properties, etc. is required in addition to careful attention to the method to be employed for each type of work in order to ensure rational as well as economical work progress. It has become increasingly difficult in recent years to secure suitable soil spoil areas because of stringent environmental demands. Accordingly, it may be necessary to use the surplus soil with stabilisation treatment rather than simply disposing of it as poor soil or its conversion to another use even if long distance transportation is involved. This option often proves to be more economic and less disruptive to the main construction work.

For transportation plan for large-scale slope earthwork, planning of the distribution of materials most suited to each part of an embankment is necessary, taking the properties of the soil produced by slope cutting work based on the soil investigation results into consideration. For example, the distribution of good quality soil which is easy to compact and which has a large bearing capacity should be planned at the upper part of the embankment, while special attention is required when placing large rocks and cohesive soil in the lower part of the embankment.

3.2 Cut Slopes

As natural slope and ground is generally complicated and its properties are not uniform, the rock mass and soil layer forming the existing slope and 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.

With time, a cut slope may experience progressive weathering or erosion, resulting in failure due to increased seepage water following a downpour, etc. Particularly when a large-scale slope is created on the types of ground described in 3.2.2, special attention is required to prevent an accident or disaster during or after the construction work.

3.2.1 Standard Cross-Section of Cut Slopes

(1) Standard Slope Gradients

Natural ground is extremely complicated and not uniform in its properties, and cut slope tends to gradually become unstable after the completion of work. Therefore, stability analysis is meaningful only in rare cases when examining the stability of cut slope. 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 3.1. Table 3.1 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 not having berms.

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 controlled by the shearing strength of rock and the amount of rock cracks. The range of standard values shown in Table 3.1 is wider than that of standard values for embankments described later. So, 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.

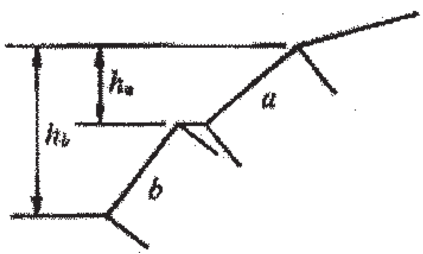
The standard slope gradients shown in Table 3.1 may not be applicable in certain cases: (a) cut slope of which the conditions are those described in 3.2.2, (b) higher cut height than those shown in Table 3.1 and (c) case where the failure of a cut slope may cause damage to neighbouring structures or requires a long restoration time, significantly relocation of inhabitants and disrupting the road functions. In these cases, it is necessary to change the slope gradient together with the introduction of suitable measures, such as slope protection work and slope drainage work, etc. Slope gradient examples for weathered granite are shown in Table 3.2.

Table 3.1 Standard Gradients of Cut Slope (source: PWRI, 2004)

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

Notes:

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.



h_a: cut slope height for slope surface a

h_b: cut slope height for slope surface b

- The gradient does not include a berm.
- The cut slope height opposite to the gradient means the total cut slope height covering the entire cut slopes above the cut slope in design.

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

Table 3.2 Standard Slope Gradient for Weathered Rocks (source: PWRI, 2004)

Category of Bedrock	**Ground Conditions**						**Slope Height and Gradient (m)**				
	Conventional Rock Category		Situation of Weathering		Condition of Drilling Core	Elastic Wave Velocity of Ground (P Wave) km/s	0	10	20	30	50
Decomposed Weathered Rock	D	D_L D_H	Sedimentary Soft Rock	Decomposed	Sandy	0.4 – 1.1	1.0 – 1.2	1.2 – 1.5	1.5 – 1.8		
Weathered Granite	C	C_L	Extremely Soft Rock	Nearly decomposed rock with few cracks or concentration of cracks	Sandy to fine flakes	1.1 – 1.5	0.6 – 0.8	0.8 – 1.0	1.0 – 1.2	1.2 – 1.5	
Slightly Weathered Granite	C	C_M	Soft Rock	Rock discoloured to a yellowish brown to the core and developed joints	Brecciated to short bar-like	1.5 – 2.3	0.4 – 0.6	0.6 – 0.8	0.8 – 1.0	1.0 – 1.2	1.2 – 1.5
Non-Weathered Granite	C	C_H	Hard Rock	Mostly fresh rock mass with developed joints in a massive manner	Bar-Like	> 2.3	0.3 – 0.4	0.4 – 0.6		0.6 – 0.8	
	B										
	A										

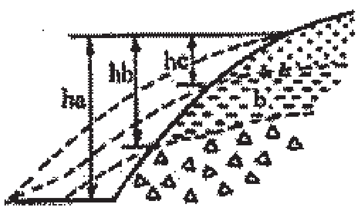
Decomposed Weathered Rock
Core: Sandy
Rock Category: D

Slightly Weathered Granite
Core: Brecciated to short bar-like
Rock Category: CM

Weathered Granite
Core: Sandy to fine flakes

Rock Category: CL

Non-Weathered Granite
Core: Bar-Like
Rock Category: CH,B,A



Slope height and rock category
ha: slope height to rock category a
hb: slope height to rock category b
hc: slope height to rock category c

In the case where a cut slope with a steeper gradient than the standard slope gradient is necessary to reduce the earthwork volume, reinforcement of the cut slope with retaining walls and/or the reinforced soil method with steel bar is required.

(2) Slope Shape

As shown in Figure 3.1, the gradient of slope, which 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.

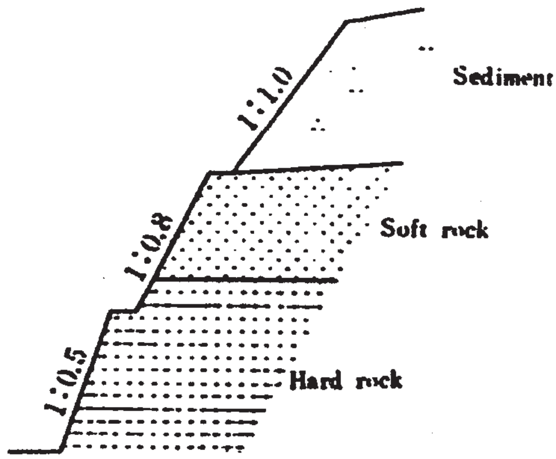


Figure 3.1 Ground Conditions and Shapes of Slopes (source: PWRI, 2004)

(3) Berms

Excepting the case stated in sub-clause (2), a berm about 1 to 2 m 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 scaffold for repairing.

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 towards the bottom of the 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 (refer to Figure 3.2).

3) Location of berms

Therefore, 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.

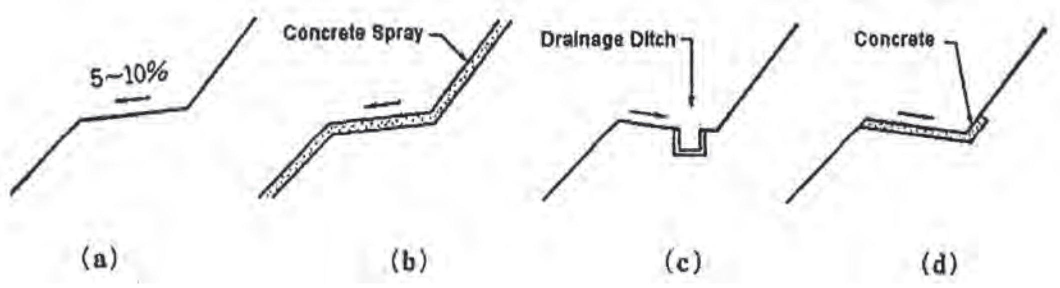


Figure 3.2 Cross- Sectional Gradient of Berm (source: PWRI, 2004)

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.

(4) Stability Analysis for Cut Slopes

Stability analysis for cut slopes is not usually carried out except for cut slopes at landslide sites or former failure sites, but may be carried out for the design of restoration work for cut slopes which have deformed during or after construction work. In this case, a cross-section of the failure site is used to assume the slip surface in order to conduct stability analysis against sliding.

3.2.2 Cuts Requiring Extra Precautions

(1) Cuts in Colluvial Deposits or Heavily Weathered Slopes

In the talus cone, weathered base rock slope, trace of volcanic ash and pyroclastic, or other old slope failure area, slope failure sometimes occurs due to the decline of strength of low solidified soil during rainfall even in the natural condition. If such a place is excavated to a gradient steeper than that of natural slope, the cut slope will become unstable and a failure may sometimes occur such as “(2) Surface failure B-1” or “(3) Large scale failure/Landslide C-1” in Table 2.1.

As countermeasures against these kinds of failures, the following methods can be considered:

a) Site where a failure such as “(2) Surface failure -1)” of Table 2.1 is predictable:

As shown in Figure 3.3, if a wide step is provided near the line of bedrock, collapsed sediment and falling from the above will be easily retained on the step. The gradient of the colluvial deposit or portion of weathered rock layer should be made as gentle as possible.

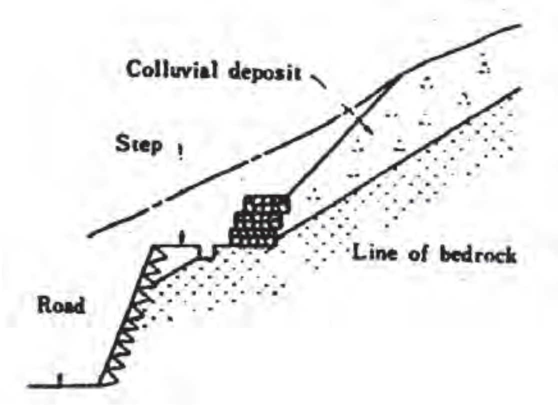


Figure 3.3 Countermeasures against Failures (source: PWRI, 2004)

b) Site where a failure such as "(3) Large scale failure/Landslide -1)" of Table 2.1 is predictable:

In this case, the countermeasures such as large-scale removal of soil (with a slope of 1:1.5 to 2.0 or more gentle, including berms), sufficient groundwater drainage works or prevention works (pile works against landslide) should be performed.

However, all methods stated above will greatly affect the construction cost and a complete study is required during design.

(2) Cuts in Easily Erodible Ground

Sediments mainly consisting of loose soil are easily eroded by surface water to frequently result in Rock Falls, small failure or outflow of soil.

The erosion against water actions should be basically dealt with by slope protection works or drainage works described in Paragraph 3-4 rather than with the change of slope gradient. Therefore, the water should be fully drained from the top and toe of slope. Permeation of water from the top of slope should be prevented whenever possible. It is important to provide an extra area in front of the toe of the slope so as not to cause any direct influence on the road surface in the event of failure.

(3) Cuts in Rocks with Many Fissures

Base rocks usually have many weak lines such as column-shaped or platy joints created by the contraction during cooling of lava. These lines are often seen in basalt, andesite and rhyolite.

These kinds of rock failures are such as "(2) Surface failure -3)" and "(3) Large scale failure/Landslide -2)" indicated in Table 2.1.

The stability of these slopes is controlled by the degree of development of fissures and the degree of fractures, and then an overall review should be performed based upon elastic wave exploration, index of degree of fissuring, and the comparison with the actual records made for existing nearby slopes.

(4) Cuts in Dip Slope Structures with Fissures

Slope failures such as "(2) Surface failure -3)" and "(3) Large scale failure/Landslide -2)" shown in Table 2.1 may sometimes occur where the slope has a dip slope structure and where there are fissures which have developed regularly in a certain direction such as bedding stratification developed in sedimentary rocks, columnar and platy joints developed in igneous rocks, and where the tilting direction of these fissures coincides with the direction of the face of the cut slope. In this case, it is desirable to have a gradient of slope (including no berm) equal to or gentler than "α" as a rule (refer to Figure 3.4).

In addition, attention is required when joint is developed cross to bedding stratification, even if bedding stratification is support plate, it is easy to cause collapse.

However, if the "α" of the dip slope structure is gentler than 30 degrees, then the slope is not necessarily considered to be unstable even if the slope ratio is steeper than 1:1.8 and thus the gradient may be determined based upon other factors.

On the other hand, if the dip slope structure has a steep "α" larger than 60 degrees, the slope is not necessarily considered to be stable in many cases even though the slope ratio is 1:0.6 or less.

Generally, it is not recommended to have a slope steeper than 1:0.8 for slopes higher than 10 m having a dip slope structure.

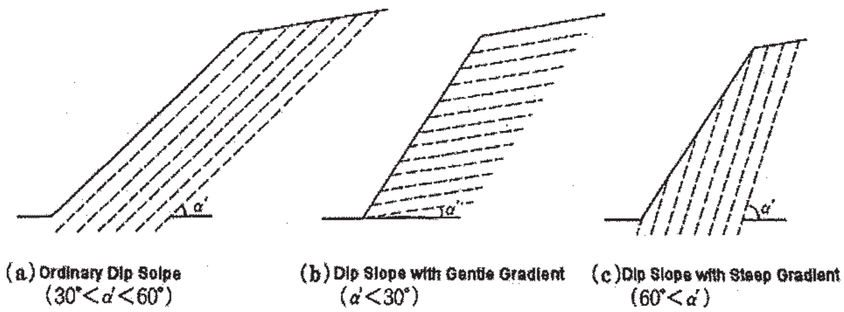


Figure 3.4 Relationship between Cracks and Slope Surface of Dip Slope (source: PWRI, 2004)

(5) Cuts where high amount of Groundwater is Existing

Cut slopes tend to become unstable and thus the gradients of such slopes must be gentler if cuts are to be made at places where much spring water is present or groundwater levels are high regardless of geological conditions.

It is required to give the higher priority to the review of groundwater drainage works than the review of gradients of cut slopes in areas where there is a lot of groundwater present.

(6) Large-Scale Slopes

The standard gradient of slopes shown in Table 3.1 are for slopes lower than 15 m, and gradients for slopes larger than these must be determined by taking account of the actual conditions. When examining these conditions, the following precautions should be taken:

a) For rocks containing a large amount of montmorillonite, which is considered to be an expansive rock, it is required to secure a gradient of slope capable of assuring the stability even after slight progress of weathering.

b) The cols of mountains frequently have fault-fractured zones and it will become necessary to examine the gradient of a cut slope depending upon the direction and degree of fracture, if these zones are found to be present in deep parts after drillings or elastic wave explorations.

c) For the cuts in steep slopes as shown in Figure 3.5, the ground is first classified into soil, soft and hard rock portions and then the cuts are usually made with gradients suited to each portion. However, as shown by “Plan A” of Figure 3.5 a thin cut layer may be sometimes created up to the top of a slope and an unexpectedly large and long slope may result. If it is required to reduce the area of a cut slope because of restrictions of land ownership, right-of-way and environmental conditions, it is possible to protect the steep slope by means of prevention work shown by “Plan B” of Figure 3.5 or by other similar structures.

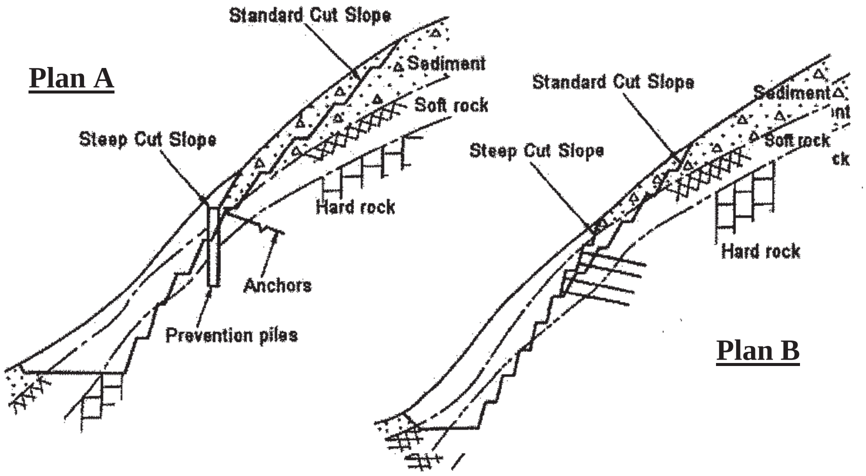


Figure 3.5 Cuts in a Steep Natural Slope (source: PWRI, 2004)

d) In the case of long slopes, it is desirable to provide steps (about 3m wide) for inspection and repair at 20 to 30 m intervals in height in addition to ordinary berms.

3.3 Slope Protection

3.3.1 Selection of Slope Protection Works

Slope protection works aim at preventing the erosion and weathering of a slope by covering a slope with vegetation or a structure or stabilizing a slope with drainage works or a retaining structure. The standard types of slope protection works are shown in Table 3.3 and these can principally be classified into those involving vegetation and those involving a structure.

For the selection of suitable slope protection works, it is essential to consider such geological and soil conditions of the slope as the rock and soil properties and pH value, hydrogeological condition and water catchment, weather conditions and size and gradient of the slope together with aspects such-as construction cost, working conditions, maintenance and conservation of the landscape/environment.

Vegetation works are performed to prevent erosion due to rain water by growing plants on the faces of slopes, thus firmly binding the faces with roots of plants. Vegetation works are also performed to ease the temperature change on the ground surface and to provide aesthetical appearance by creating greenery. Vegetation is frequently used in places where the vegetation is possible and since the costs for vegetation are relatively low in most cases.

Table 3.3 Main Types of Slope Protection Works and Their Purposes (source: PWRI, 2004)

Category	Type of Work	Purpose and Characteristics
Planting	▪ Hydro-seeding ▪ Borrow spraying ▪ Planting ground spraying ▪ Sodding ▪ Sodding mat ▪ Planting sheet	Erosion prevention; surface water flow; total planting cover
	▪ Simple seed matting works ▪ Simple sodding works	Erosion prevention and partial planting of embankment slope
	▪ Planting sandbags	Erosion prevention of slope surface made of poor soil or hard soil
	▪ Spraying with planting of young trees	Erosion control and landscaping
	▪ Planting	Landscaping
Slope Prevention by Structure	▪ Net hurdling ▪ Gabion works	Control of sediment outflow at slope surface due to erosion or spring water
	▪ Precast concrete crib works	Erosion prevention when filled up with soil or cobblestones
	▪ Mortar/concrete spraying ▪ Stone pitching ▪ Block pitching	Prevention of weathering, erosion and seepage of surface water
	▪ Concrete pitching ▪ Spray crib works ▪ Cast-in-place concrete crib works	Prevention of collapse of slope surface; retaining at sites likely to face slight earth pressure; prevention of exfoliation of rock base
	▪ Stone/block masonry retaining walls ▪ Gabion works ▪ Crib retaining walls ▪ Concrete retaining walls	Resistance to a certain level of earth pressure
	▪ Reinforced earth (reinforced earth embankment, reinforced cut slope method) ▪ Rock bolt works ▪ Ground anchor works ▪ Pile works	Resistance to sliding force of sliding soil mass

However, as the root system of such planting work remains relatively shallow, planting is not very effective for slopes liable to deep sliding. Moreover, it is difficult to find the plants which grow under such structures as viaducts and bridges with little sunlight or rainwater or with a rock base with little soil. Even in the case of slopes of which the gradient is approximately 1:0.8 to 1:1.2, planting alone may not be sufficient to prevent surface erosion or failure depending on the soil properties. For these slopes, it is necessary to apply slope protection works with a structure.

There are many types of slope protection works with a structure, ranging from relatively small-scale works aimed at stabilising an embankment for effective planting to relatively large-scale works aimed at preventing the weathering, erosion or surface failure of a slope and further to very large-scale works designed to prevent large slope failure. Among the various types of slope protection works, while retaining wall works, pile works, cast-in-place concrete crib works complemented by anchor works and reinforced earthworks can be assumed to have a certain degree of resistance to earth pressure, other types of slope protection works are not essentially designed for use in unstable places subject to earth pressure. Accordingly, the application of different measures is necessary if these works are subject to earth pressure due to a change of circumstances in the future.

If spring water exists on a slope, adoption of slope drainage works in addition to slope protection works is essential to prevent the scouring as well as destabilisation of the slope.
As the soil properties or the state of spring water are often not uniform even at a single slope, the types of works which are suitable for the specific conditions of different places must be selected. In this case, the primary principle of countermeasure work is to introduce heavy works at the lower part of the slope and lighter works at the upper part of the slope.

The on-site working conditions are often very complicated and the purposes of slope protection works tend to overlap with each other. Suitable slope protection works should be carefully selected, taking the likely cost into consideration. The standard flow for the selection of slope protection works is shown in Figure 3.6 and Figure 3.7 for reference purposes. The following points should be referred to as judgment criteria when individual judgments are required in this flow.

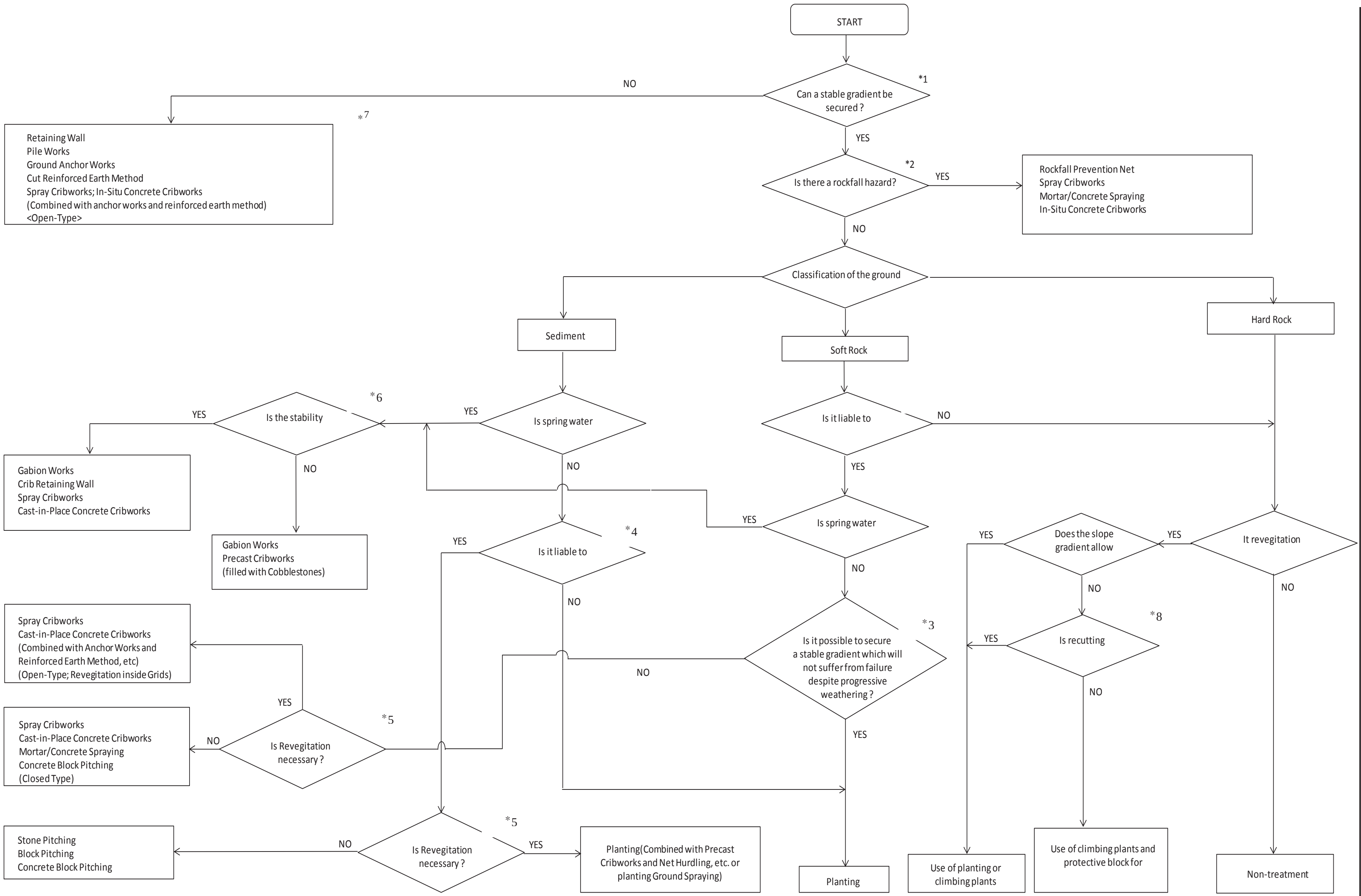


Figure 3.6 Selection Flow of Slope Protection Works for Cut Slope (source: PWRI, 2004)

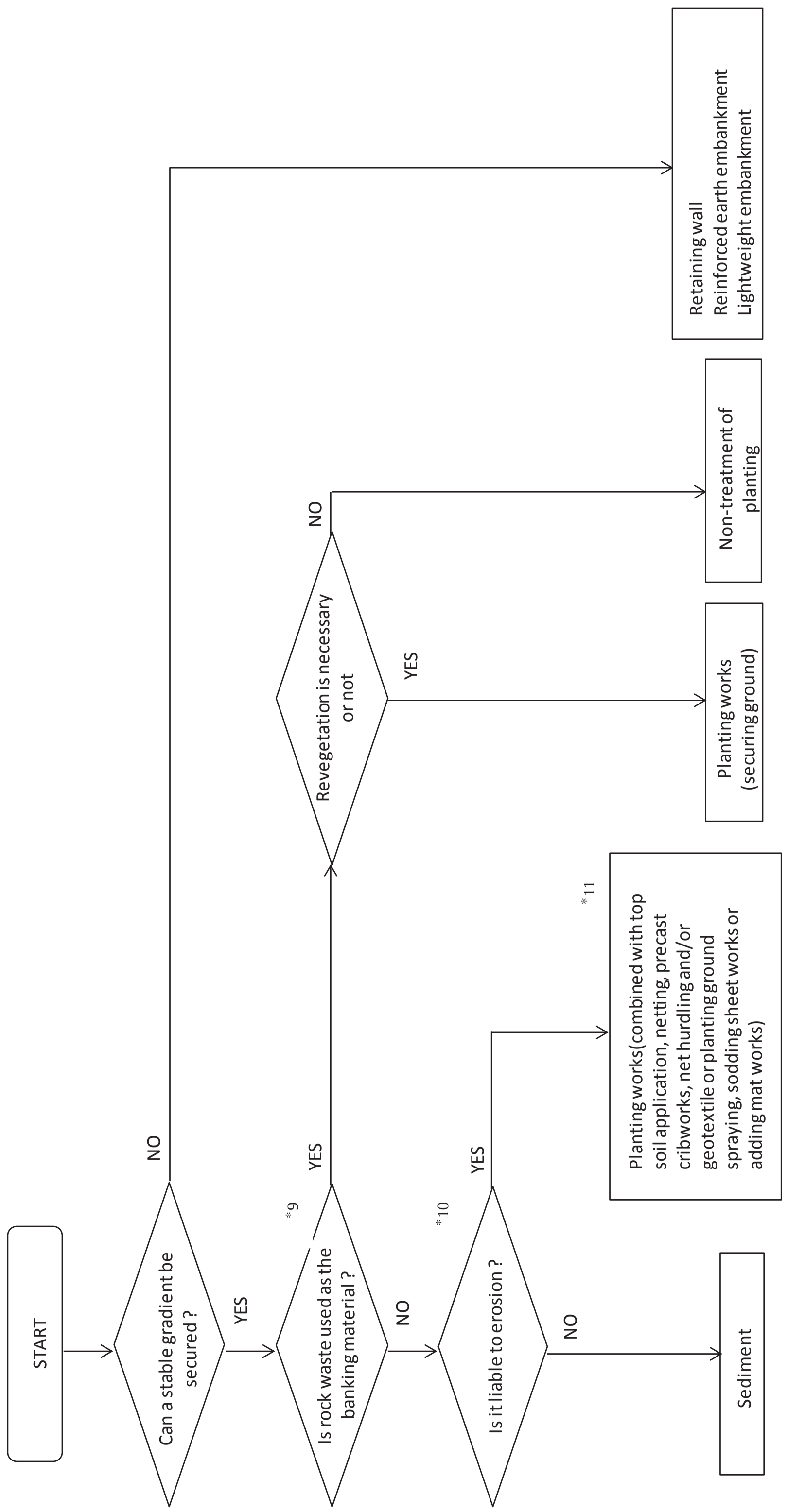


Figure 3.7 Selection Flow of Slope Protection Works for Embankment Slopes (source: PWRI, 2004)

*1 As a stable gradient corresponding to the soil properties of the ground, the average gradient of the standard slope gradients for different soil properties of the ground shown in Table 3.1 should be used as a yardstick. In the case where such a stable gradient cannot be secured, re-cutting should be carried out if possible.

*2 Existence of a Rock Fall hazard should be judged with reference to 2.3 - Survey on Rock Fall and 3.4 - Countermeasure for Rock Fall.

*3 The average gradient of the standard slope gradients for uncondensed soil is used as the yardstick for a stable gradient which does not lead to slope failure despite the progress of weathering.

*4 Strata mainly consisting of sandy soil, such as the pit sand and the terrace gravel stratum are particularly vulnerable to erosion by surface water.

*5 Suitable type of slope protection works should be judged taking mitigation of the impacts on the natural environment, harmony with the surrounding landscape and continuity of the target vegetation, etc. into consideration.

*6 Suitable types of slope protection works should mainly be judged based on the expected degree of stability, and mat gabions, crib retaining walls, shotcrete crib works or cast-in-place concrete crib works should be applied when the perceived degree of stability is particularly low.

*7 In the case of a slope where slope protection works with a structure are carried out, planting is additionally carried out if such work is required as an environmental or landscape preservation measure.

*8 Re-cutting means re-cutting for vegetation purposes.

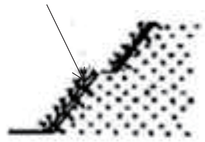
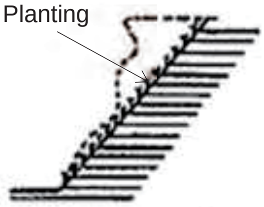
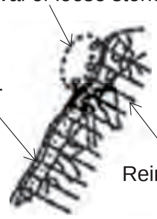
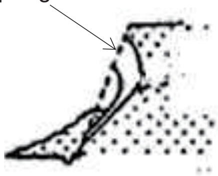
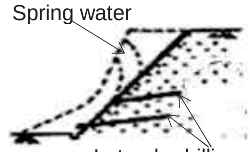
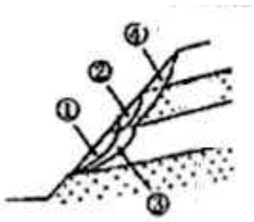
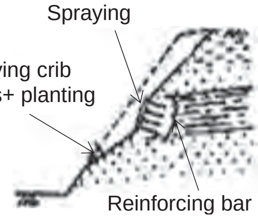
*9 Rock crushed muck mainly means hard debris which is unlikely to become fragile due to weathering. Other types of muck are considered to be similar to general soil.

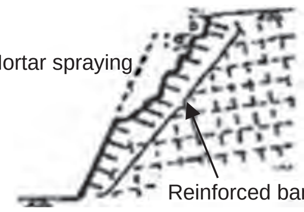
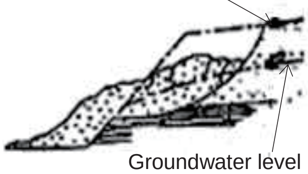
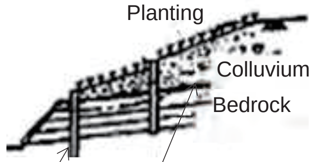
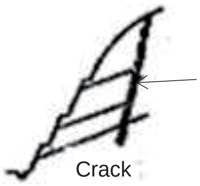
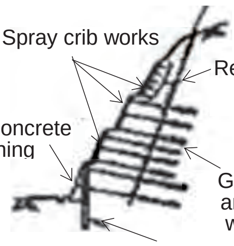
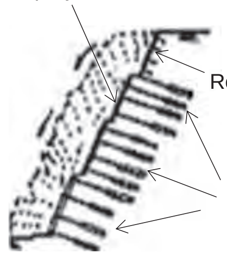
*10 Typical banking materials liable to erosion are sand and sandy soil.

*11 Slope protection works which are resistant to erosion by rainwater, etc. should be selected.

Several types of slope protection works are available for different types of failures and some examples are shown in Table 3.4.

Table 3.4 Type of Failure of Cut and Natural Slopes and Examples of Slope Protection (source: PWRI, 2004)

Category	Description	Type of Failure	Example of Slope Protection
1. Erosion/fall	1) Separation of the surface or production of a gully by repeated drying and wetting, rain; could move to a deep failure if consolidated	 Gully erosion by surface water	 Netting + planting or precast concrete cribwork + planting
	2) Fall of an overhang section on a slope		 Re-cutting + planting
	3) Fall of rocks with plenty of cracks and joints	 Loose stone type Rock Fall	 Mortar spraying (removal of loose stones) + reinforced earthworks
2. Surface Failure	1) Slipping of the lower heavily weathered rock layer due to the slipping of top soil, often induced by spring water	 Failure caused by piping	 Re-cutting + precast concrete works (filled with cobblestones) + lateral drilling
	2) Slipping of the surface layer as a result of weathering, etc.	 Surface failure with advancing weathering, etc.	 Cutting with different gradients + spraying crib works + reinforced earthworks + planting + mortar spraying

	3) Slipping of rocks along a dip slope structure or cracks in the bedrock (joints, small fault and/or thin layer); frequently in the case of the latter	 Failure along cracks of rocks	Removal of unstable rocks  Mortar spraying + reinforced bar
3. Large-Scale Failure/ Landslide Type Failure	1) Large-scale slipping of a slope consisting of a soft layer with a low degree of consolidation or a slope with unstable factors in terms of the geological structure following a rise of the ground water level	 Slipping along surface of discontinuity in terms of permeability	 Re-cutting + pile works/lateral drilling + planting
	2) Large-scale slipping of a rock body which has such a geological structure as a dip slope, fault or fracture zone	 Sliding along fault fracture zone	 Pile works + spray crib works + ground anchor works + reinforced earth works +concrete lining
	3) Overturning of a dip slope or rocky slope with developed cracks	 Overturning of dip slope	 Spray crib works + reinforced earth works + ground anchor works

3.3.2 Important Points for Introduction of Slope Protection Works

(1) Slope Gradient Suitable for Plant Growth

Although it depends on the form of plant colonies to be created and the method of plant introduction, it is generally safe to assume that planting alone should be sufficient to prevent the erosion or surface slope failure to a certain extent provided that the slope gradient is gentler than 1:1.0 — 1:1.2 for soft rock and cohesive soil or 1:1.5 for sand and sandy soil. When the slope gradient becomes steeper than that above, it becomes difficult to maintain the slope stability with planting alone, necessitating the concurrent use of crib works or net hurdling (see Table 2.3).

(2) Slopes Consisting of Sandy and Other Soil Liable to Erosion

When cut slopes are made of sandy and other soil liable to erosion with little spring water, planting alone is generally employed. However, if prevention of erosion by surface water is required, crib works or net hurdling is employed in addition to planting. Where there is much spring water, gabion works, crib works filled with cobble stones or net hurdling, etc. is employed depending on the actual level of spring water. The installation of sub-surface drainage works in a tree-like manner with further protection by concrete blocks, etc. covering such works is highly effective to prevent scouring at the back of slope protection works. The introduction of drainage facilities at slope shoulders and each berm regardless of the amount of spring water is also desirable.

Embankment slopes consisting of sandy soil should preferably be protected by top soil of some 30- 50 cm or more in thickness. In the case of a high embankment, the toe of slope is vulnerable to scouring or failure due to seepage water, resulting in mudflow. In such an area, the introduction of a drainage layer or sub-surface drainage works in addition to planting or the employment of a combination of net hurdling, pre-cast crib works and/or a block masonry retaining wall with planting is necessary.

(3) Slopes with high amount of Spring Water

In regard to slopes with high amount of spring water, underground drainage facilities such-as sub-surface drainage works and horizontal drainage holes should be actively introduced together with the application of such open-type slope protection works as crib retaining walls, gabion works and crib works filled with cobble stones as slope protection works.

(4) Rock Slopes with Small-Scale Rock Fall Hazard

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

(5) Slopes Composed of Hard Soil

It is required to perform digging and soil dressing at some portions of a slope so as to allow the roots to grow, and sodding should then be performed on the dressed soil of hard slopes made of dense sandy soils (exceeding the soil hardness of 27 mm), hard clayey soils (exceeding the soil hardness of 23mm), soft rocks or hard clay.

(6) Slopes Made of Soil with Problematic Acidity

Plant growth is difficult when the pH value of soil is lower than 4 from the beginning or where an old stratum of raised sludge from the bottom of a lake is liable to the quick change to extremely acidic soil due to sudden exposure to air resulting from cutting. At such sites, it is desirable to replace the original soil with borrowed materials, to neutralize the soil with lime, to introduce drainage or waterproofing measures which are appropriate for the specific site conditions. This is in order to prevent any adverse impacts by seepage water which is highly acidic because of the properties of the mother rock making up the slope on the growth of introduced plants or to employ slope protection works with such a structure as pitching work.

(7) Slopes with Non-Uniform Conditions of Soil Properties and Spring Water

As the soil properties and the state of spring water are often not uniform even at a single slope, the types of works which are suitable for the specific conditions of different places must be selected. The selection of similar works is preferable together with treatment of the ground with drainage and other necessary works as the use of different types of works to protect a small area is detrimental to the landscape.

3.3.3 Planting

(1) Characteristics of Planting

Planting is carried out with the expectation that, once fully grown, plants can perform functions such-as preventing slope erosion and the obstruction of rainwater, mitigating the strong impact of raindrops on the ground, reducing the velocity of the surface flow, holding of soil by the root system and increasing the seepage capacity of the ground surface. In addition, harmonisation with environment and landscape in surrounding area can be expected. However, as the growth depth of plant root system is limited, planting cannot be expected to prevent the deep failure of slopes. The following preconditions are attached to planting because of the use of live plants as the material.

a) State of ground: The ground for plant growth must be stable opposed to erosion or failure.

b) Plant selection: The selected plants must be compatible with the soil properties and gradient of the subject slope and the local weather conditions and must also be compatible with the purpose of vegetation work.

c) Work method: The work method must ensure the continual deterrence of erosion until full plant growth is achieved so that the plants can permanently provide the required slope protection.

d) Work timing: Planting must be done during a period when suitable conditions like temperature, moisture content and sunlight, etc. are ensured until the germinated plants grow sufficiently to resist erosion.

e) Extraordinary weather, diseases and pests: There must be no unfavourable external factors for plant growth.

When the introduction of planting is required for slopes which fail to meet the above conditions, such as slopes with an unstable surface or slopes where planting is difficult, combination with a structure, the creation of new bed for growth of plants or the adoption of an advanced plant management technique should be considered.

(2) Establishment of Planting Targets

While the primary purpose of planting is the prevention of erosion as well as surface failure, it is important at the same time to carefully select suitable plants with a view to harmonize with the surrounding environment and reducing the maintenance work volume, taking the future full growth situation of the plants into consideration. When establishing the planting targets, the relevant policies for maintenance after initial planting must also be taken into consideration.

There are three types of target plant colonies for vegetation based on natural appearance, i.e. forest type, shrub type and grassland type. In addition, there is a special type for landscaping. For planting design, vegetation targets should be established taking the surrounding landscape and the maintenance conditions into consideration and types of plants and a work method corresponding to the slope surface conditions should be examined.

In general, in the case of mountain areas and other areas where the natural landscape is deemed to be important, it is preferable to opt for a high forest or vegetation to shift from shrub to a high forest in regard to establishing continuity with the surrounding vegetation and reducing the maintenance work burden. High trees may cause slope failure by root shaking by strong winds, height of the trees must be maintained artificially. In suburban areas and areas near farmland or pasture, it may sometimes be preferable to maintain a good view by means of planting herbaceous plants and/or flowering trees even though these require more maintenance work (Table 3.5).

Table 3.5 Types of Target Plant Colonies (source: PWRI, 2004)

Target Type of Plant	Target Appearance	Conditions of Applicable Sites
High/middle Forest Type	Community dominated by trees	▪ Surrounded by forest ▪ Natural park area
Shrub Type	Community dominated by shrubs	▪ Surrounded by forest ▪ Surrounded by farmland
Grassland Type	Community dominated by herbaceous plants	▪ Surrounded by grassland ▪ Surrounded by farmland ▪ Mortar sprayed plane
Special Type	Special or artificial plant colony	▪ Sites where special consideration is required in regard to the surrounding landscape or natural environment ▪ Scenic area

(3) Types and Characteristics of Planting and Bed for Plants

There are many planting methods which are suitable for different species as well as topographical, soil and climatological conditions. Careful examination is necessary in regard to the plants to be used and the method of introducing such plants. Basically, the selected method should be able to firmly fix the bed for plants which satisfies the germination and growth requirements of the target plants to the slope. The nature and thickness of this bed are determined by the degree of the plants' demand for fertilizer as well as the germination characteristics and the soil properties and gradient of the target slope. Table shows the characteristics of various types of artificial planting. Meanwhile, Table 3.7 shows the types, characteristics and points to note for the application of bed for growth of plants which is to be carried out together with planting.

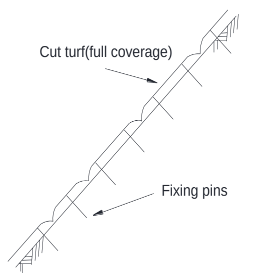
Type		Characteristics	Important Points
Drainage		▪ Prevention of slip surface failure due to increased groundwater or erosion due to the running down surface water ▪ Importance of air permeability ▪ Removal of acidic water	▪ Assured water collection and structure to prevent seepage to the slope surface ▪ Cross-sectional area eliminating overflow and non-leaking structure for a drainage ditch ▪ Assured waste water disposal at the end of the drainage
Crib works	Spray Crib works Cast-in-Place Concrete Crib works	▪ Capable of creating a structure to deal with different shapes and sizes of failure at the shallow end of a slope ▪ Possible application of planting inside crib works ▪ Spray crib works are capable of dealing with undulations of the slope surface	▪ Careful examination is required when applied to a slope consisting of expensive or contractive rock or soil.
	Precast Concrete Crib works	▪ Capable of fixing and maintaining soil or planting sandbags as revegetation foundations to the slope surface	▪ Applied to slopes of which the gradient is gentler than 1:1.0 and where the crib works will not sink due to scouring, etc.
Net Hurdling		▪ Partial fixing of slipping sediment, mitigation of the speed of descending water or cushioning of falling rocks	▪ In general, should be used in combination with planting ▪ The introduction of woody plants (seeding or planting of young trees) to secure proper functioning in the future together with net hurdling is desirable
Netting	Metal Netting	▪ Effective to prevent exfoliation of the slope surface due to the running down of surface water to prevent Rock Fall	▪ A net with too fine a mesh or a long-life net may be detrimental to the growth of woody plants
	Textile Netting	▪ Effective to prevent exfoliation of the slope surface due to the running down of surface water and to maintain artificial foundations	▪ Difficult to deal with Rock Fall due to the lack of rigidity
Windbreak Works		▪ Netting with a fine mesh and fencing works are useful to alleviate the drying of plumules and seedlings and wind damage.	▪ Careful analysis of the wind direction, wind force and expected degree and scope of the effects is required.
Planting Sandbags		▪ Useful to secure a rooting area on the slope surface and to maintain fixed roots	▪ Careful examination of the required mesh and durability of the sandbags is required. ▪ Applicable to a gentle slope surface of which the gradient is less than 1:0.8

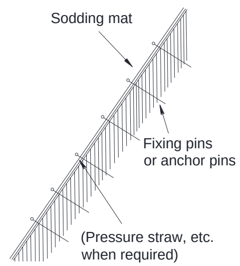
Table 3.6 Characteristics of Works of Bed for Plant and Important Points for Application (source: PWRI, 2004)

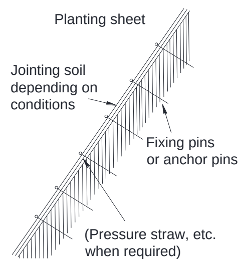
Table 3.7 Types and Characteristics of Artificial Planting (source: PWRI, 2004)

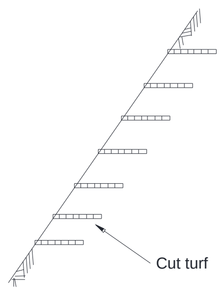
Type		Sodding	Sodding Mats	Planting Sheet	Simple Sodding	Simple Seed Matting	Planting Sandbags
Work Method		Sodding over the entire area	Sodding over the entire area	Sodding with full coverage or in strips	Placing of cut turf while applying top soil	Created of seeded belts while applying top soil	Fixing of planting sandbags
Materials to be used	Foundation Material	Cut turf; rolled turf	Mat-like material with some thickness containing seeds, fertilizer and foundation material for growth	Sheet-like material with attached seeds and fertilizer	Cut turf	Textile belts with attached seeds and fertilizer	Textile bags filled with soil/improved soil and seeds, etc.
	Plants	Cut turf field turf Rolled turf exotic herbaceous plants	Seeds of exotic or native herbaceous plants	Seeds of exotic or native herbaceous plants	Field turf	Seeds of exotic or native herbaceous plants	Woody seeds; seeds of exotic or native herbaceous plants
	Fertilizer	Complex fertilizer Slow-release fertilizer	Advanced complex fertilizer	Advanced complex fertilizer	Complex fertilizer; Slow-release fertilizer	Advanced complex fertilizer	Compost; PK complex fertilizer; slow-release fertilizer
Supplementary Materials		Fixing pins; sowing soil; jointing soil	Fixing pins; anchor pins	Fixing pins; anchor pins; sodding soil or joining soil	-	-	Fixing pins; anchor pins
Accompanying Work		-	-	-	-	-	Grooving; crib works
Erosion Resistance after Work		Relatively large	Large	Large	Small	Small	Large
Application Conditions	Geology	Cohesive soil (hardness:<27 mm) Sandy soil (hardness: <23 mm)	As left	As left	As left	As left	Sediment with little nutrients or hard sediment/rock
	Gradient	Gentler than 1:1.0	Gentler than 1:1.0	Gentler than 1:1.0	Gentler than 1:1.2	Gentler than 1:1.2	Gentler than 1:0.8
Remarks		Applied to a small area where landscaping effect is required	Necessary to ensure close contract of the mats with the slope surface	▪ Necessary to ensure close contract of the sheet with the slope surface ▪ Additional fertilizer application may be necessary for soil with little nutrients	▪ Applied to small embankments ▪ Unsuitable for sandy soil	▪ Applied to small embankment ▪ Additional fertilizer application may be necessary for soil with little nutrients ▪ Unsuitable for sandy soil	▪ May fall if the gradient is steeper than 1:0.8 ▪ Soil with excellent fertilizer retention should be used if herbaceous seeds are used

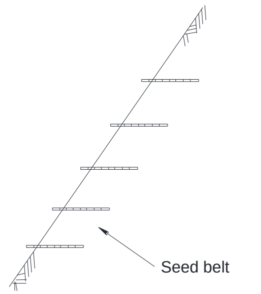
Standard Drawing

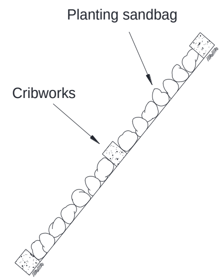
Sodding:


Sodding Mats:


Planting Sheet:


Simple Sodding:


Simple Seed Matting:


Planting Sandbags:


3.3.4 Slope Protection Works with Structures

Various types of slope protection works with structures are carried out for slopes which are unstable without slope protection and which are unsuitable for vegetation, slopes where the long-term stability against erosion cannot be guaranteed by only vegetation or slopes which are liable to failure and/or Rock Fall. Table 3.3 lists the different types of slope protection works with structures which are already described in 3.3.1 — Selection of Slope Protection Works.

(1) Stone and Concrete Block Pitching

Stone pitching and concrete block pitching are mainly used to prevent slopes from being eroded and weathered and are employed for non-cohesive soil, mudstone or easily collapsible clay slope with a slope gradient gentler than 1:1.0.

In addition, they can be used for saving land by making the slope gradient steeper than the standard and for protecting the backfilled portions of over bridges, or earth pressure relief type abutments. Materials for stone pitching and concrete block pitching and thickness of materials are to be determined depending upon the gradient of slope and purpose of use, and are normally as shown in Table 3.8.

Table 3.8 Slope Gradient and Thickness of Stone and Concrete Block (source: PWRI, 2004)

Location / Type of pitching slope ratio[1)]	Protection of ordinary Slope			Protection at special places (Backfilling of over bridge, earth pressure relieved and front of abutment, etc.		
	Stone pitching	Concrete block pitching	Concrete plate pitching	Stone pitching	Concrete block pitching	Concrete plate pitching
1.0-1.2	35-25 [1)]	35	<20	35	35	<20
1.2-1.5	35-25 [2)]	35	<20	-	25	<20
1.5-1.8	<25	<12	<20	-	<18	<20

Notes;
1) Unit: cm
2) Applied to slopes of less than 5m in height when the gradient is steeper than 1:1.5
3) Boulders are used for the case of thickness of 25cm for stone pitching to slopes of less than 3m in height

The height and slope length are generally not more than 5 m and 7 m respectively. In the case of stone pitching, it is preferable to adopt as gentle gradient as possible because of the difficulty of tightly binding the stones.

If spring water or seepage water is present, backfilling with cobblestones or crusher-run is required to ensure good drainage at the back of the pitch works (see

Figure 3.9).

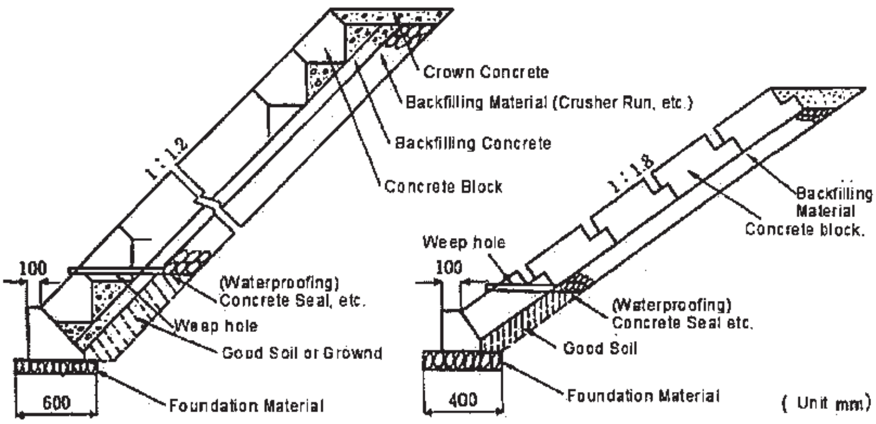


Figure 3.8 Examples of Concrete Block Pitching (source: PWRI, 2004)

Weep holes with a diameter of approximately 50 mm should be introduced at a rate of one every 2 - 4 m^2 as standard. The density of these holes should be increased at sites where the amount of spring water is large. At such sites, stone pitching should be carried out following the installation of sufficient drainage facilities (drainage conduits and waterproofing mats, etc.) with respect to the fact that many slopes have collapsed in the past due to the lack of such precautionary measures.

(2) Concrete Pitching

This is used when concrete block crib work or mortar spraying is not considered appropriate for the slope of bedrock with many joints or loose talus cone layer.

For large or steep slopes, it is desirable to reinforce the concrete with reinforcing bars or wire mesh and also to install non-slip anchor pins or anchor bolts (refer to

Figure 3.9). The plain concrete pitching will require a minimum thickness of about 20 cm. In general, non-slip anchors should be placed at a rate of one anchor per 1 to 2 m^2, and the depth of embedment should be 1.5 to 2.0 times the thickness of the concrete. It is important to determine the length of anchor pins or anchor bars to suit such specific purposes as the prevention of slope failure and slippage of the concrete pitching depending on the geological conditions of the site.

Figure 3.9 Example of Concrete Pitching (source: PWRI, 2004)

(3) Mortar and Concrete Spraying

This is used on easily weatherable rock and rock likely to be weathered and stripped off even though there is no spring water in slope and there is no danger for the time being as well as for mudstone not suited to vegetation.

The thickness of spraying is determined by taking account of the slope conditions and weather conditions, and the standard thickness of spraying is 8 to 10 cm for mortar spraying and 10 to 20 cm for concrete spraying. Prior to spraying, it is required to lay the wire mesh over the face of slope and to anchor it. The standard number of anchors is 1 to 2 every square meter. When spring water is present on the spraying surface, the introduction of sufficient drainage facilities is necessary (Figure 3.10). When thick spraying is required because of a steep gradient or when the slope surface is considerably uneven, an increase of the number (density) of anchor pins or anchor bars is desirable depending on the actual need. As part of spraying, weep holes should be introduced at a standard rate of at least one hole per 2 - 4 m^2 of the spraying area. As the durability of spraying is significantly affected by the weather conditions, particularly during the work, in addition to the composition of the admixture, spraying work conditions, equipment performance and skill of workers, careful attention must be paid to the timing of the work and the working hours.

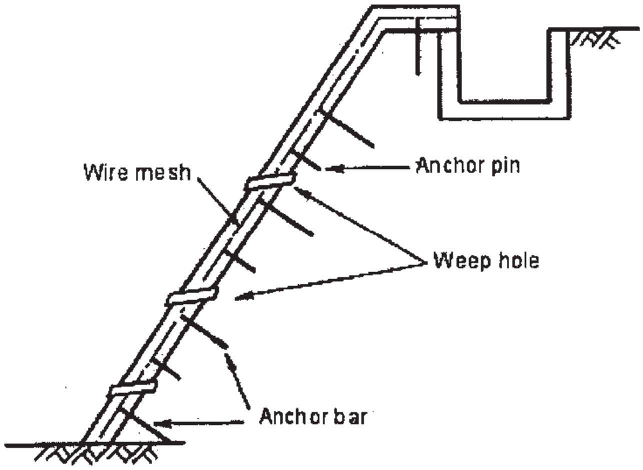


Figure 3.10 Example of Mortar Concrete Spraying (source: PWRI, 2004)

In general, spraying should not be carried out in the following cases.

1) Normal spraying work is severely disturbed by strong wind.

2) The cement is likely to be washed away from the spraying surface because of heavy rain.

3) Spraying operation is likely to be disturbed by extreme drying due to strong wind and fine weather.

While the guidance admixture ratios by weight of cement, sand and aggregate are C:S = 1:4 (C: cement weight; S: sand weight) for mortar spraying and C:S:G = 1.4:1 — 1:4:2 (G: aggregate weight), a cement volume of more than 400 kg/m^3 and the adoption of a water-cement ratio of not more than 60% are desirable. The strength of the mortar and concrete should be decided after trial mixing using 15 N/mm^2 (150 kgf/cm^2) as the standard.

(4) Precast Crib works

Precast crib works are employed at cut slopes liable to erosion, sites where revegetation is unsuitable because of the specific conditions despite the slope having a standard slope gradient and sites where revegetation will not eradicate the possibility of surface failure. The target slopes are those with gradients which are gentler than 1:1.0. The use of anchor pins of some 50 — 100 cm in length at nodal points of the frame is desirable to prevent sliding of the frame (see Figure 3.11) while protecting the inside of the frame, which is backfilled with good quality soil, with vegetation.

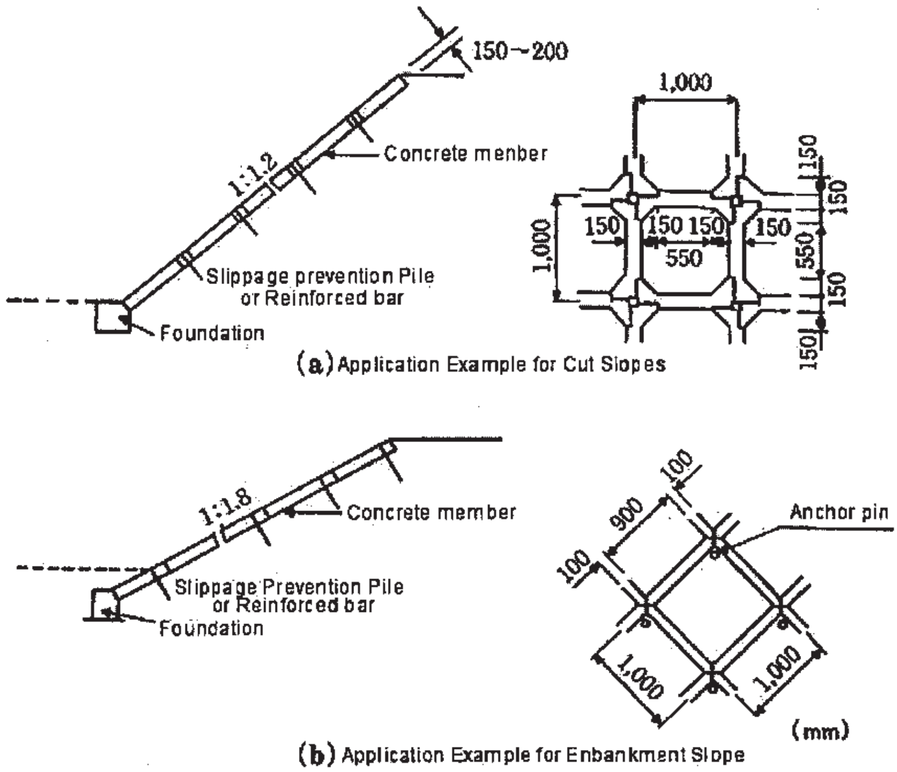


Figure 3.11 Example of Concrete Block Crib works (source: PWRI, 2004)

(5) Cast-in-Place Concrete Crib works

This method is used when the long-term stability of the slope is questionable or when concrete block crib work is likely to collapse on a slope made of weathered rock accompanied with spring water or on a large slope.

Also, this type of work plays a supporting function when loose stones cannot be fixed by concrete spraying on bedrock which has many joints and cracks. Moreover, it may be used independently or jointly with ground anchor works to prevent slope failure.

Frames are made of cast-in-place reinforced concrete, and the spaces inside the frames are filled with and protected by stone pitching, concrete block pitching, concrete pitching, mortar spraying or sodding depending upon the conditions.

Cast-in-place concrete crib works offer superior bending strength than concrete block crib works because of the beam structure using reinforcing bars. Anchor bars to stop the sliding of the crib works are introduced at nodal points of the frame depending on the slope conditions (see Figure 3.12).

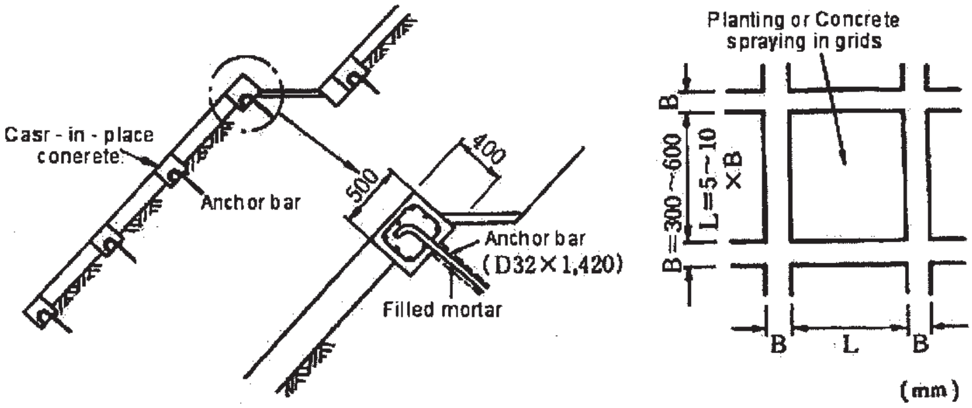


Figure 3.12 Example of Cast-in-Place Concrete Crib works (source: PWRI, 2004)

(6) Shotcrete Crib works

Shotcrete crib works are used for slopes consisting of bedrock with many cracks or slopes where the protection is urgently required. While the standard function of spray crib works is the same as those of cast-in-place concrete crib works, the good workability means that spray crib works can be applied for slopes with an uneven slope surface. Moreover, the shape of crib works can be flexibly changed in accordance with the slope conditions (see Figure 3.13).

Figure 3.13 Example of Spray Crib works (source: JET)

The volumes of cement and water for the spraying admixture are determined to achieve a design standard strength of 15 N/mm^2 (150 kgf/cm^2) or higher using a flow value of 120 mm as the norm for strength as in the case of (3) - Mortar and Concrete Spraying.

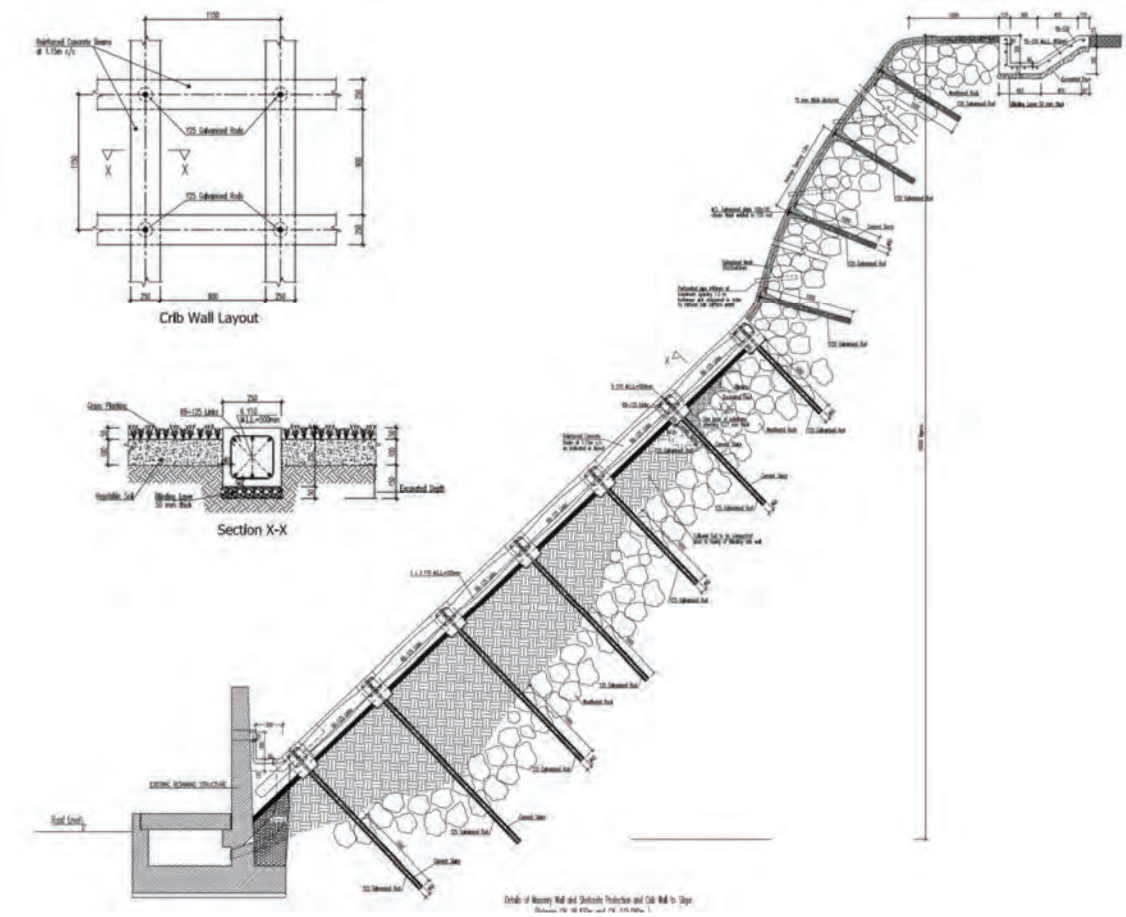
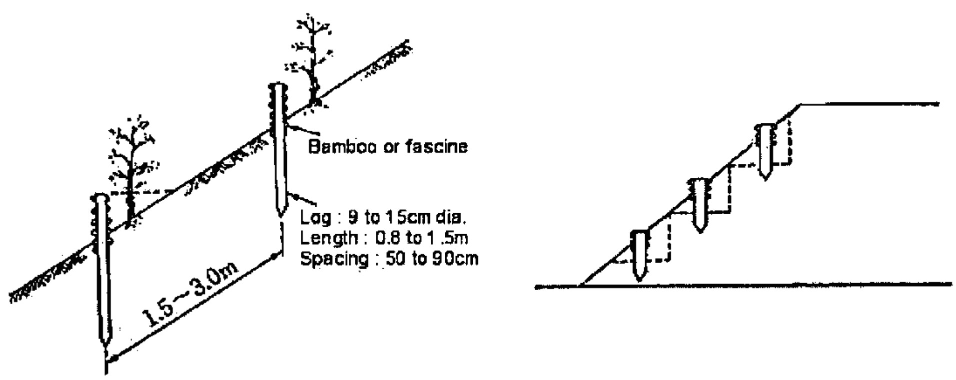


Figure 3.14 Example of Concrete Crib works and Concrete Spraying, Batelage (source: MPI)

(7) Net Hurdling

Net hurdling is often used to prevent outflow of soil from the slope surface until the plants are fully grown. The net is made by fagot, bamboo, high polymer materials or others to wooden and fixed by stakes driven into the ground to retain the soil (see Figure 3.15).



(a)Top portion of net hurdling above ground (b) Installation of net hurdling by bench cut

Figure 3.15 Examples of Net Hurdling (source: PWRI, 2004)

(8) Gabion Works

(8) Gabion Works

Gabions are used where there is spring water on a slope and soil is likely to run off, where a collapsed portion is to be restored. Ordinary wire cylinders and wire mat gabions are available as gabions, and ordinary cylinders are mainly used for the removal of spring water on the surface layer of slope, for draining surface water.

Wire mat gabions are used for restoration work after failures in landslide zones and in places where spring water is present. In many cases (refer to Figure 3.16), they are employed in retaining works rather than slope works.

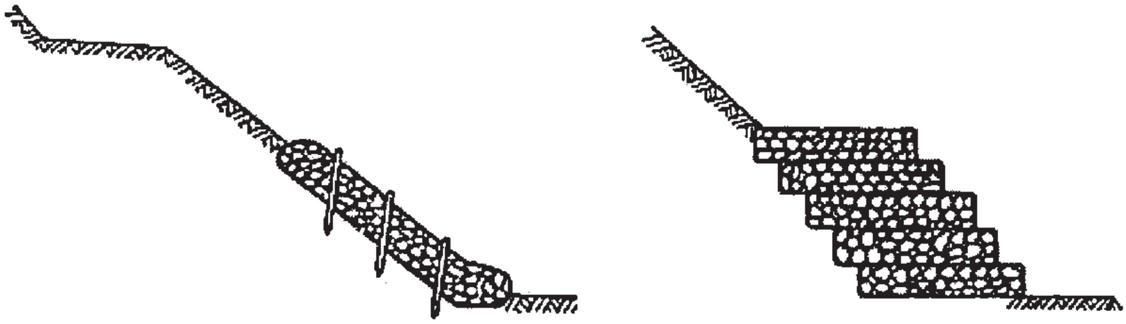
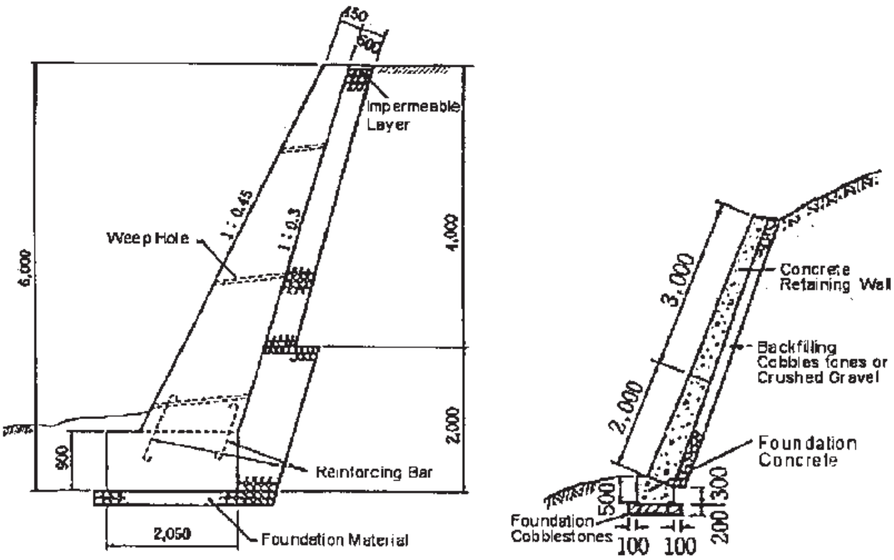


Figure 3.16 Examples of Gabion Works on Slope (source: PWRI, 2004)

(9) Retaining Walls

Retaining walls are constructed for slopes where cutting or banking with a stable gradient is impossible due to the site conditions, topographical restraints or the presence of water channels and/or other adjacent structures or facilities (see Figure 3.17).

While the design of a small-scale retaining wall tends to rely on experience without examination of the stability or sliding as well as supporting forces, examination of the stability pursuant to 3.7 - Retaining Walls is necessary for slopes with a height of 5 m or more which have problems in regard to the geological properties and/or foundation ground. There is another type of retaining wall which catches a partial failure of a slope or cut slope at the roadside instead of directly holding down the slope (see Figure 3.18).



(a) Leaning Type Retaining Wall for Embankment (b) Leaning Type Retaining Wall for Cut Slopes

Figure 3.17 Example of Concrete Retaining Wall (Leaning Type) (source: PWRI, 2004)

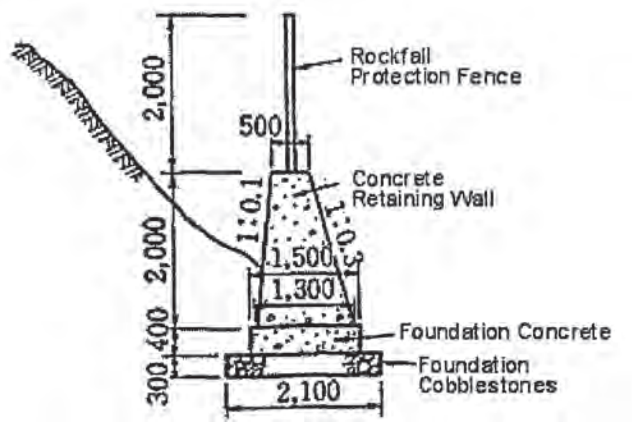


Figure 3.18 Example of Concrete Retaining Wall Used in Combination with Rock Fall Protection Fence (source: PWRI, 2004)

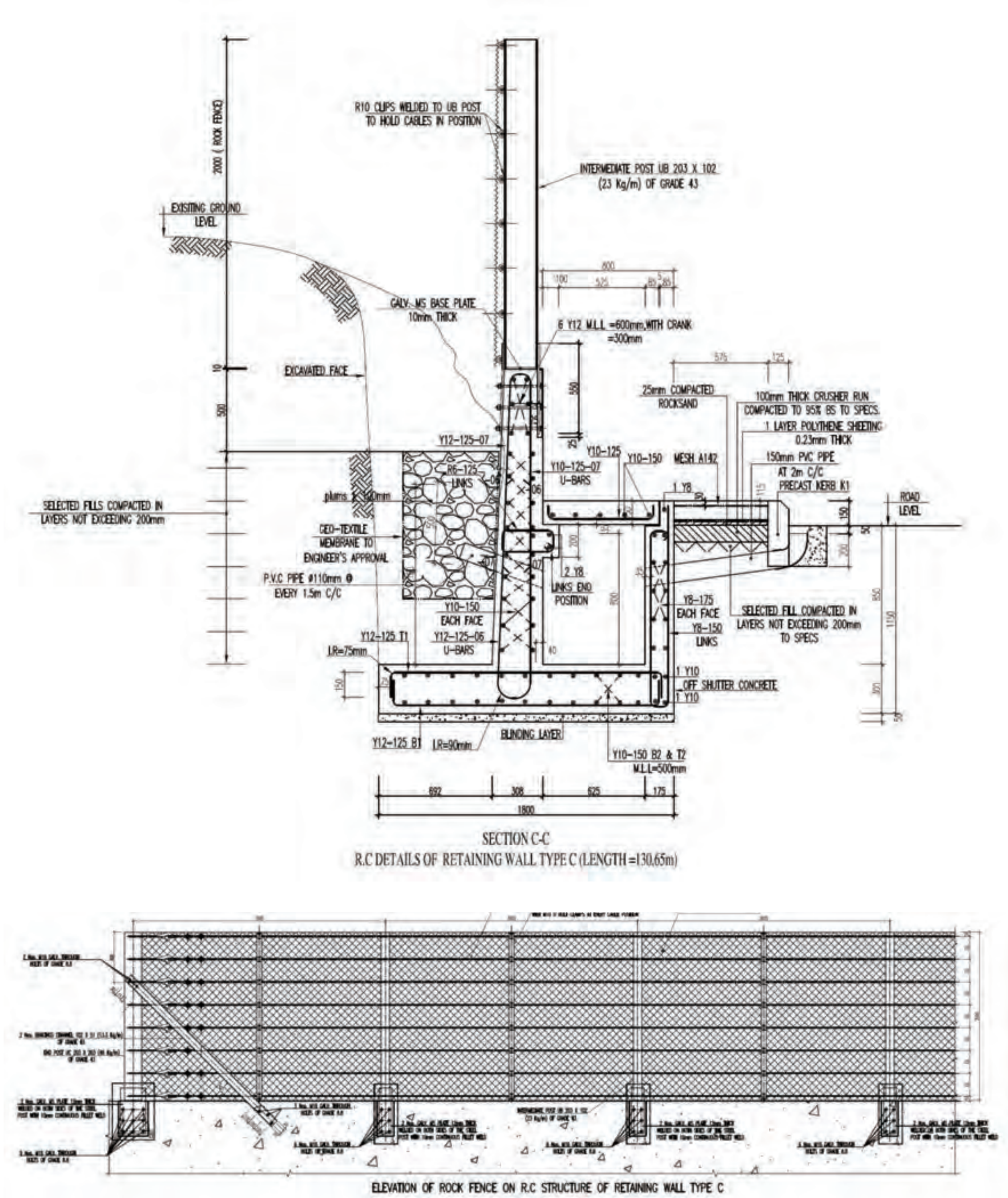


Figure 3.19 Example of Concrete Retaining Wall, Hermitarge – Cromandel (source: MPI)

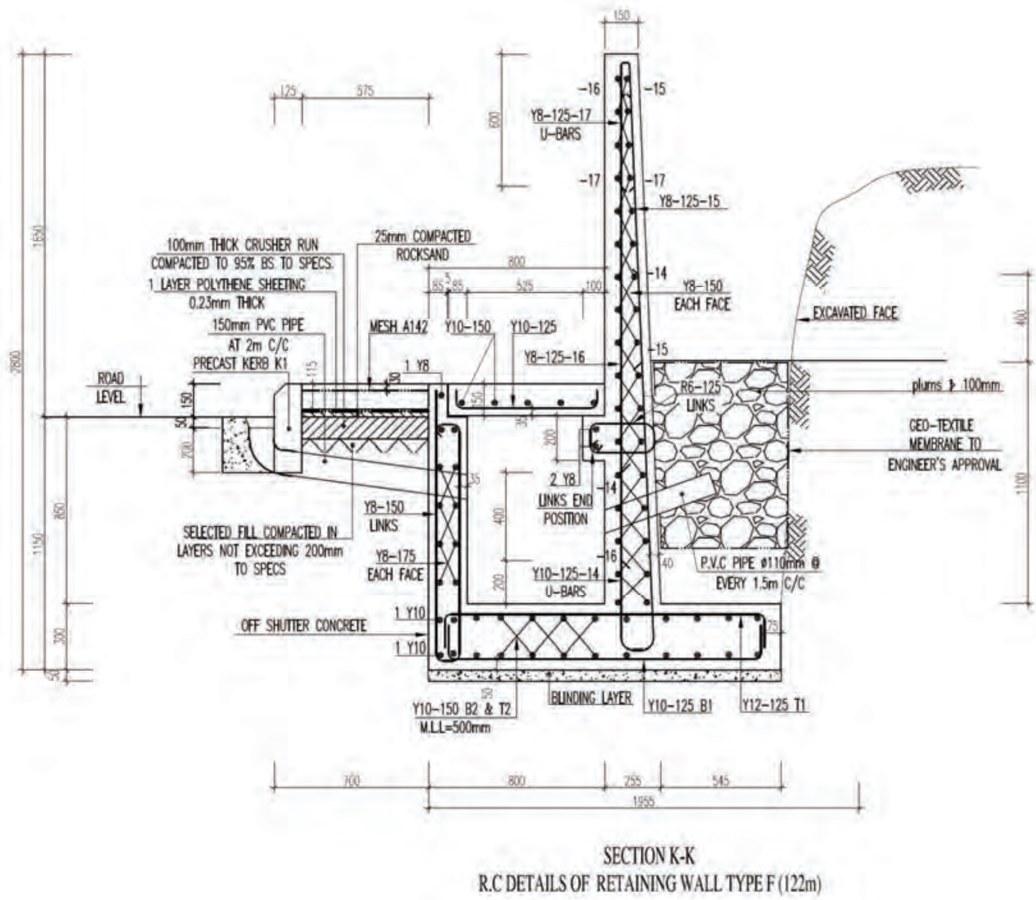


Figure 3.20 Example of Retaining Wall for Hermitarge – Cromandel (source: MPI)

(10) Ground Anchor Works

Ground anchor works are usually used to provide suppressive force for slopes which are liable to failure due to joints and/or cracks in the bedrock and slopes which have relatively dense soil, but which also have a risk of failure. Ground anchor works can also be used as supporting works for temporary earth retaining walls.

Ground anchor works generally consist of three parts: anchor body, free anchor part and anchor head, as shown in Figure 3.21. As high tensile force acts on the tension member, prestressed steel (prestressed steel bars, prestressed steel strands) is generally used to increase the tension of the steel. For stability analysis of ground anchor works for a slope, calculation of the required anchor force using a stability analysis which assumes circular sliding, straight sliding and compounded sliding is essential (see Figure 3.22).

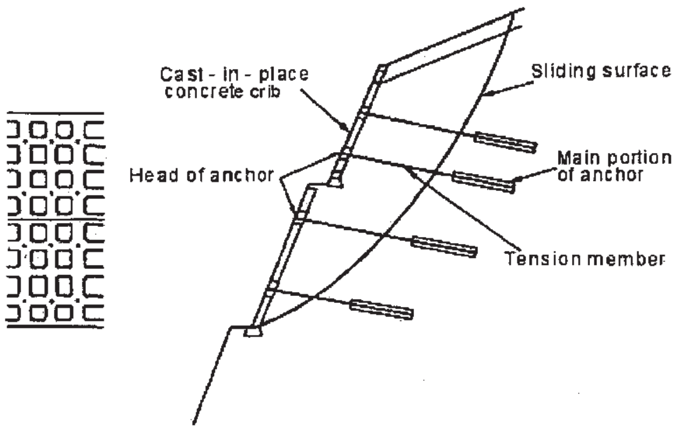


Figure 3.21 Example of Ground Anchor Work (source: PWRI, 2004)

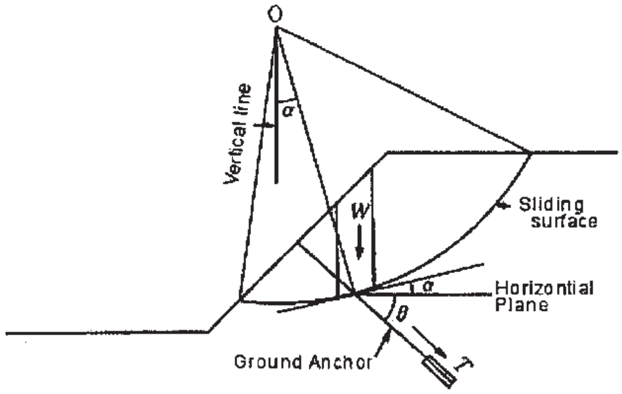


Figure 3.22 Stability Analysis of Slope using Ground Anchor (source: PWRI, 2004)

Ground anchor works are believed to perform the following two functions (see Figure 3.23).

1) Increase of the vertical force on the slip surface to increase the shear resistance force

: Tightening function (T sin(α+θ) tanφ)

2) Reduction of the sliding force

: Retaining function (T cos(α+θ))

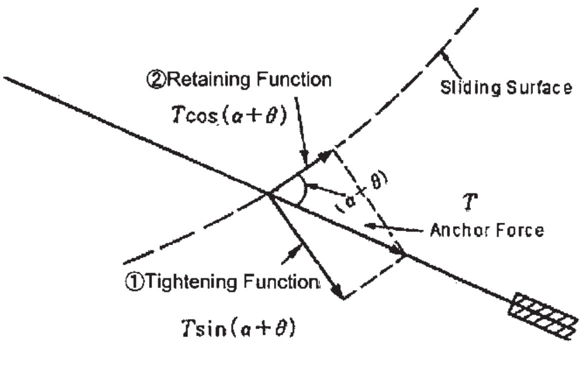


Figure 3.23 Two Functions of Ground Anchor (source: PWRI, 2004)

For the design of ground anchor works to stabilize a slope, an expression which assumes the simultaneous performance of the above two functions is generally used. In certain circumstances, however, the concrete design may reflect the priority given to one of these two functions.

With ground anchor works, bleeding water at the time of grouting often accumulates and reduces the anchorage force. The installing angle for the anchors must, therefore, avoid the range between -10° and +10° from the horizontal plane. Moreover, the fixed length of the anchors, i.e. the length of the anchor body, should, in general, be not less than 3 m and not more than 10 m.

When anchors are used as general structures other than temporary structures, they must normally be given double corrosion protection.

(11) Reinforced Earth Works

Reinforced earth work is defined as a construction method involving the use of various reinforcing materials to stabilize embankment slopes and cut slopes where the gradient is much steeper than slopes which have no reinforcing material. Reinforced earth works are used for slopes requiring reinforcement because of the impossibility of securing a stable slope gradient for an embankment or cut slope, in turn due to constraints posed by the topography and other factors as shown in the selection flow (Figure 3.6 and Figure 3.7). The reinforcing materials to be used for reinforced earth works for an embankment can be in different forms, including bar, membrane and grid. The actual material to be used can be unwoven geotextile, woven geotextile, netting or synthetic fibres. Reinforced earth works are mainly used for the construction of reinforced embankments and reinforced earth retaining walls, etc. A type of reinforced earth works using continuous long fibres has been developed in recent years (Figure 3.24).

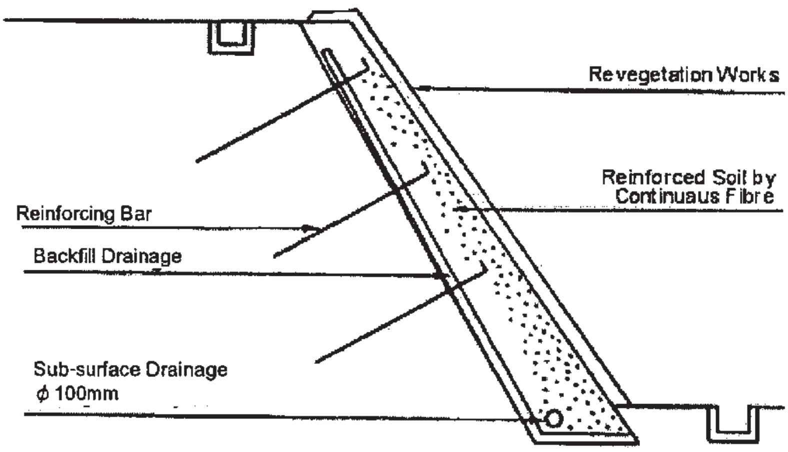


Figure 3.24 Example of Reinforced Earth Works using Continuous Long Fibre (source: PWRI, 2004)

Reinforced earth works for cut slopes (hereinafter referred to as “the cut reinforced earth method”) is a method to enhance the stability of an entire slope with the use of reinforcing materials installed into the ground. This method is used as a measure to prevent relatively small-scale failure, to reinforce a slope with a steep gradient or to reinforce a temporary slope as part of excavation work for a structure (Figure 3.25). The cut reinforced earth method generally involves the use of reinforcing materials (mainly steel bars), grout material, head member and slope protection works as shown in Figure 3.26.

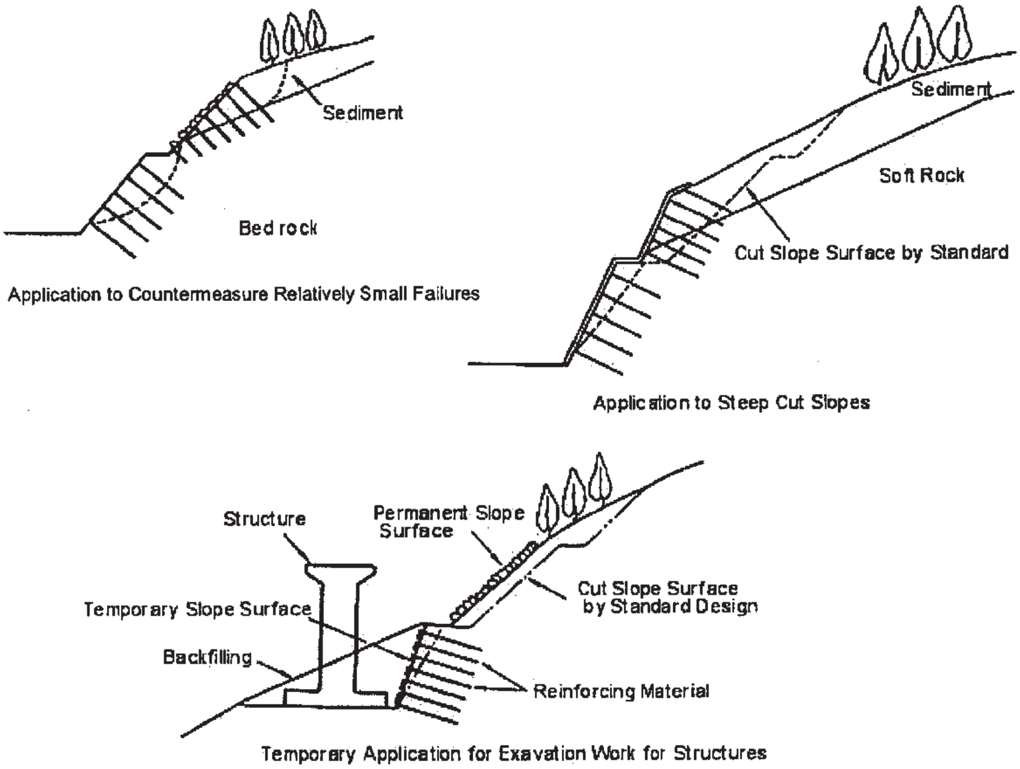


Figure 3.25 Application Example of Reinforced Earth Works for Cut Slopes (source: PWRI, 2004)

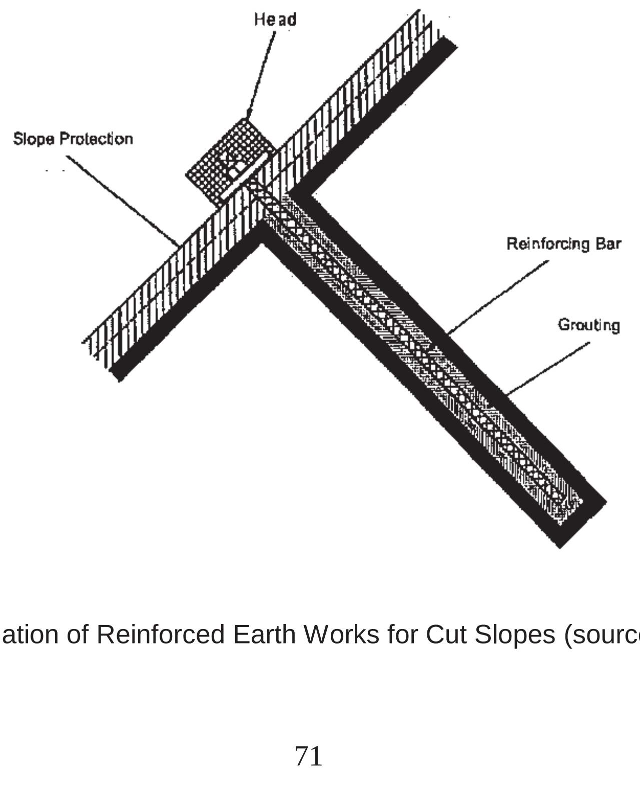


Figure 3.26 Formation of Reinforced Earth Works for Cut Slopes (source: PWRI, 2004)

3.4 Countermeasures for Rock Fall

3.4.1 Selection of Countermeasures for Rock Fall

The important basic principles for countermeasures for Rock Fall are the minimisation of damage due to Rock Fall by installing “Rock Fall prevention works” and “Rock Fall protection works”, taking the importance of the road, expected scale of Rock Fall, probability of Rock Fall occurrence, frequency and actual situation of damage and other relevant matters into consideration and also ensuring of the safety of the slopes using the available means, including road passage control.

There are two types of countermeasures for Rock Fall, i.e. (i) Rock Fall prevention works addressing the sources of Rock Fall and (ii) Rock Fall protection works to mitigate the damage by Rock Fall which has taken place.

The most basic requirements for the selection of countermeasures for Rock Fall are accurate prediction of what type and scale of Rock Fall is likely to occur at which part of the slope in question and what form of movement the falling rocks are likely to follow and a decision on how to stop these falling rocks or how to let them pass the road and objects harmlessly.

The selection of the most appropriate type of work or combination of different types of work as well as slope conditions at the site are essential by carefully analysing the expected effects, durability, workability, construction cost and maintenance, etc. while referring to Table 3.9. Figure 3.27 is a flow chart which should prove useful for the selection of a suitable countermeasure(s) for Rock Fall. As this flow chart mainly focuses on the function of each type of work, it is needless to say that the durability, workability, construction cost, maintenance and other relevant conditions must be considered at the same time for the actual selection of a suitable countermeasure(s).

Table 3.9 Reference Table for Application of Countermeasures for Rock Fall
(source: PWRI, 2004)

Category	Type of Work \ Characteristics	Legend	Effects of Countermeasure: Prevention of Weathering /Erosion	Effects of Countermeasure: Prevention of Occurrence	Effects of Countermeasure: Change of Direction	Effects of Countermeasure: Absorption of Energy	Effects of Countermeasure: Resistance to Inpact	Durability	Maintenance Requirements	Difficulty of Work	Reliability	Cost
		◎	Excellent					Excellent	Low	Easy	Excellent	Inexpensive
		○	Good					Good	Medium	Fair	Good	Varies
		△	Good in some cases					Damage by rockfall	High	Difficult	Good in some cases	Expensive
Rockfall Prevention Work	Cutting			◎				◎	○	△	◎	○
	Removal Works			◎				○	○	△	○	○
	Foot Protection			◎				◎	○	○	◎	○
	Gluing Works		○	○				△	○	◎	△	△
	Ground Anchor			◎				○	◎	○	◎	○
	Wire Rope			◎				○	○	△	○	◎
	Drainage Works		◎					○	○	○	○	◎
	Net Hurdling		○	○	△			○	○	◎	△	◎
	Planting		○	○				○	◎	◎	△	◎
	Shotcrete		◎	○				○	○	◎	○	◎
	Pitching		◎	◎				◎	◎	○	○	◎
	Cribworks		◎	◎				◎	◎	◎	◎	○
	Retaining Wall		◎	◎	△			◎	◎	○	◎	○
	Rockfall Protection Work + Rock Bolt			◎				○	○	◎	○	◎
	Shotcrete + Rock Bolt		◎	◎				○	○	○	◎	◎
	Pitching + Rock Bolt		◎	◎				◎	◎	○	◎	○
	Cribworks + Rock Bolt		◎	◎				◎	◎	○	◎	◎
	Cribworks + Ground Anchor		◎	◎				◎	◎	○	◎	○
	Retaining Wall + Ground Anchor		◎	◎				◎	◎	○	◎	△
Rockfall Protection Work	Cover Type Rockfall Protection Net			○	○	◎		○	○	◎	○	◎
	Pocket Type Rockfall Protection Net				○	○	○	○	○	◎	○	◎
	Rockfall Protecion Fence				◎	○	△	○	○	◎	○	◎
	Multiple Step Rockfall Protection Fence			△	◎	◎		○	○	◎	○	◎
	Rockfall Protection Shelf				◎	◎	◎	◎	◎	○	○	○
	Rockfall Protection Retaining Wall				◎	○	△	◎	○	◎	○	◎
	Rock Shed				◎	◎	◎	◎	◎	○	◎	○
	Rockfall Protection Earth Dyke/Ditch				◎	○	△	◎	○	◎	○	○

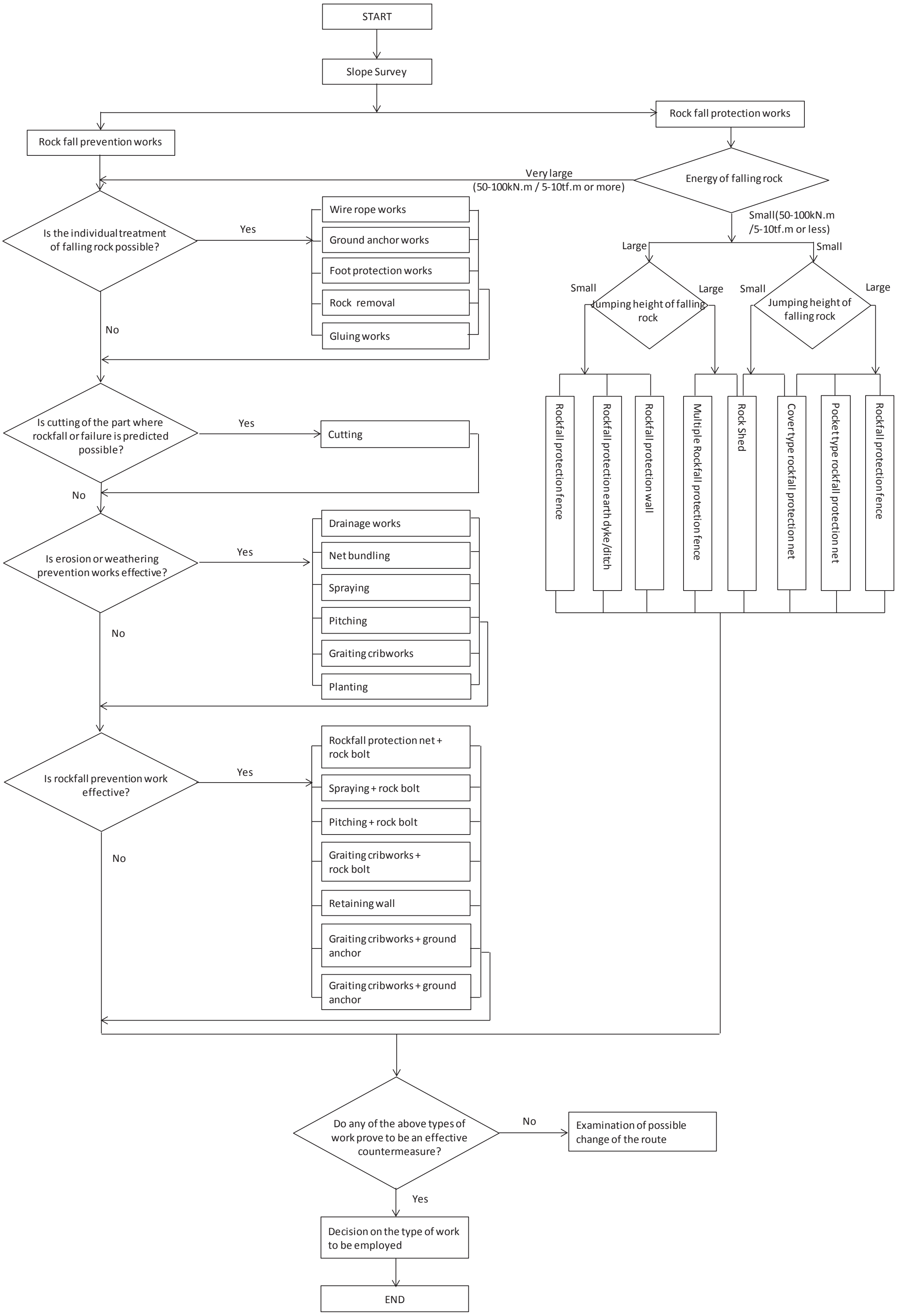


Figure 3.27 Selection Flow of Countermeasures for Rock Fall (source: PWRI, 2004)

3.4.2 Important Points for Application of Countermeasures for Rock Fall

(1) Rock Fall Prevention Work

Although Rock Fall prevention work is a highly effective countermeasure for Rock Fall, the complete prevention of Rock Fall using only Rock Fall prevention work may be difficult. In reality, this type of work should be considered as a countermeasure to reduce the frequency of Rock Fall. Accordingly, it is preferable to employ this type of work in conjunction with a type of Rock Fall protection work in many cases. Many Rock Fall prevention works are identical to slope protection works. Examples of Rock Fall prevention works are shown in Figure 3.28 and Figure 3.29.

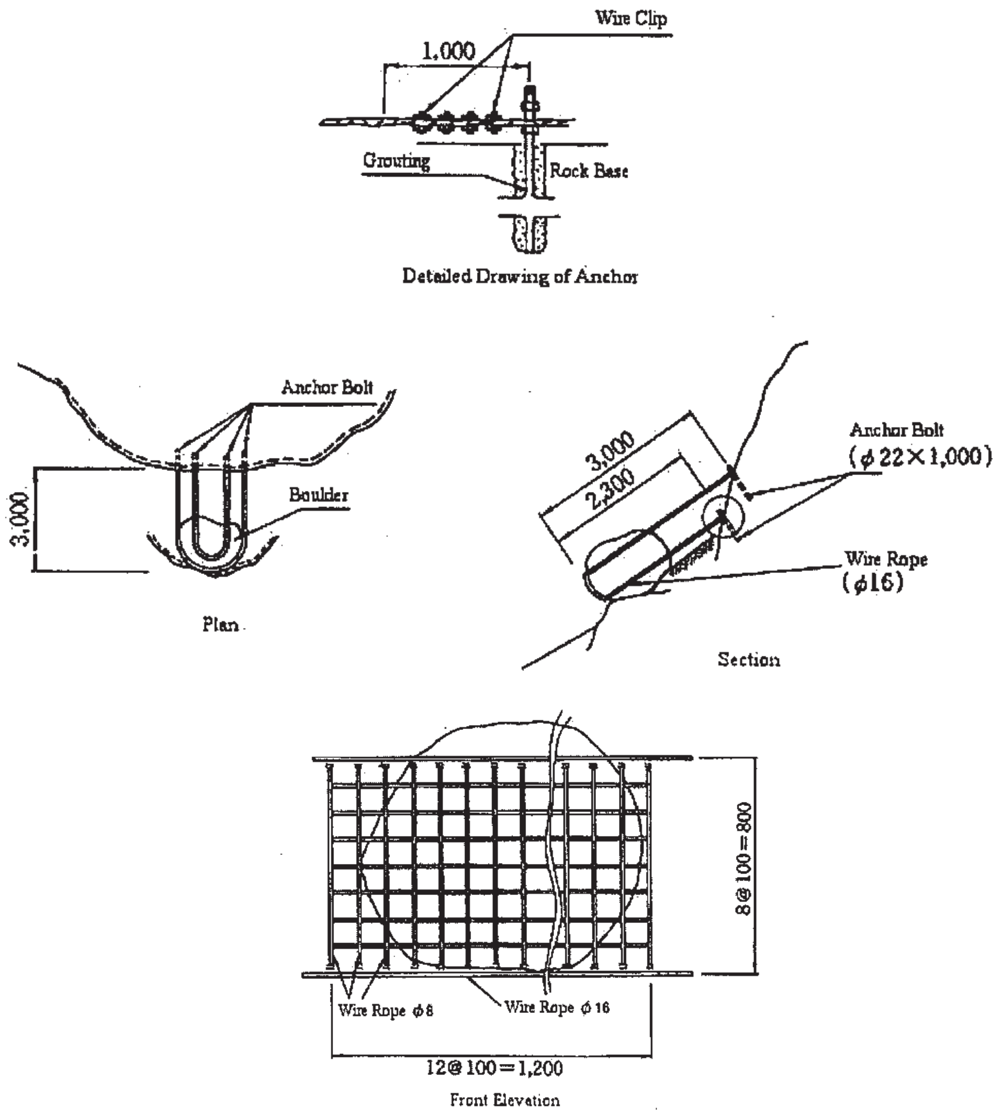


Figure 3.28 Example of Wire Rope Works (source: PWRI, 2004)

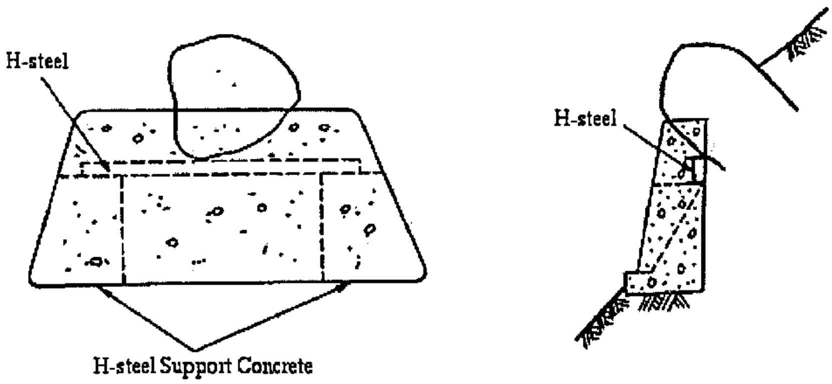


Figure 3.29 Example of Concrete Foot Protection (source: PWRI, 2004)

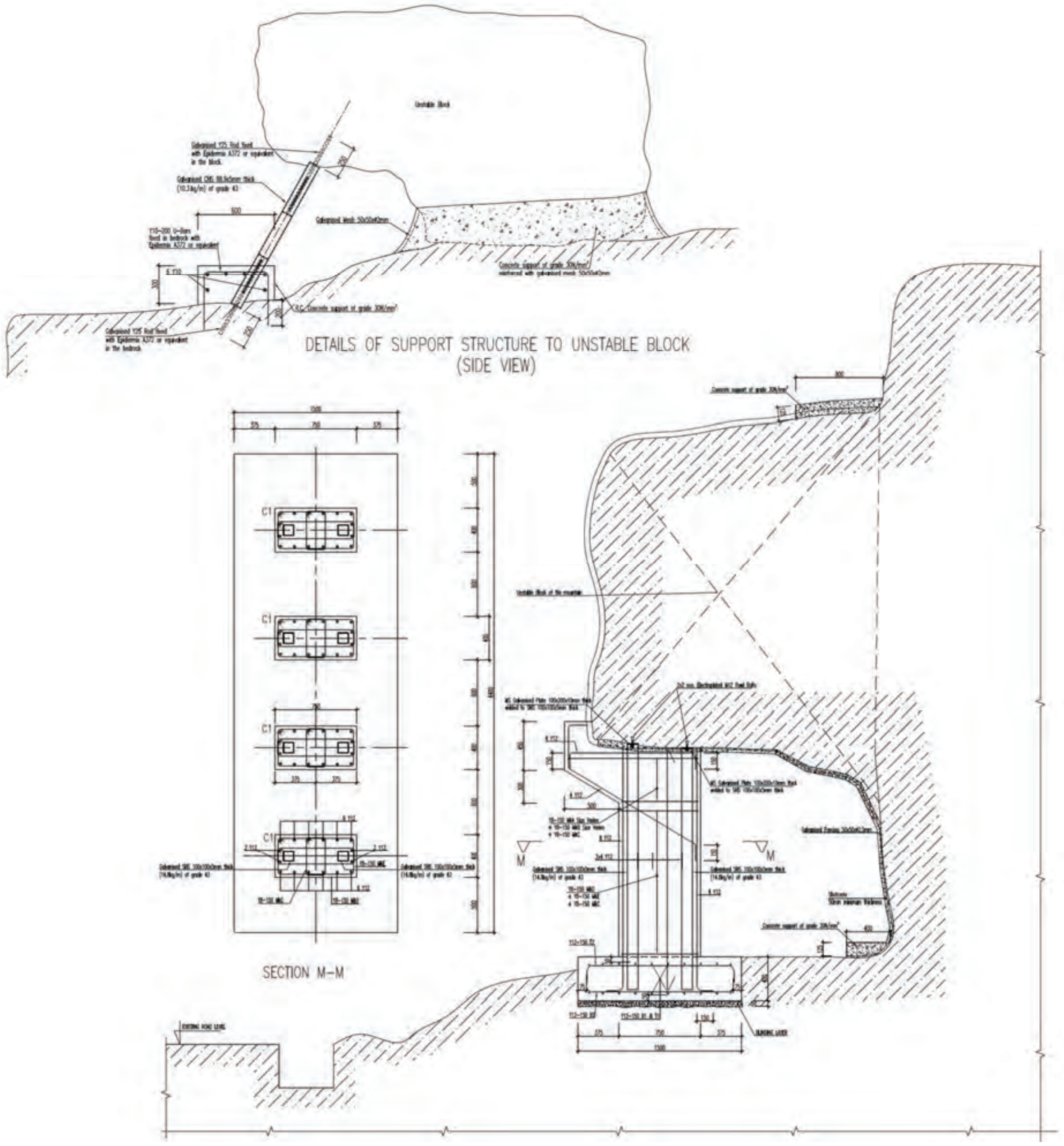


Figure 3.30 Example of Foot Protection, Signal Mountain (source: MPI)

(2) Rock Fall Protection Work

For the design of Rock Fall protection work, it is firstly necessary for the external forces to be dealt with by a structure. In this context, it must be noted that the weight and velocity of falling rocks and the working direction and location of a Rock Fall protection works of falling rocks vary considerably depending on such factors as the topography, geology, degree of weathering of the slope, vegetation and the presence of any other Rock Fall prevention or protection works at the site. Accordingly, the most suitable values representing these factors must be estimated based on field investigation results and past experience of Rock Fall.

Rock Fall protection works can be designed by either the energy calculation method or the static strength calculation method. In the case of a Rock Fall protection net and a Rock Fall protection fence, design calculation at the time of their construction is not necessarily required. Instead, their specifications can be determined based on the specifications used for similar slopes.

1) Rock Fall Protection Net

A Rock Fall protection net uses such light materials as a wire net and wire ropes to entirely cover a slope which has a Rock Fall hazard and there are two types of such net as described below.

- ✓ Cover type Rock Fall protection net
- ✓ Pocket type Rock Fall protection net (Rock Fall curtain)

The former intends to confine rocks which have lost their binding power with the ground with friction between the net and the ground and the tensile force of the wire net, producing a function which is similar to that of Rock Fall prevention work. In contrast, the latter consists of hanging ropes, posts, wire net and wire ropes. The upper part has an entrance for falling rocks and it has the function of absorbing the energy of falling rocks through collision between the net and the falling rocks.

The design of a pocket type Rock Fall protection net follows the following processes (Figure 3.31).

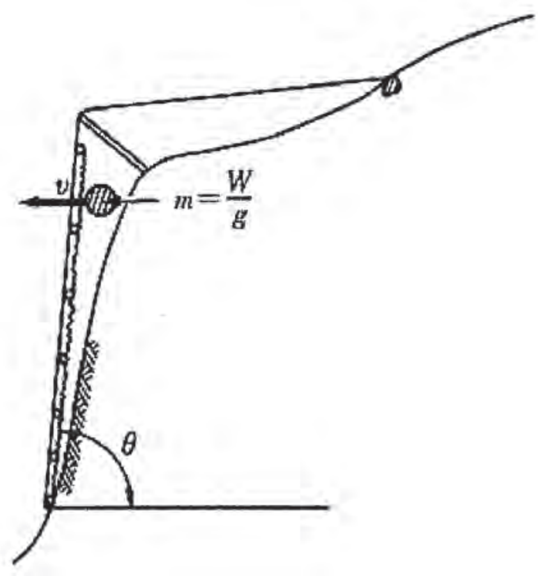


Figure 3.31 Prevention of Impact of Falling Rocks (source: PWRI, 2004)

(a) Calculation of energy of falling rock E_w

$$E_w = (1 / 2) \cdot (W / g) \cdot (V \sin\theta)^2 \qquad (3.4.1)$$

Where,

E_w : energy of falling rock (kN・m (tf・m))
W : weight of falling rock (kN (tf))
V : velocity of falling rock (m/sec)
g : gravity acceleration (m/sec^2)
θ : inclination angle of the net (°)

(b) Calculation of absorbable energy by pocket type Rock Fall protection net

$$E_T = E_N + E_R + E_P + H_{ER} + E_L \qquad (3.4.2)$$

Where,

E_T : energy absorbed by protection net
E_N : energy absorbed by wire net
E_R : energy absorbed by wire ropes
E_P : energy absorbed by posts
E_{HR}: energy absorbed by hanging ropes
E_L : difference in energy before and after collision

(c) If the absorbable energy is found to be larger than the energy of the falling rocks, the stability of the anchor should be examined to withstand the breaking load for the wire ropes.

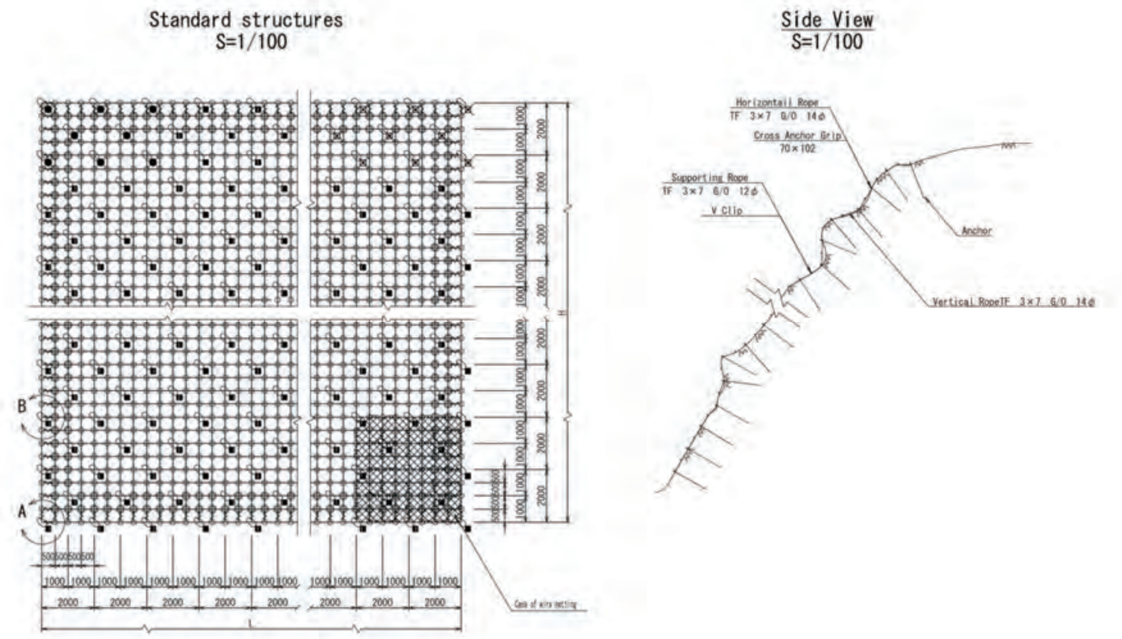


Figure 3.32 Rock Fall Protection Net, Maconde (source: MPI)

2) Rock Fall Protection Fence

A Rock Fall protection fence is an effective countermeasure for relatively small-scale Rock Falls and the type and dimensions should be determined based on the slope conditions.

Two types of Rock Fall protection fences exist, i.e. wire rope and wire net type and H-beam type (see Figure 3.33). As the former uses wire ropes and wire net with excellent extensibility, the energy absorption capacity is relatively large. When the installation of a long Rock Fall protection fence is necessary, it is necessary to divide the entire length into suitable sections for the installation of the fence at each section. In this case, the end parts of the Rock Fall protection fence in each section should overlap to prevent falling rocks from passing through the gaps between neighbouring fences.

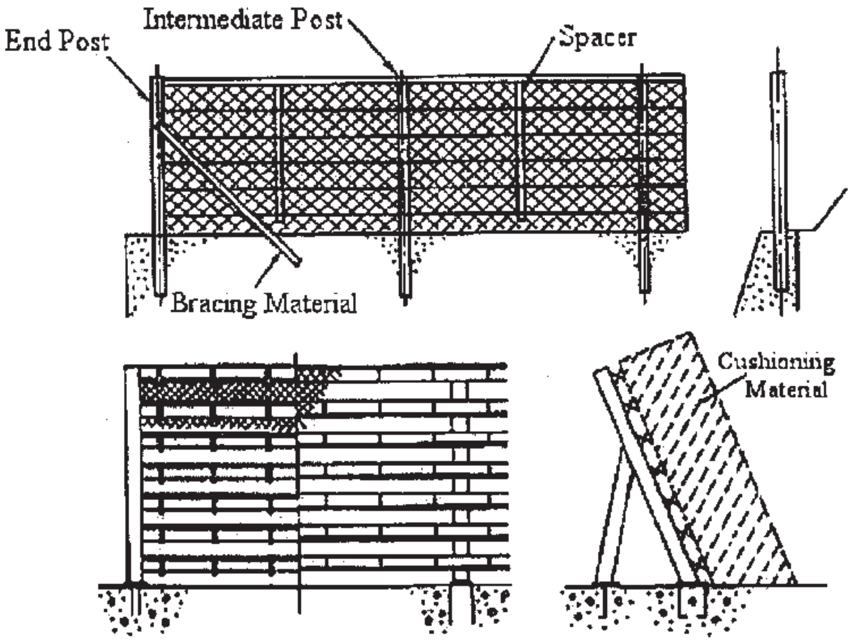


Figure 3.33 Types of Rock Fall Protection Fences (source: PWRI, 2004)

Any design of a Rock Fall protection fence must examine the cross-section and positioning of the members and the stability of its foundations so that the fence can absorb the energy of falling rocks within its allowable displacement.

Only the load of falling rocks is considered for the design of a Rock Fall protection fence. The collision position with the falling rocks is assumed to be the central point between the posts and two-thirds of the height of the fence from the bottom as shown in Figure 3.34. The remaining one-third of the height is considered to be the height margin. The collision direction of the falling rocks is set at a right angle to the fence.

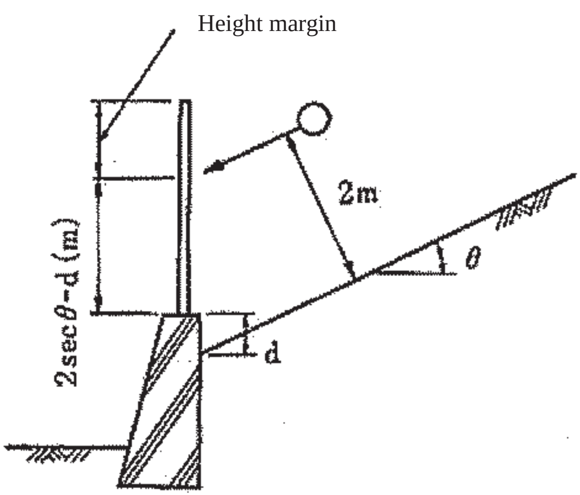


Figure 3.34 Height of Rock Fall Protection Fence (source: PWRI, 2004)

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

$$E_i = (1+\beta)(1-\mu/\tan\theta)W \cdot H \qquad (3.4.3)$$

Where,

E_i : energy of falling rocks (kN・m (tf・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 (tf))
H : height of fall (m)

The allowable maximum displacement angle of the posts is 15°.

The absorbable energy by a Rock Fall protection fence (ET) is calculated by the following formula.

$$E_T = E_R - E_P + E_N \qquad (3.4.4)$$

Where,

E_R : energy absorbed by wire ropes
E_P : energy absorbed by posts
E_N : energy absorbed by wire net

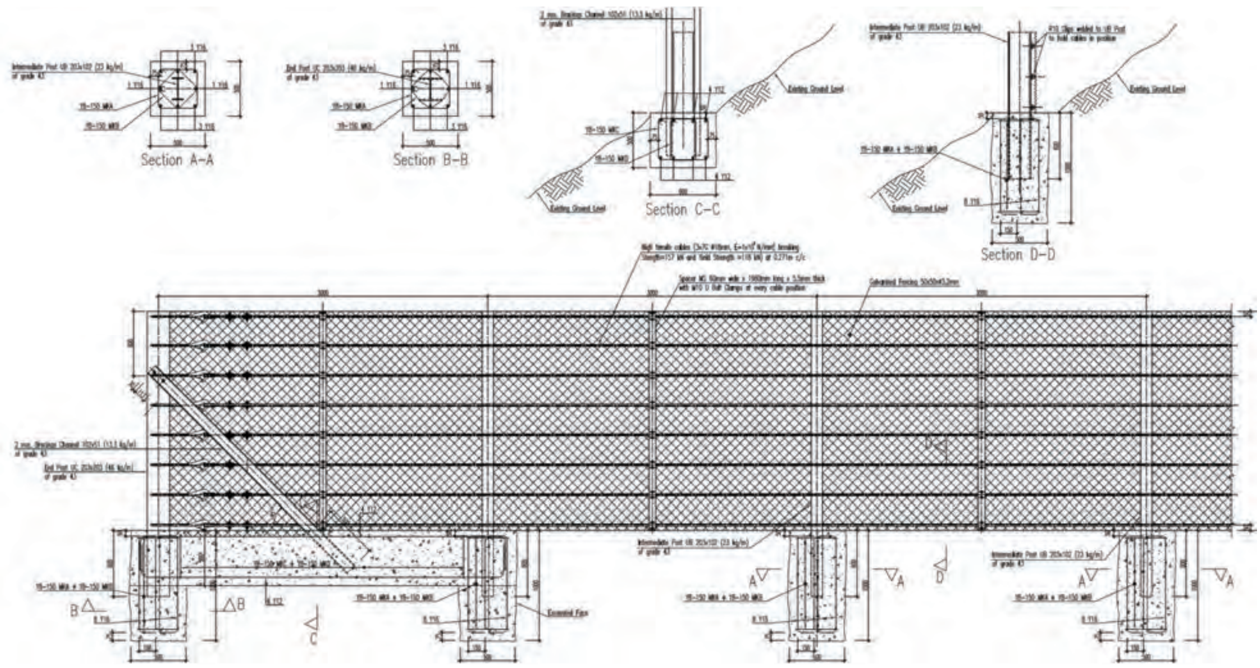


Figure 3.35 Height of Rock Fall Protection Fence, Signal Mountain (source: MPI)

3) Rock Shed

A rock shed is used where there is a series of steep slopes with a high Rock Fall hazard with little room at the roadside, where an expected large-scale Rock Fall cannot be prevented by a Rock Fall protection fence or where the high falling height suggests that falling rocks may well jump over a Rock Fall protection fence. The design is usually carried out using the allowable stress method by converting the impact load of falling rocks to the static load.

The primary objective of Rock Fall protection work, including a rock shed, is to absorb the kinetic energy of falling rocks. However, it is essential to select a structural form, materials and structural specifications to increase the energy absorbability. Sand and gravel are laid above the roof of the rock shed to act as a cushioning material (sand cushion) with a minimum thickness of 90 cm.

Depending on the site of a rock shed, soil deposition may occur on the roof of the rock shed. In this case, the load of the deposit must be taken into consideration. Use of the following Formula (3.4.5) is recommended to calculate the impact load of falling rocks when sand is used as a cushioning material.

$$P=2.108 \cdot W^{2/3} \cdot \lambda^{2/5} \cdot H^{3/5} \cdot \alpha \quad (P= 2.455 \cdot W^{2/3} \cdot \lambda^{2/5} \cdot H^{3/5} \cdot \alpha) \quad (3.4.5)$$

Where,
P : impact force of falling rock (kN (tf))
W : weight of falling rocks (kN (tf))
λ : Lame's constant (kN/m^2 (tf/m^2))
H : height of fall (m)
A : rate of increase based on the ratio between the sand layer thickness and diameter of falling rocks
$\alpha=1.0(T/D)^{-0\ 5}$ (however, when T / D > 1, $\alpha=1.0$)
T : thickness of sand layer (m)
D : diameter of falling rocks (m)

It is necessary to carefully determine Lame's constant. Recent experiment results suggest that the impact force of weight is similar to the calculated value based on Lame's constant at 1,000 kN/m^2 (100 tf/m) when the laid sand layer thickness is similar to the diameter of the falling rocks. However, Lame's constant can exceed 1,000 kN/m^2 (100 tf/m) depending on the particle size distribution, water content and degree of compaction of the sand used. While the head H can be used as the height of the fall of free falling rocks, the height of the fall of falling rocks on a slope with a β gradient can be converted by Formula (3.4.6) (see Figure 3.36).

$$H' : (1-\mu/\tan\theta)H \quad (3.4.6)$$

Where,
H' : converted height of fall (m)
H : head of slope (m)
θ : gradient of slope (°)
μ : equivalent friction coefficient of slope

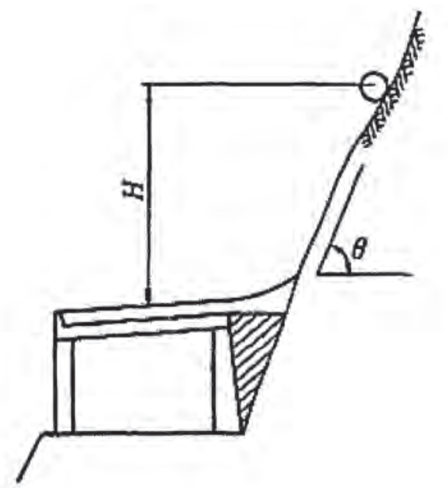


Figure 3.36 Falling Height of Rock Fall to the Rock Shed (source: PWRI, 2004)

4) Rock Fall Protection Retaining Wall

A Rock Fall protection retaining wall is used as a protection work 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. It 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.

3.5 Countermeasures for Debris Flow

3.5.1 Selection of Countermeasures for Debris Flow

When a planned road crosses a mountain stream where debris flow is predicted, it is desirable for its route to avoid an area flooded by debris flow. If the crossing of such an area is unavoidable, a suitable countermeasure(s) should be selected and implemented as shown in Figure 3.37, depending on the expected type and frequency of debris flow and the position and elevation of the road surface.

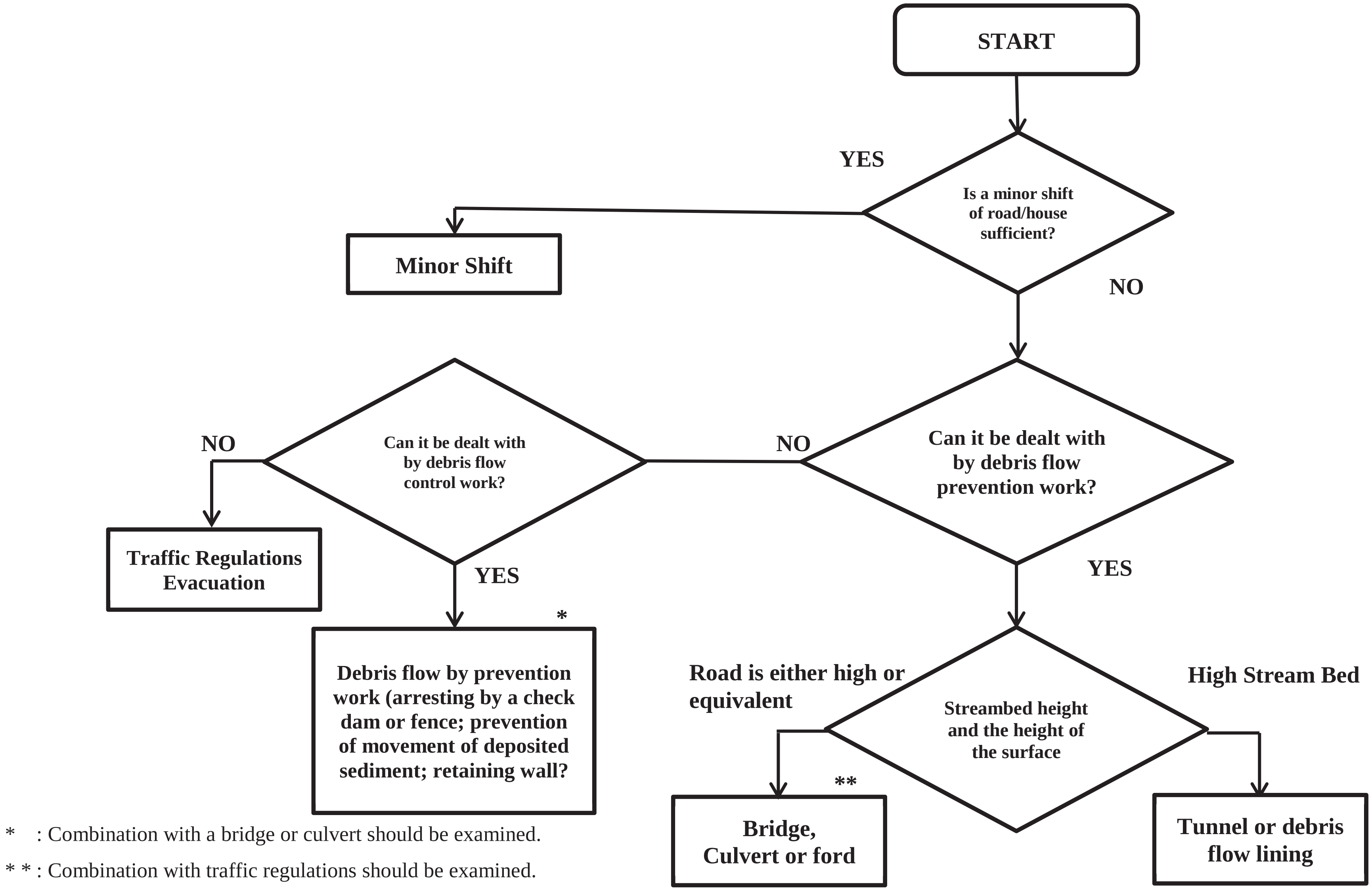


Figure 3.37 Flow Chart for Selection of Countermeasure for Debris Flow to the Road (source: PWRI, 2004)

For the selection of a countermeasure 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, in principle, 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 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.

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 not to plan the route passing through such a site and the route should be shifted to either the upstream or downstream and a crossing provided by a bridge with sufficient clearance (see Figure 3.38).

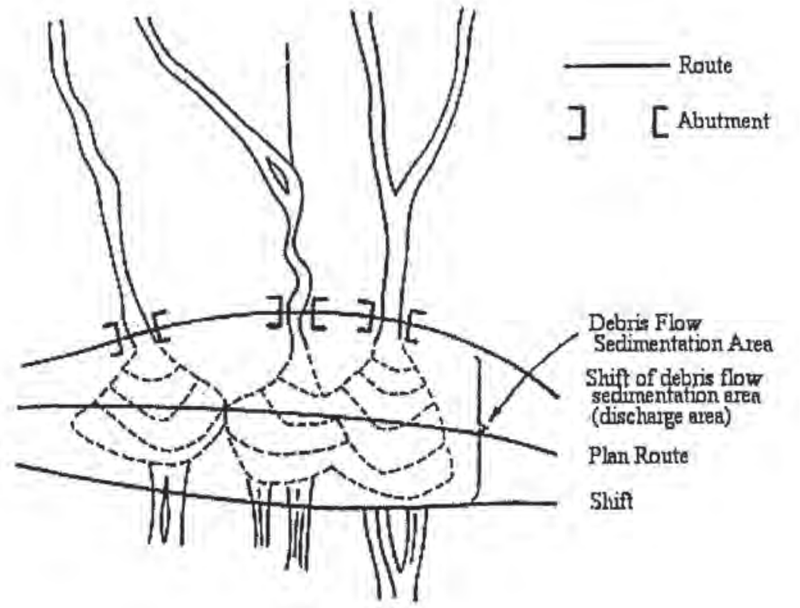


Figure 3.38 Minor Shift in Debris Flow Sedimentation Area (source: PWRI, 2004)

When the road surface is not much higher than the stream bed, 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 countermeasure is not deemed to be sufficient, it may be necessary to consider the construction of a dam to control debris flow. 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.

3.5.2 Important Points for Countermeasures for Debris Flow

(1) 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.

a) Peak Discharge

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

$$Q_{sp} = C_*/(C_*-C_d) \cdot Q_p \qquad (3.5.1)$$

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 stream bed (= 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.

$$C_d = \gamma_w \cdot \tan\theta/((\gamma_s-\gamma_w)(\tan\varphi - \tan\theta)) \qquad (3.5.2)$$

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 stream bed (°)

θ : stream bed gradient (°)

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

$$Q_p = 1/3 \cdot f \cdot r_e \cdot A \qquad (3.5.3)$$

Where,

F : peak flow index

r_e : mean rainfall intensity in flood concentration time (mm/h)

A : catchment area (km^2)

b) 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.

$$v= 1/n \cdot h^{2/3}(\sin\theta)^{1/2} \qquad (3.5.4)$$

Where,

v : mean velocity of debris flow (m/sec)

h : wave height of debris flow (m)

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 water level can be calculated using the peak discharge, the velocity-wave height formula and the width of the stream bed in the passing area of debris flow.

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

(3) 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 3.39).

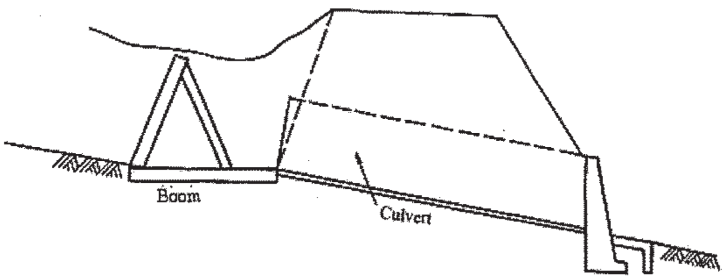


Figure 3.39 Culvert and Boom (source: PWRI, 2004)

(4) Ford

When there is little head between the stream bed 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 3.40).

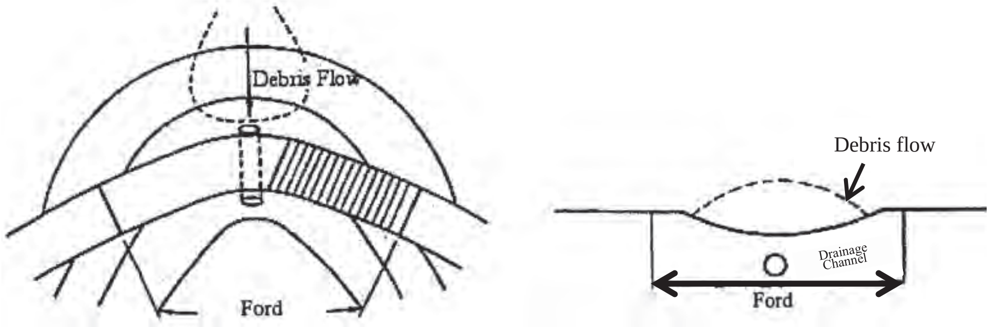


Figure 3.40 Ford (source: PWRI, 2004)

(5) 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 3.41).

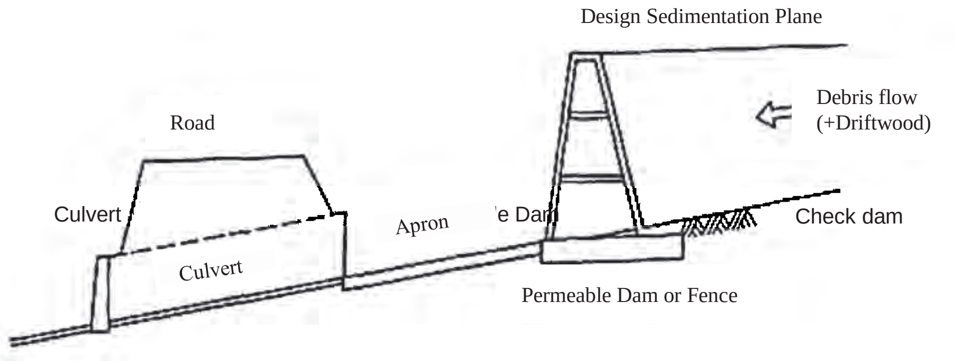


Figure 3.41 Capture of Discharged Material by Permeable Dam or Fence (source: PWRI, 2004)

3.6 Slope Disaster Related Structures (Drainage, Retaining Wall and Culvert)

3.6.1 Drainage

(1) Road Drainage

Drainage is a critical issue for roads. The infiltration of rainwater and/or groundwater to the interior of an embankment can be a major factor for pavement damage while slope erosion due to running rainwater or slope failure due to seepage water destabilizes the 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.

During road construction, careful consideration of drainage is essential to ensure the traffic ability of heavy construction machinery and to properly manage the water content during construction.

There are many road drainage systems as shown in Figure 3.42 and Figure 3.43. Depending on the type of target water, these are basically classified as surface drainage, underground drainage, slope drainage, drainage from the backfill part or the inside of a structure and transverse drainage by a culvert, etc. Figure 3.44 shows the various types of road drainage by purpose.

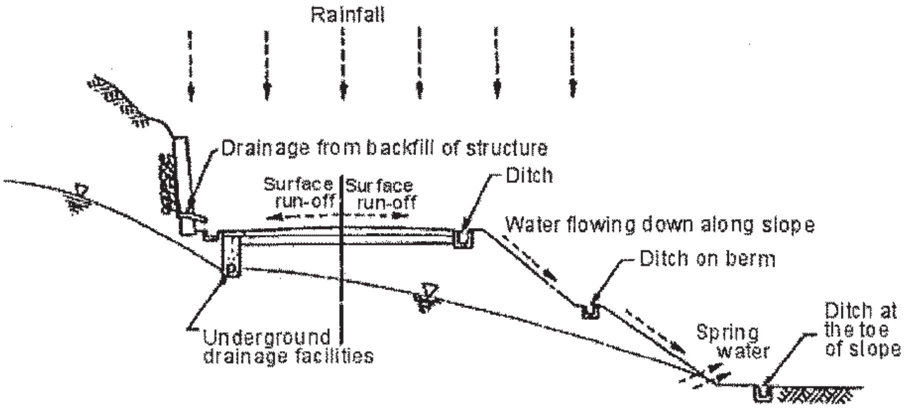


Figure 3.42 Type of Drainage (source: PWRI, 2004)

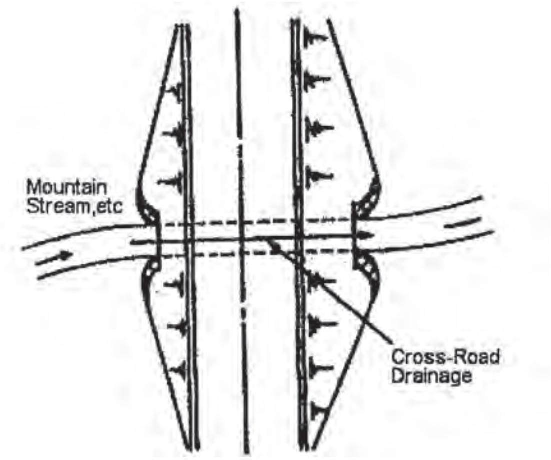


Figure 3.43 Type of Drainage (Transverse Drainage) (source: PWRI, 2004)

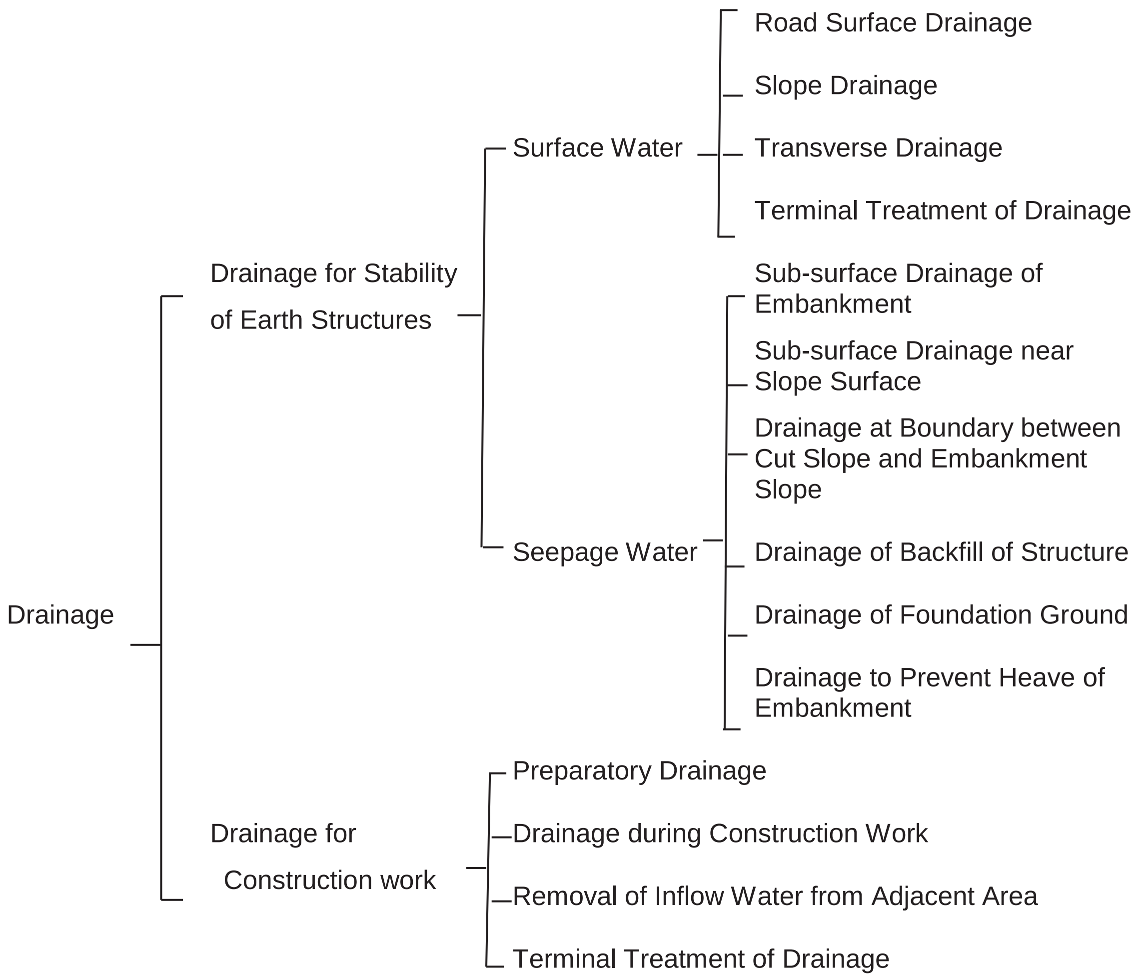


Figure 3.44 Classification of Road Drainage (source: PWRI, 2004)

As the largest factor in the decision on the capacity of drainage facilities is generally the rainwater discharge volume, accurate estimation of the rainfall characteristics is important. In addition, attention must be paid to the frequency of road use, site conditions, anticipated degree of damage by a level of discharge above the design discharge volume, and construction cost of individual drainage facilities.

While the discharge volume of rainfall varies depending on the recurrence period of rainfall, Table 3.10 and Table 3.11 show the model recurrence periods to be adopted as the design standards for drainage facilities.

Table 3.10 Selection Standard by Road Classification in Japan (source: PWRI, 2004)

Classification of Roads / **Designed Traffic Volume (Vehicles/Day)**	National Expressway	National Highway	Prefectural Road	Municipal Road
Larger than 10,000	A	A	A	A
10,000 to 4,000	A	A, B	A, B	A, B
4,000 to 500	A, B	B	B	B, C
Less than 500	-	-	C	C

Table 3.11 Standard Recurrence Period of Rainfall Applicable to Drainage Facilities in Japan (source: PWRI, 2004)

Class (Refer to the Table 3.10)	Level of Drainage Capacity	Recurrence Period of Rainfall	
		(a)	(b)
A	High	3 years rainfall	More than 10 years rainfall (c)
B	Normal		7 years rainfall
C	Low		5 years rainfall

Note:

(a) Applicable to normal road drainage such as road surface or small scale slope;

(b) Applicable to important road drainage such as transverse drainages which remove runoff water from large scale natural slope or located at important flat urban area where local drainage is difficult; and

(c) 30 years is advisable for very important transverse drainage from the viewpoint of road maintenance and operation.

(2) Surface Drainage

a) Discharge Volume

The rainwater discharge volume must be known to decide the drainage facility capacity. Conventionally, the drainage facilities were empirically determined from run-offs due to rainfalls in the past. However, it is desired to calculate the run-off by using the following rational formula:

$$Q = (1 / 3.6 \cdot 10^6) \cdot C \cdot I \cdot a \qquad (3.6.1)$$

where

Q : Run-off (m^3/sec)

C : Coefficient of run-off

I : Rainfall intensity within time of concentration (mm/h)

a : Catchment area (m^2)

A flow chart for the rainwater discharge volume calculation process is shown in Figure 3.45.

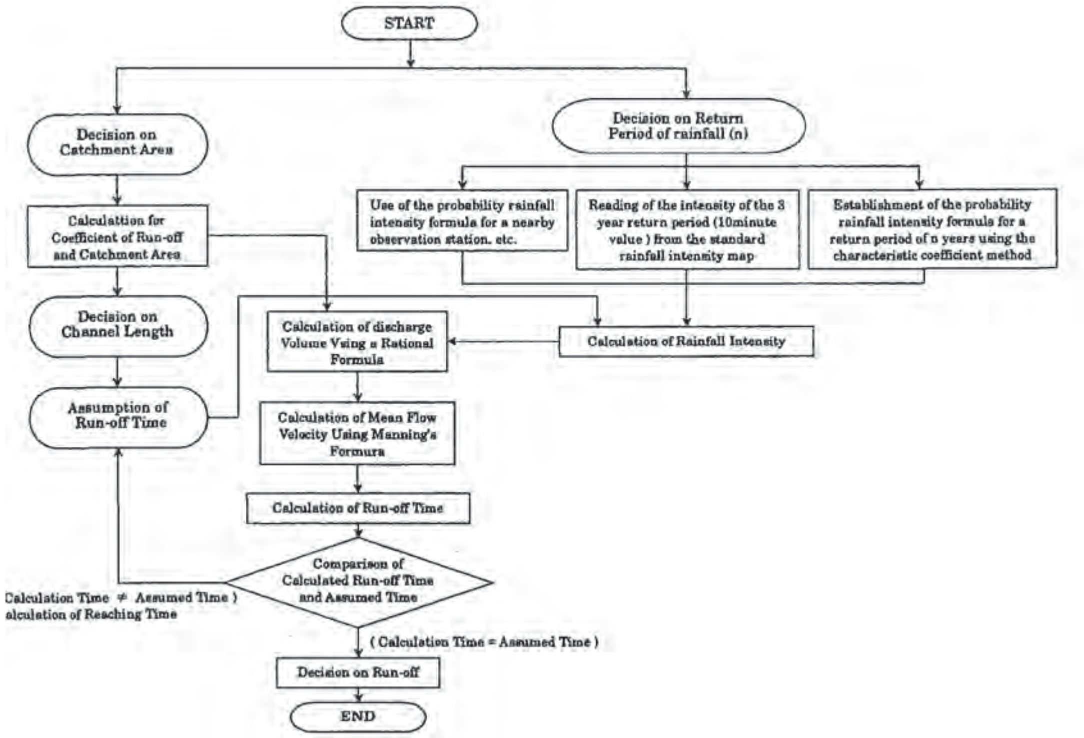


Figure 3.45 Calculation Processes for Run-off (source: PWRI, 2004)

1) Rainfall Intensity

The rainfall intensity is determined by one of the following methods based on the recurrent period of rainfall selected from Table 3.10 and Table 3.11.

(a) Application of the stochastic rainfall intensity formula for a nearby rain observation station

(b) Use of the standard rainfall intensity map

(c) Application of the characteristic coefficient method

For the design of such road surface drainage facilities as side ditches, method (b) above should be used. For the design of important drainage facilities, such as determination of the cross-section for water flow for a culvert, etc. which runs across a road, method (a) above should be used. However, if reference data on rainfall observed by a nearby rain observation station is unavailable, method (c) should be used.

(a) Application of the stochastic rainfall intensity formula for a nearby rain observation station Talbot's formula (3.6.2) shown below is most widely applied for the determination of rainfall intensity.

$$I \sim a / (t + b) \qquad (3.6.2)$$

Where
I : rainfall intensity (mm/h)

a, b: constant varying by regions
t : Rainfall duration (min.) (time of concentration)

This formula requires rainfall data for arbitrary rainfall duration of "*t*". It is, therefore, necessary to obtain rainfall data from a nearby rainfall measurement station to the planned site for road drainage to assess the probability of occurrence.

(b) Use of the standard rainfall intensity map

This method involves the use of the standard rainfall intensity map which is prepared from the national map for the 10-minute rainfall intensity with a recurrence period of three years based on the method described in (c) next. As the reference data used for the preparation of the map is mainly based on the data in urban areas, a 20% - 40% increase should be considered in cases where there is an increase of the rainfall due to topographical factors, such as a mountainous area and other specific factors.

(c) Application of the characteristic coefficient method

In the case of this method, only 1-hour rainfall and 10 minutes rainfall data is used from the wide range of rainfall data to establish the stochastic rainfall intensity formula and its accuracy is known to be virtually the same as the accuracy achieved by the conventional stochastic calculation method. A national rainfall intensity map based on this method is expected to be prepared using 1 hour and 10-minute rainfall data for 25 years at the meteorological observatories and stations throughout Mauritius.

2) Catchment Area

A catchment area can take different forms depending on the specific purpose of surface drainage facilities. It can consist of (a) only the right of the way, (b) both the right of the way and neighbouring slope surfaces and/or flat land or (c) a relatively large adjacent area, such as an adjacent swamp.

Facilities such as side ditches are allocated to either (a) or (b), while transverse drainage facilities, including culverts, are allocated to (c).

3) Time of Concentration

The time of concentration t is classified into the time for water to reach the drainage facilities from the farthest point in the catchment area (inflow time t1) and the time to reach the design site via a drainage pipe, etc. (down flow time t_2). The design of road facilities should be based on the following expressions.

- Road surface drainage $t = t_1$

- Drainage pipe/culvert $t = t_1 + t_2$

(a) The inflow time is considerably affected by many factors, including the conditions of the ground surface, gradient and size and topographical features of the catchment area. In general, however, it is sufficient to use 15 - 30 minutes for mountain lands, 3 - 5 minutes for cut slopes and 5 minutes for urban areas depending on the slope length based on past experience.

(b) The down flow time at a point where it is necessary to calculate the rainwater discharge volume can be approximately estimated by dividing the longest aggregate length of the side ditches and culvert, etc. in the upstream by the mean flow velocity. This mean flow velocity is calculated by Manning's formula (3.6.3).

$$V = 1 / n \cdot R^{2/3} \cdot i^{1/2} \qquad (3.6.3)$$

Where,

v : mean velocity of flow (m/sec)
n : coefficient of roughness ($sec/m^{1/3}$)
R : hydraulic mean depth (m)
(= A / P; A: cross-sectional area for water flow; P: length of wetted perimeter)
i : water surface gradient (or water channel gradient)

In urban areas, the standard mean velocity is 0.5 - 1.0 m/s for side ditches, 0.6 - 1.0 m/s for small diameter drainage pipes and 0.8 - 2.0 m/s for large diameter drainage pipes.

4) Coefficient of Run-off

The coefficient of discharge varies depending on the rainfall intensity and characteristics of a specific catchment area and its uniform determination is difficult. As a result, various organizations use their own value.

Table 3.12 and

Table 3.13

Table 3.13 should be referred to for drainage facilities such-as road surface drainage facilities for which the rainfall recurrence period is short while Table 3.14 should be referred to for drainage facilities such-as culverts for which the rainfall recurrence period is relatively long. When the land use is complicated, the weighted average value using the component area ratio (Pi) should be considered.

$$C = \Sigma(Pi \cdot Ci) \qquad (3.6.4)$$

Table 3.12 Basic Coefficients of Run-off by Ground Surface Condition (source: PWRI, 2004)

Ground surface condition		Coefficient of run-off
Road surface	Pavement Gravel Road	0.70 - 0.95 0.30 - 0.70
Shoulder, slope, etc.	Fine-grained soil Coarse-grained soil Hard Rock Soft Rock	0.40 - 0.65 0.10 - 0.30 0.70 - 0.85 0.50 - 0.75
Lawns on sandy soil	Gradient 0 to 2% 2 to 7% More than 7%	0.05 - 0.10 0.10 - 0.15 0.15 - 0.20
Lawns on clayey soil	Gradient 0 to 2% 2 to 7% More than 7%	0.13 - 0.17 0.18 - 0.22 0.25 - 0.35
Roof Intermediate Area between houses Park with abundant lawn and trees Mountainous area with gentle slope Mountainous area with steep slope		0.75 - 0.95 0.20 - 0.40 0.10 - 0.25 0.20 - 0.40 0.40 - 0.60
Wetland, water surface Cultivated field		0.70 - 0.80 0.10 - 0.30

Table 3.13 Average Coefficient of Run-off by Type of Land Use (source: PWRI, 2004)

	Type of Land Use	Coefficient of Run-off
Commercial Area	▪ Downtown ▪ Adjacent area to downtown	0.70 - 0.95 0.50 - 0.70
Industrial Area	▪ Dense industrial area ▪ Not so dense industrial area	0.50 - 0.80 0.60 - 0.90
Residential Area	▪ Residential area with little open land ▪ Apartment area ▪ Residential area with much open land/gardens	0.65- 0.80 0.50- 0.70 0.30- 0.50
Green Area and Others	▪ Park and cemetery ▪ Sports ground ▪ Marshalling yard ▪ Dry farmland and woods, etc.	0.10- 0.25 0.20 - 0.35 0.20 - 0.40 0.10- 0.30

Table 3.14 Coefficient of Run-off (source: PWRI, 2004)

Road surface and slope surface	0.70 -1.0	Urban area	0.60 - 0.90
Steep mountain land	0.75 - 0.90	Catchment area of mountain stream	0.75 - 0.85
Gentle mountain land	0.70 - 0.80	Catchment area of small river on flat land	0.45 - 0.75
Undulating land and woods	0.50 - 0.75	Catchments area of major river of which more than half run flat land	0.50 - 0.75
Flat farmland	0.45 - 0.60		

b) Surface Drainage Facilities

Proper attention must be paid to the drainage of surface water in order to ensure the stability of earth structures, such as embankments. Among drainage facilities which target surface water, side ditches are the predominant facilities for road surface drainage while drainage ditches introduced at the top of a slope and berms are the predominant facilities for slope drainage. Side ditches are mainly used to deal with surface water from adjacent land. In the case of a road which crosses the mouth of a valley, the installation of a culvert across the road, which is capable of dealing with the design discharge volume calculated by Formula 3.6.1, may be necessary even if the discharge volume during fair weather is small. Side ditches or drainage ditches which are used as surface water drainage facilities may be simply dug, lined with turf or made of concrete. Dug ditches are used as provisional facilities. Permanent drainage ditches are made of concrete or asphalt admixture. The cross-sectional form of a concrete drainage ditch can be L-shaped, U-shaped or semi-circular-shaped. Drainage ditches made of precast concrete are also widely used.

The drainage capacity of these side ditches and drainage ditches can be calculated by the following formula using the cross-sectional area for water flow and the mean velocity.

$$Q = A \cdot v \qquad (3.6.5)$$

Where,

Q : drainage volume (m^3/sec)
A : cross-sectional area of the water flow section (m^2)
v : mean velocity established by Manning's formula (m/sec)

When the velocity in the drainage ditch is too large, water splash occurs at the bends in the case of an open concrete ditch, possibly leading to the scouring of nearby earth structures. Similarly, scouring of the bottom may occur in the case of dug side ditches or similar simple ditches. When the velocity is too small, sedimentation may occur. These eventualities must be taken into consideration in the design of the longitudinal gradient and cross-section. It is desirable to allow a 20% margin for the cross-sectional area calculated by Formula (3.6.5) in anticipation of sedimentation. A higher margin is necessary for places where a large amount of soil may be discharged at the time of a downpour.

(3) Slope Drainage

a) Drainage for Cut and Embankment Slopes

Damage of slope due to water can be roughly divided into the surface erosion due to 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 3.46 shows the drainage facilities for roadside slopes.

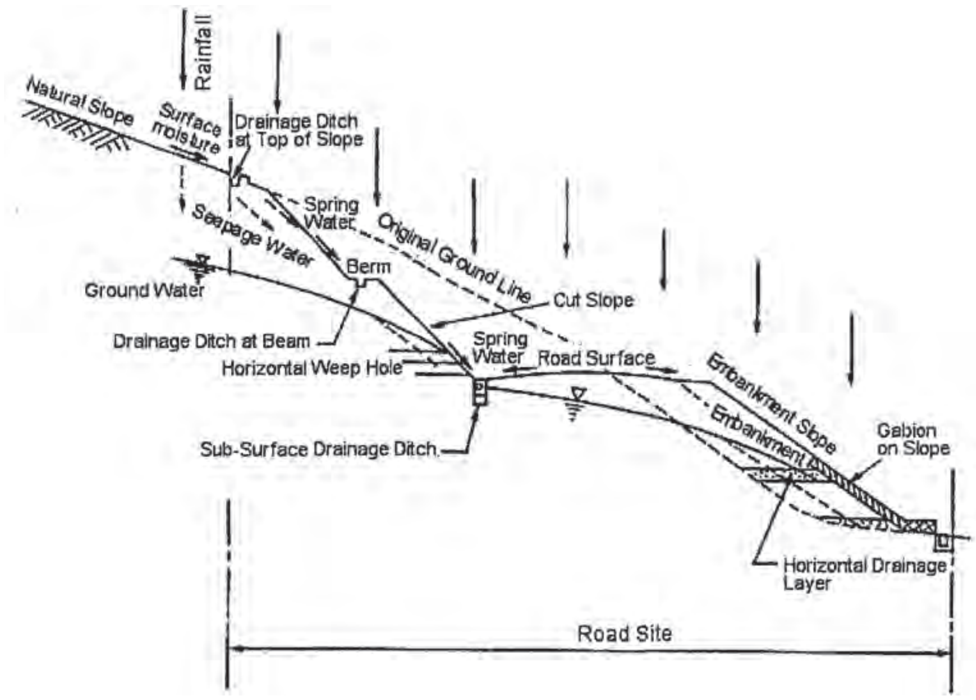


Figure 3.46 Slope of Road and Flow of Water (source: PWRI, 2004)

1) Cut Slopes

It is required to install drainage ditches, according to circumstances, earth banks or even concrete banks so as to prevent ground water from flowing onto the cut slope from adjacent natural slope, in order to avoid any slope failure by changing the direction of water flow or by storing water.

In the case of a large slope, the amount of water running down across the slope may become considerably large at the downstream portion, so that it is required to install drainage facilities on berms to remove water in order to prevent erosion due to the surface water. For places where spring water is expected to come from cut surfaces or where spring water occurs during rainfalls, the stability should be secured by installing slope protection work such as slope crib work with horizontal weep holes as drainage.

2) Embankment Slopes

In regard to examples of failures after completion of embankment, caution is required as shown in the following cases.

(a) Places where rainwater gathers

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 3.47 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.

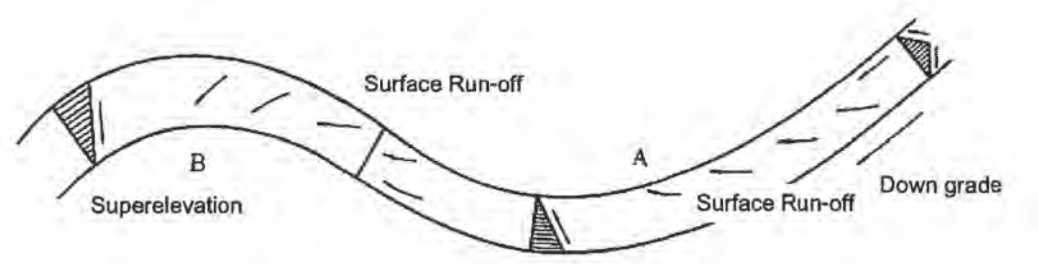


Figure 3.47 Concentration of Water on the Surface of Curved Section (source: PWRI, 2004)

(b) Half-bank (filled section) 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.

(c) 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.

(d) 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 may occur.

b) 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 3.15.

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 3.48), a vertical drainage ditch and a drainage ditch at the berm (Figure 3.2). 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 with purpose to collect surface water must have a sufficient depth into the original ground to easily receive running water. Moreover, backfilling should be carefully carried out using impermeable materials. 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, a good method is the digging of holes as shown in Figure 3.49 and the insertion of porous piping in these holes. The length of these holes should generally be at least 2 m.

Table 3.15 Types of Slope Drainage (source: PWRI, 2004)

Purpose	Type of Drainage Works	Function
Surface drainage (drainage from road surface, slope of adjacent area)	▪ Drainage ditch at the top of a slope ▪ Vertical drainage ditch and ▪ 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

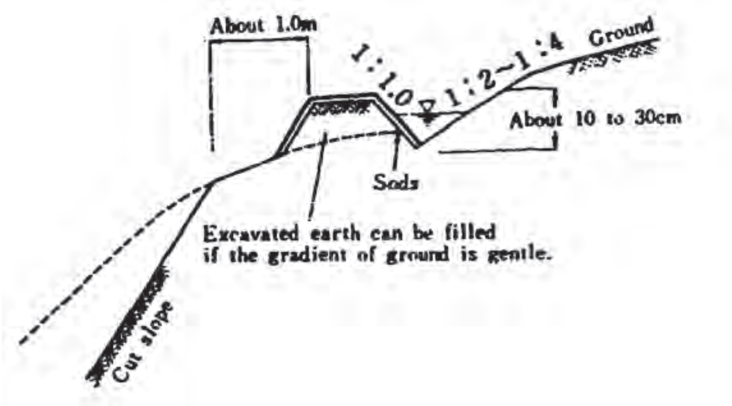


Figure 3.48 Unsupported Gutter (source: PWRI, 2004)

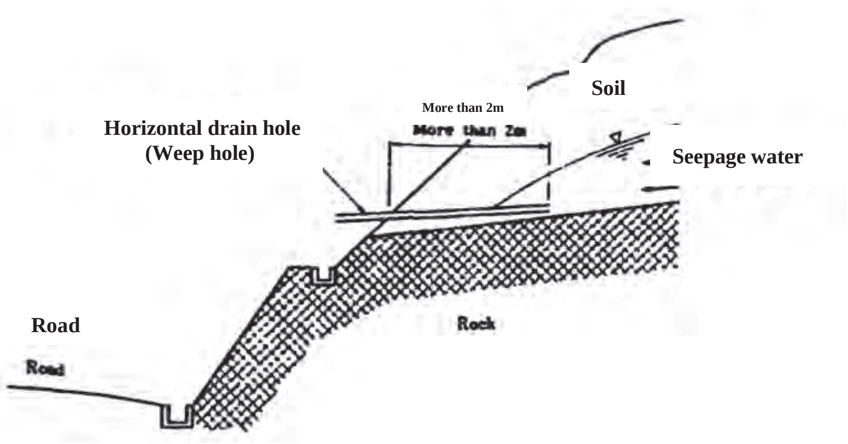


Figure 3.49 Horizontal Weep Holes (source: PWRI, 2004)

(4) Subsurface Drainage

a) Purposes of Subsurface Drainage

A decline of the shear strength of soil due to an increase of the water content is often experienced. In short, the shear strength of unsaturated soil diminishes in line with an increase of the water content. The shear resistance of soil generally declines with an increase of the pore water pressure because of the reduction of the effective stress. When this situation occurs in an embankment, its surface will be significantly damaged. For example, mud pumping through the joints or cracks of the concrete pavement occurs when the embankment base is saturated due to poor superficial drainage. When a similar phenomenon occurs in the case of an asphalt pavement, mud will flow into minute cracks on the surface layer, preventing the closure of these cracks. As a result, damage to the pavement will accelerate considerably. To prevent such phenomenon, it is necessary to conduct subsurface drainage to lower the groundwater level below the land and road surface. This is in order to shut off or drain seepage water into the embankment from adjacent areas of the development as well as the land and road surface.

b) Subsurface Drainage Facilities

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. The drainage facilities used for subsurface drainage include sub-surface drainage ditches, transverse sub-surface drainage ditches and an impermeable layer. When the groundwater surface is virtually flat at flat land, a sub-surface drainage ditch is introduced on both sides of the road (Figure 3.50-(a)). When groundwater inflows from only one side of the land and road surface at sloping land, a sub-surface drainage ditch is introduced at the area side near the mountain as shown in Figure 3.50-(b). An additional ditch is required below the median when the road width is very large (Figure 3.50-(c)).

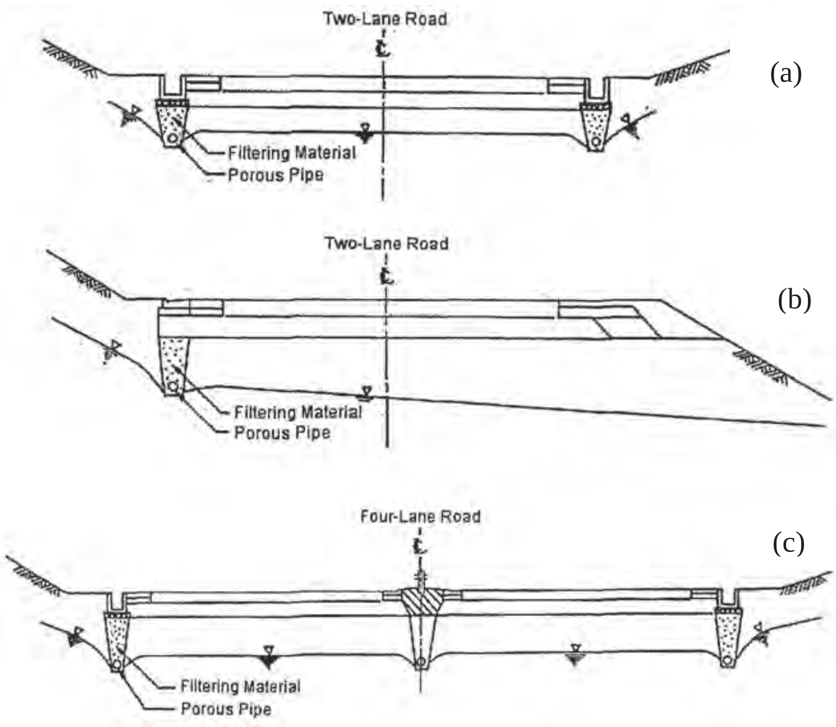


Figure 3.50 Sub-Surface Drain Ditch (source: PWRI, 2004)

In areas with particularly abundant groundwater, sub-surface drainage alone is not sufficient. A horizontal impermeable layer is therefore introduced in the embankment 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 (filled section) and half-cut section of a road or the longitudinal boundary between the Cut slope and Embankment slope of a road, the sub-surface drainage ditches shown in Figure 3.46 should be introduced.

In many cases, a depth of some 1.0 - 2.0 m is required for land and 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 3.51). 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.

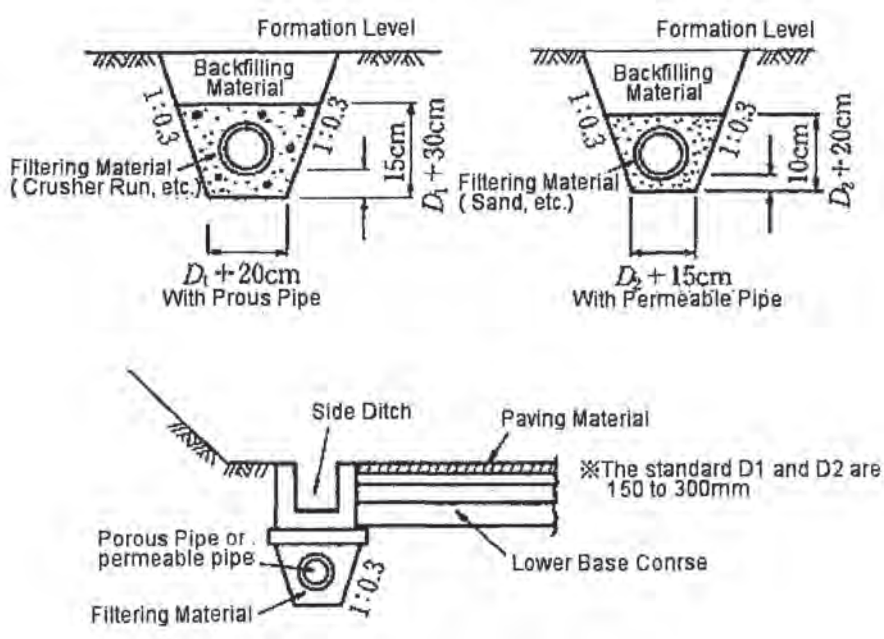


Figure 3.51 Example of Sub-Surface Drainage Ditch (source: PWRI, 2004)

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 fine 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 porous pipes by the inflow inside the embankment soil and provide sufficient permeability. It is therefore desirable for filtering materials to satisfy the following conditions.

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

$$\frac{D_{15}(filtering \quad material)}{D_{15}(subgrade \quad soil)} > 5 \qquad (3.6.6)$$

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

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.

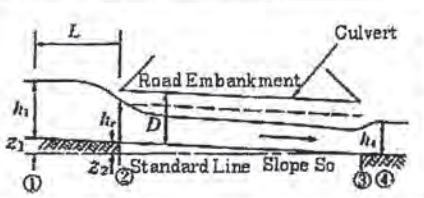
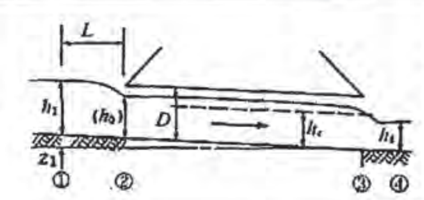
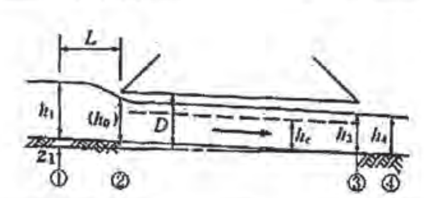
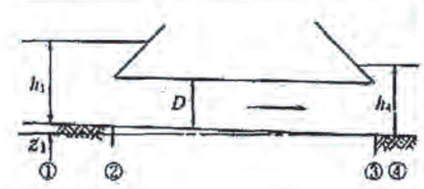
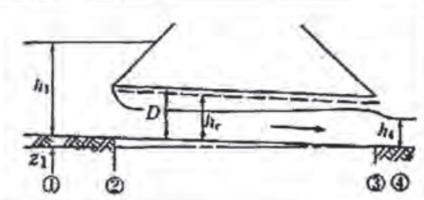
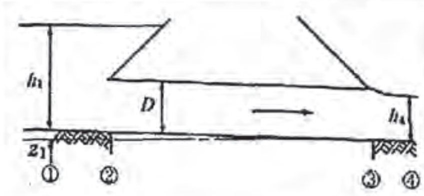
(5) Transverse Drainage across Road

When a road crosses an existing water channel or mountain stream, etc. drainage facilities are introduced across the road. While such facilities usually take the form of a culvert, a bridge may be constructed when the span is very large or when it appears that a culvert will be insufficient to perform the required drainage function.

The cross-section of a culvert for water flow must be large enough to safely allow the passing of the design discharge volume. The value obtained by Formula (3.6.1) should be used as the design discharge volume for a culvert.

In general, the gradient, bottom elevation and width of a culvert should be as identical as possible to those of the existing water channel to prevent sedimentation or erosion. However, when the introduction of a culvert is planned at a mountain stream with a very steep river bed gradient, a culvert gradient within approximately 10% is desirable to ensure workability and to prevent its slippage and abrasion by soil.

When the width of a culvert is narrower than the width of the water channel in the upstream, sudden narrowing of the water channel width raises the water level immediately upstream of the culvert. It is, therefore, desirable for the width of the entire culvert or at least its entrance to be as wide as possible so that the culvert can smoothly be attached to the water channel upstream.

Type	Hydraulic Condition	From of Flow	Remarks
1	The critical depth occurs at the entrance. $D > (h_1 + z_1 - z_2)/1.5$ $h_4 < h_c$ $S_0 > S_c$		Measures to prevent scouring are necessary against hydraulic jump may occur near the exit.
2	The critical depth occurs at the exit. $D > (h_1 + z_1 - z_2)/1.5$ $h_4 < h_c$ $S_0 < S_c$		The introduction of scouring prevention measures is desirable at the exit.
3	Gentle flow throughout (subcritical flow) $D > (h_1 + z_1 - z_2)/1.5$ $h_c < h_4 \leqq D$		The most desirable condition for desiging.
4	Full capacity flow throughout (the exit is submerged) $D < h_4$		This may occur as an extraordinary event but should not be used for designing.
5	Rapid flow at the exit $h_4 \leqq D \leqq (h_1 + z_1 - z_2)/1.5$		ditto
6	Full capacity flow throughout (free discharge at the exit) $h_4 \leqq D \leqq (h_1 + z_1 - z_2)/1.5$		ditto

Note: Symbols
D: culvert height; h: water depth; z: riverbed elevation; S: riverbed gradient;
hc: critical depth; Sc: critical

Figure 3.52 Classification of Water Flow at Culvert (source: PWRI, 2004)

The situation of water flow at the site of a culvert is not only affected by the discharge volume and conditions of the culvert but also by the conditions of the water channel, both upstream and downstream. This situation is generally classified into six types as shown in Figure 3.52.

Types 4 through 6 in Figure 3.52 must be avoided at the design stage as they are all hydraulically inferior and liable to cause serious adverse impacts on an embankment by means of scouring, seepage water and overflow due to the accumulation of water at the upstream side of the road embankment.

The cross-sectional area of a culvert should be designed using a suitable formula for each type after satisfying the hydraulic conditions to make the water flow fall in Type 1 through Type 3 in Figure 3.52. At the same time, the height (or diameter) or culvert "D" should be determined to meet the following conditions.

1) The water surface does not touch the upper surface of the culvert.

2) The water depth in the upstream of the culvert does not exceed 1.5 times of the height of the culvert.
   $D > (h1+ z1- z2) / 1.5$

3) The water level in the upstream of the culvert does not exceed the height of the embankment.
   $h1 < $ (embankment height)

Above conditions 1) and 2) are necessary conditions for Type 1, 2 and 3 to be viable while condition 3) indicates the requirement to ensure that the raised water level in the upstream does not flow over the embankment.

(6) Drainage during Construction Work

Preparatory drainage during construction work and temporary drainage at an embankment, cut slope and borrow pit are the key to the successful construction work. As such, temporary drainage may necessitate an extension of the construction period and/or the replacement of materials, careful attention must be paid to preparatory and temporary drainage, not only at the time of planning but also at the design stage of earthwork.

Particularly in the case of a large-scale cut slope, embankment or a large-scale borrow pit, excavation or banking work could change the direction of water flow and/or the catchment area, resulting in adverse impacts on the existing water channel or river. In view of such a possibility, the advanced examination of disaster prevention measures such-as drainage ditches and a sedimentation basin depending on when ever such measures are deemed necessary is essential.

3.6.2 Retaining Wall

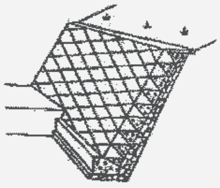
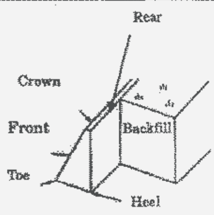
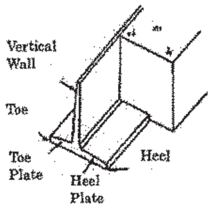
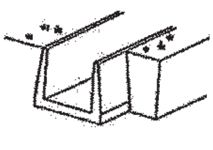
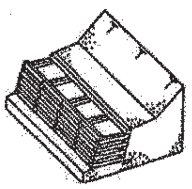
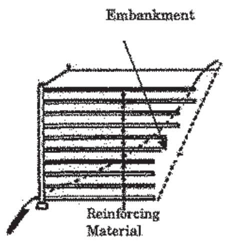
A retaining wall is a structure which is constructed to stabilize the soil or to protect a slope surface when banking or cutting cannot be carried out in accordance with the standard cross section because of constraints posed by the right-of-way and/or topography. Accordingly, it is essential to design an appropriate structure for a retaining wall based on a comprehensive judgment on the topographical, geological and work conditions.

(1) Selection of Structural and Foundation Types

There are many types of structures for retaining walls, and Table 3.16 shows the criteria relating to the application height, characteristics and important points for application, etc. for the selection of a suitable structural type.

The types of foundations for a retaining wall are principally classified into spread foundations and pile foundations. The preferable type of foundations for a retaining wall are spread foundations in view of their movement together with the bearing stratum and the embankment at the back. Even if the surface layer is soft, spread foundations tend to be used with the replacement or improvement of the soft layer provided that the supporting layer exists at a relatively shallow depth from the ground surface (approximately 2 - 3 m). Pile foundations are used when the application of spread foundations is difficult.

Table 3.16 Types of Retaining Walls and Criteria of Selection (source: PWRI, 2004)

Type	Shape	General Application Height	Characteristics	Important Points for Application
Concrete Block (Stone) Masonry Retaining Wall		• Up to 7 m (the gradient and backfill thickness change depending on the height) • Possibly up to 15 m when large blocks are used	• Used for the prevention of small-scale failure at the lower part of a slope or for the protection of slope surface	• Used when the earth pressure is low due to compacted ground at the back or good back soil • Relatively inferior structure in terms of the aseismatic performance
Gravity Retaining Wall		• Up to approx. 5 m	• In principle, the cross-section should ensure that the horizontal load is supported by its own height, not generating tensile stress to the structure's cross-section	• Used at a site with good supporting ground in view of the large reaction force of the base plate • Unsuitable for pile foundations
Cantilever (Inverted T-Shape/L-Shape/ Inverted L-Shape) Retaining Wall		• Approx. 3 – 10 m	• The vertical wall resists the horizontal load as a cantilever • The weight of the earth above the heel plate can be used to stabilise the retaining wall	• Applicable in the case of pile foundations • Many precast products are available
U-Shape Retaining Wall			• Integral side walls and base plate; used for canal roads, etc. • Strats may be used between the side walls	• Often used below groundwater level, making it necessary to examine the impacts of the water pressure and stability against buoyancy •
Crib Retaining Wall		• Up to approx. 15 m	• Cribworks of precast concrete members or similar with hollow parts filled with a filling material; offers good permeability • Resists horizontal load with the weight of the members and filling material	• Designed in a similar manner to a leaning type retaining wall
Reinforced Soil Retaining Wall		• Approx. 3 – 18 m	• The walls are formed by reinforcing earth with friction between the reinforcing material and earth or supporting pressure by an anchor plate; there are many construction methods	• Some deformation occurs to ensure the reinforcement effect • While spread foundations can be employed at relatively soft ground, sufficient analysis of the stability of the entire structure, etc. is necessary
Other Types of Retaining Walls	The appropriate type of retaining wall is adopted depending on many constraining conditions, including the topography, geology, soil properties, working conditions and surrounding environment.			

(2) Determination of Design Conditions

a) Determination of Soil Parameter

I. Parameters Used for Calculation of Earth Pressure, etc.

(a) Parameters for shear strength of soil

The parameter for shear strength of soil is obtained from either the unconfined compression test or the triaxial compression test. The empirically inferred value using Formula (3.10.1) or Formula (3.10.2) based on the value of SPT (standard penetration test) can also be used.

■ Cohesion c of clayey soil

$c = 6N \sim 10N$ (kN/m^2) (0.6N~1.0N (tf/m^2)) (3.10.1)

■ Shear resistance angle φ of sandy soil

$\varphi = 15 + (15\,N)^{1/2} \leq 45°$, $N > 5$ (3.10.2)

If it is difficult to conduct the soil test for retaining walls of up to 8 m in height, the empirical value shown in Table 3.17 can be used.

Table 3.17 Shear Strength Parameters of Backfilling Soil (source: PWRI, 2004)

Type of Backfilling Soil	Shear Resistance Angle (φ)	Cohesion (c) 2)
Gravelly Soil 1)	35°	-
Sandy Soil	30°	-
Clayey Soil (W_L <50%)	25°	-

Note:
1) In case of pure sand, it is possible to use the value of gravelly soil
2) In case that soil parameter is assumed with this table, the value of cohesion should be neglected.

(b) Unit volume weight of soil

The unit volume weight of soil γ (kN/m^3(tf/m^3)) used for calculation of the earth pressure is established using a sample of the soil used for back-filling (banking). If it is difficult to conduct the soil test for retaining walls of up to 8 m in height, the value shown in Table 3.18 can be used instead of conducting the soil test.

Table 3.18 Unit Volume Weight of Soil (Unit: kN/m^3 (tf/m^3)) (source: PWRI, 2004)

Type of Ground	Soil Type	Loose Soil	Dense Soil
Natural Ground	Sand and Gravel	18 (1.8)	20 (2.0)
	Sandy Soil	17 (1.7)	19 (1.9)
	Cohesive Soil	14 (1.4)	18 (1.8)
Embankment	Sand and Gravel	20 (2.0)	
	Sandy Soil	19 (1.9)	
	Cohesive Soil W_L <50%)	18 (1.8)	

Note:
The value achieved by subtracting 9 kN/m^3(0.8 tf/m^3) from the value in the table can be used as the unit volume weight of soil below the groundwater level.

II. Parameters Used for Calculation of Bearing Capacity of Foundations

(a) Allowable bearing capacity of ground

The allowable bearing capacity of the ground is generally determined by conducting an in-situ test. When it is difficult to conduct an in-situ test for retaining walls of up to 8 m in height, the value shown in Table 3.19 can be used.

(b) Friction angle φ_B and adhesion C_B between foundation base and ground

When the shear parameters c and φ of the bearing stratum are established by the soil test and investigation, the friction angle of the foundation base φ_B is determined to be $\varphi_B = \varphi$ for cast-in-place concrete retaining walls and $\varphi_B = 2/3\varphi$ for precast concrete retaining walls.

The adhesion C_B between the base plate and the ground should be determined taking disturbance to the ground during construction work into consideration. When it is difficult to conduct a soil test the value shown in Table 3.20 can be used.

Table 3.19 Types of Bearing Stratum and Allowable Bearing Capacity (Normal Value)
(Source: PWRI, 2004)

Type of Bearing Stratum		**Allowable Bearing Capacity q_a (kN/m^2) (tf/m^2))**	**Remarks**	
			qu (kN/m^2(kgf/cm^3))	**N Value**
Bedrock	Uniform hard rock with few cracks Hard rock with many cracks Soft rock/Mudstone	1,000 (100) 600 (60) 300 (30)	>10,000 (>100) >10,000 (>100) >1,000 (>10)	- - -
Gravel Layer	High density Low density	600 (60) 300 (30)	- -	- -
Sandy Ground	High density Medium	300 (30) 200 (20)	- -	30 – 50 20 - 30
Cohesive Soil Ground	Very hard Hard	200 (20) 100 (10)	200-400 (2.0-4.0) 100-200 (1.0-2.0)	15 – 30 10 - 15

Table 3.20 Friction Coefficient and Adhesion between Foundation Base and Ground
(source: PWRI, 2004)

Condition of Shearing Face	**Type of Bearing Ground**	**Friction Coefficient M = tan Φ_B**	**Adhesion C_B**
Rock / Gravel and Concrete	Bedrock Gravel Layer	0.7 0.6	Not Considered Not Considered
Laying of Rubble or Crushed Stone between Foundation Ground and Foundation Concrete	Sandy Soil Cohesive Soil	0.6 0.5	Not Considered Not Considered

Note:
In the case of precast concrete, the friction coefficient is viewed as not exceeding 0.6 even if the foundation is bedrock

(c) Materials Used and Allowable Stress

1) Concrete

In general, concrete where the strength is equal to or higher than the design strength shown below should be used.

- Plain concrete : 18 N/mm^2 (180 kgf / cm^2)
- Reinforced concrete : 21 N/mm^2 (210 kgf / cm^2)

The allowable compressive stress, allowable shear stress and allowable bond stress of the concrete used for reinforced concrete members are shown in Table 3.21. However, the allowable bond stress is only applied to reinforcing bars where the diameter is up to 51 mm.

Table 3.21 Allowable Stress of Concrete (source: PWRI, 2004)

Type of Stress	Design Reference Strength of Concrete	**21 (210)**	**24 (240)**	**27 (270)**	**30 (300)**
Compressive Stress	Bending Compressive Stress	7 (70)	8 (80)	9 (90)	10 (100)
	Axial Compressive Stress	5.5 (55)	6.5 (65)	7.5 (75)	8.5 (85)
Shear Stress	Bearing of Shearing Force by Concrete Alone	0.36 (3.6)	0.39 (3.9)	0.42 (4.2)	0.45 (4.5)
	Bearing of Shearing Force Jointly by Concrete and Diagonal Tensile Reinforcement	1.6 (16)	1.7 (17)	1.8 (18)	1.9 (19)
	Punching Shear Stress	0.85 (8.5)	0.9 (9.0)	0.95 (9.5)	1.0 (10)
Adhesive Stress	Against Deformed Reinforcing Bar	1.4 (14)	1.6 (16)	1.7 (17)	1.8 (18)

(Unit: N/mm^2 (kg/cm^2))

2) Reinforcing Bars

The allowable stress for reinforcing bars of up to 51 mm in diameter is as shown in Table 3.22.

Table 3.22 Degree of Allowable Stress for Reinforcing Bars (source: PWRI, 2004)

Degree of stress and type of member		Type of Reinforcing bar	**SD295A SD295B**	**SD345**
Degree of Tensile Stress	Case where the effect of an impact load is not included in a combination of loads	Members under normal circumstances [1]	180 (1,800)	180 (1,800)
		Members under severe environment [2]	160 (1,600)	160 (1,600)
	Basic value of allowable stress when a combination of loads includes the effect of an impact load		180 (1,800)	200 (2,000)
	Case where a lap joint length or fixed length of reinforcing bar is to be calculated		180 (1,800)	200 (2,000)
Degree of Compressive Stress			180 (1,800)	200 (2,000)

(Unit: N/mm^2 (kg/cm^2))

Notes:

1) Applicable to a normal environment or permanently positioned in either water or soil.

2) Applicable to cases where drying and wetting are repeated more frequently than in a normal environment and where the members are placed in soil below the level of groundwater containing harmful substances.
3) Increase of Allowable Stress by Combination of Loads

The allowable stress to consider the effect of wind load and collision load is calculated by multiplying the value of allowable stress stipulated in Table 3.21 and Table 3.22 by an increasing coefficient corresponding to the specific combination of loads as shown in Table 3.23.

Table 3.23 Additional Coefficient for Degree of Allowable Stress (source: PWRI, 2004)

Combination of Loads	Additional Coefficient
When considering the effect of wind load	1.25
When considering the effect of collision load	1.50

(d) Load

For the design of a retaining wall, the various types of loads listed below should generally be taken into consideration. However, it is not necessary to consider all types of load depending on the various conditions at the site of a retaining wall and the type of structure.

(a) Dead load; (b) Live load; (c) Earth pressure; (d) Water pressure and buoyancy; (e) Wind load; (f) Collision load;

The dead load used for a cantilever type retaining wall includes the weight of the soil by taking soil above the heel plate as part of the body in addition to the body weight. The live load is considered to constitute the surcharge for design purposes and its value is generally set at q =10 kN/m^2 (1.0 tf/m^2).

(e) Earth Pressure

As a retaining wall is a structure which is in contact with the earth, it is subject to earth pressure on the wall. The earth pressure caused by about-to-collapse back soil due to the forward movement of the wall is called the active earth pressure. As the purpose of a retaining wall is to support an about-to-collapse soil mass, it is generally designed based on this active earth pressure.

The earth pressure used at the design stage of a retaining wall varies depending on whether an embankment or a cut slope forms its back.

(f) Earth Pressure Acting on Retaining Wall for Embankment

The earth pressure acting on the retaining wall for an embankment is calculated by the trial wedge method. The acting surface of the earth pressure is normally, the back face of the concrete body (Figure 3.53). In the case of a cantilever retaining wall, the base substantially extends to the back and the soil above the base is believed to show the same behaviour as a retaining wall when displacement of the retaining wall occurs. For this reason, the line vertically stretching from the heel of the base is assumed to form the virtual back face for the analysis of stability (Figure 3.54).

For the wall friction angle σ, the value in Table 3.24 is used while the value between “soil and soil" in Table 3.24 are used for the wall friction angle at the virtual back face of a cantilever retaining wall.

Earth pressure calculation should follow the processes below (see Figure 3.55).

- ✓ Assumption of the slip surface
- ✓ Calculation of the earth wedge weight and analysis of the balance of forces
- ✓ Calculation of the maximum value for P (resulting force of the active earth pressure P_A) by changing the subject slip surface

The acting position of the active earth pressure force P_A is at the centre of gravity of the earth pressure distribution. Normally, the earth pressure distribution can be assumed to be a triangular distribution and, in this case, the acting position is one-third of the distribution height H from the bottom of the earth pressure distribution.

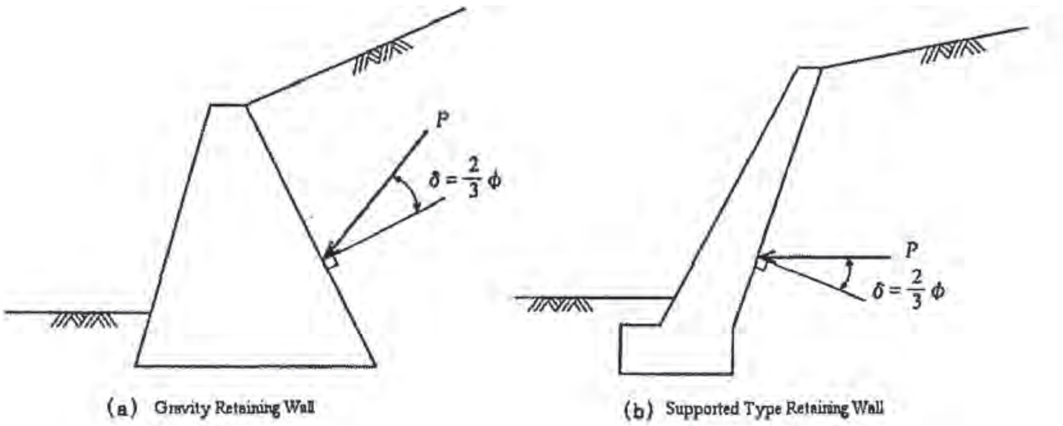


Figure 3.53 Acting Surface of Earth Pressure and Friction Force on Wall Surface in case of Gravity Retaining Wall etc. (source: PWRI, 2004)

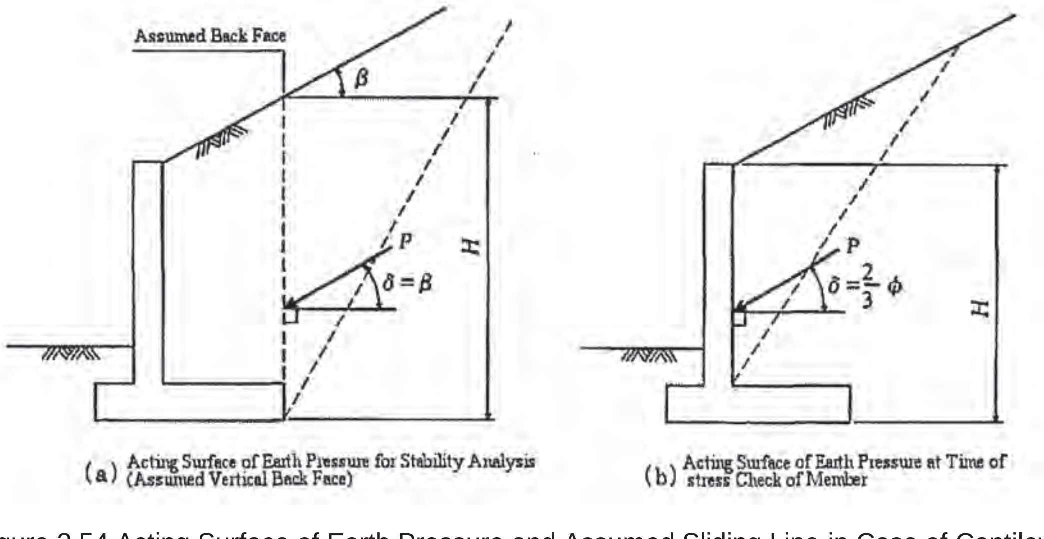


Figure 3.54 Acting Surface of Earth Pressure and Assumed Sliding Line in Case of Cantilever Retaining Wall (source: PWRI, 2004)

Table 3.24 Wall Friction Angle (source: PWRI, 2004)

Type of Retaining Wall	Subject of analysis	Type of Friction	Wall Friction Angle
Gravity Type Leaning Type, etc.	Stability	Soil and Concrete	δ = 2φ/3
	Member Stress		
Cantilever Type Counterfort Type, etc.	Stability	Soil and Soil	δ = β (see Figure 3.48)
	Member Stress	Soil and Concrete	δ = 2φ/3

Note:
When β > φ, δ = φ

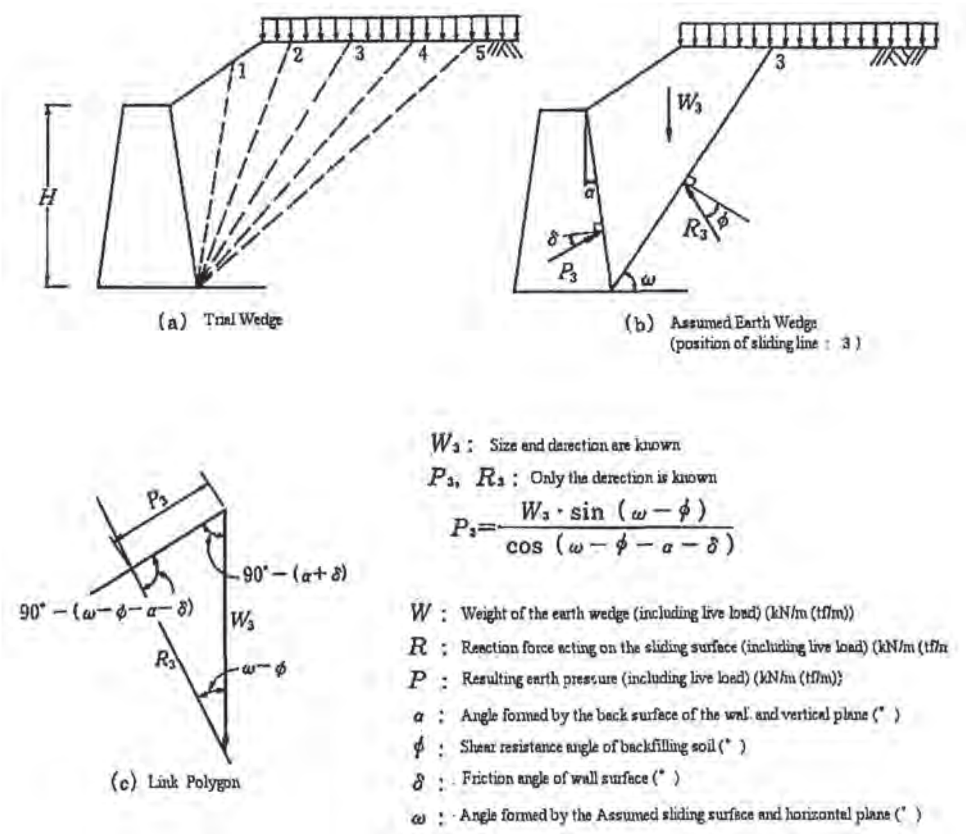


Figure 3.55 Trial Wedge Method (source: PWRI, 2004)

(g) Earth Pressure Acting on Retaining Wall for Cut Slope

As the main purpose of this type of retaining wall is to protect a cut slope, either a leaning type retaining wall or a concrete block retaining wall is mainly used. The earth pressure acting on a leaning type retaining wall differs from that acting on a retaining wall for an embankment as it involves a cut face, i.e. an abnormal boundary surface. To be more precise, the earth pressure in this case is affected by the position and inclination of such boundary surface, roughness of the boundary surface, state of drainage, width of the back-fill section properties as well as degree of compaction of the back-filling material. Accordingly, it is essential for the estimated earth pressure acting on a retaining wall for a cut slope to appropriately reflect the site conditions. The trial wedge method is used to calculate the earth pressure as in the case of the earth pressure acting on a retaining wall for an embankment.

(3) Stability Analysis for Retaining Wall

With respect to the stability of retaining wall, items 1), 2) and 3) should be examined but, depending upon the site conditions and the scale of retaining wall, item 4) - should be also examined. (Figure 3.56)

1) Stability against sliding
2) Stability against overturning
3) Stability for bearing capacity of foundation ground
4) Entire stability including backfill and foundation ground

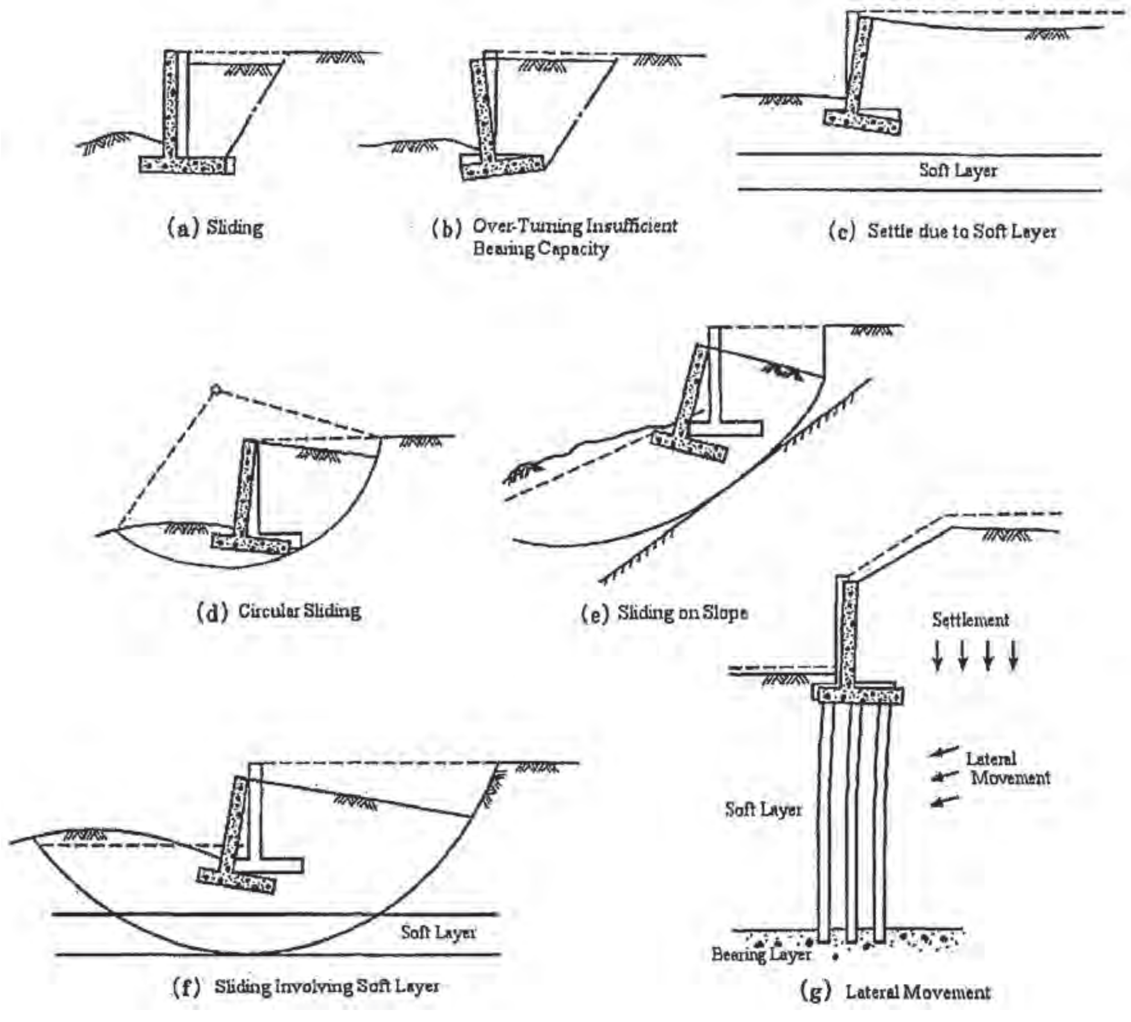


Figure 3.56 Types of Retaining Wall Failure (source: PWRI, 2004)

a) Stability against Sliding

The force, which tends to slide the retaining wall along the plane below the base, is the horizontal component of the earth pressure and is resisted by the shear resisting force created between the foundation ground and base. The factor of safety against sliding should satisfy the following formula:

$$Fs = \frac{\text{Re sisting force against sliding}}{\text{Sliding force}} = \frac{(\sum V \cdot \mu + c_B \cdot B)}{\sum H} \qquad (3.10.1)$$

Where,
$\sum V$: total vertical load on the bottom of the base
$\sum H$: total horizontal load on the bottom of the base
μ : coefficient of friction between base and foundation ground
c_B : adhesion between base and foundation ground
B : width of base of retaining wall (m)

The safety factor shall not be less than 1.5 for normal condition.

The width of base should be increased for stabilization if the factor of safety F_s of equation (3.10.1) is not able to satisfy the requirements. However, if this is not possible because of restrictions such as topographic conditions, the depth of embedment should be increased in order to consider the passive earth pressure at the front, or projection at the bottom of base should be applied to increase horizontal resistance.

b) Stability against Overturning

Load due to the weight of retaining wall, surcharge and earth pressure will act to the bottom of base of retaining wall. The ground reaction below the bottom will vary depending upon the location of point to which the resultant of these loads work. In Figure 3.57, the distance d (m) from the toe to this point can be expressed by

$$d = \frac{\sum Mr - \sum Mo}{\sum V} = \frac{W \cdot a + Pv \cdot b - Ph \cdot h)}{W + Pv} \qquad (3.10.2)$$

Where,
$\sum Mr$: moment of resistance at toe of base of retaining wall (kN･m/m (tf･m/m))
$\sum Mo$: overturning moment at toe of base of retaining wall (kN･m/m (tf･m/m))
$\sum V$: total vertical load at the bottom of base (kN/m (tf/m)

Distance of eccentricity e from the centre of the base of the point of application of resultant R can be expressed by

e = B/2 –d (3.10.8)

As the condition of stability against overturning, the acting position of the resultant must be

Case at ordinary condition : $|e| \leq B/6$ (within central one-third of the width of the base)

Case at seismic condition : $|e| \leq B/3$ (within central two-thirds of the width of the base)

c) Stability for Bearing Capacity of Foundation Ground

Ground unit reaction can be derived from following equations. (Refer to Figure 3.57)

$$\frac{q_1}{q_2} = \frac{(W + Pv)}{B}\left(1 \pm \frac{6e}{B}\right) \qquad (3.10.3)$$

The ground reaction at seismic condition should be determined by equations (3.10.4) and (3.10.5).

$$\text{With } e \leq \frac{B}{6} \quad q_1 = \frac{Pv_E + W}{B}\left(1 + \frac{6e}{B}\right) \qquad (3.10.4)$$

$$\text{With } \frac{B}{6} \leq e \leq \frac{B}{3} \quad q_1 = \frac{2(Pv_E + W)}{3d} \qquad (3.10.5)$$

Also q_1 and q_2 must satisfy the following formula:

$$\frac{q_1}{q_2} \leq q_a = \frac{q_u}{F_s} \qquad (3.10.6)$$

Where
Pv : vertical component of earth pressure resultant at ordinary condition
Pv_E : vertical component of earth pressure resultant during earthquake
q_a : allowable bearing capacity of ground
q_u : ultimate bearing capacity of ground
F_s : Factor of safety for bearing capacity of ground
(F_s = 3 for ordinary condition; F_s = 2 during an earthquake)

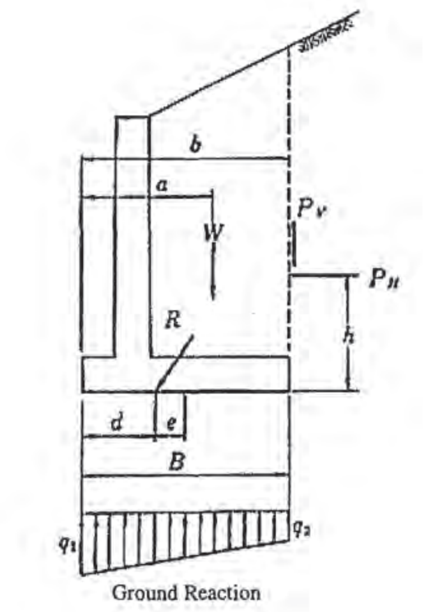


Figure 3.57 Point of Resulting Force and Ground Reaction (source: PWRI, 2004)

When a retaining wall is constructed on a slope, it is necessary to analyse the stability of the entire slope, including the embankment at the back. Multiple retaining walls are occasionally constructed on a slope. In this case, it is essential to confirm the entire stability of the slope in addition to analysis of the stability of individual retaining walls.

(4) Design of Various Types of Concrete Retaining Walls

a) Concrete Block Retaining Wall, Masonry Retaining Wall

The general configuration of a concrete block retaining wall is shown in Figure 3.58. Concrete blocks have mainly been used in recent years because of the shortage of masonry stone.

While the design of a concrete block (masonry) retaining wall (thickness of blocks: approximately 35 - 50 cm) can be carried out in accordance with the slope gradient in Table 3.25 which is determined empirically according to the height, attention should be paid to the application height. Back-filling gravel is used to reduce the water pressure on the block (masonry) wall by discharging water at the back and also to prevent a pressure increase at the back of the retaining wall by dispersing the load acting on the blocks. Accordingly, the back-filling gravel should have good permeability, such as crusher run. The standard thickness of the back-filling gravel at the upper part is 30 cm.

The use of multiple-step concrete block (masonry) retaining walls should be avoided because of the problem concerning the entire stability of the foundation ground, including the retaining walls. To be more precise, such negative developments as acting of the weight of the upper retaining walls as surcharge on the lower retaining walls and the concentration of drained water from the upper walls to a specific part of the lower walls are conceived in the case of this type of retaining wall.

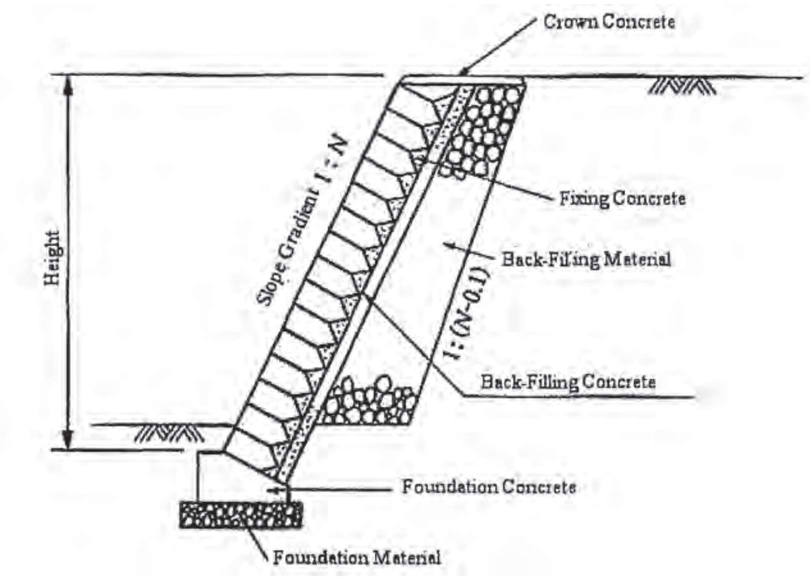


Figure 3.58 Typical Concrete Block Masonry Retaining Wall (source: PWRI, 2004)

Table 3.25 Relationship between Wall Height and Gradient of Wall (source: PWRI, 2004)

Height (m)		**0 — 1.5**	**1.5 — 3.0**	**3.0 — 5.0**	**5.0 — 7.0**
Gradient of wall	Embankment	1: 0.3	1: 0.4	1: 0.5	1: 0.6
	Cut Slope	1: 0.3	1: 0.3	1: 0.4	1: 0.5
Backfilling concrete thickness (cm)		5	10	15	20

b) Gravity Retaining Wall

This type will support the earth pressure by means of its weight. The wall should be designed in such a manner that the resultant earth pressure and weight will not create tensile stress in the body of the wall since the body usually consists of plain concrete (see Figure 3.59).

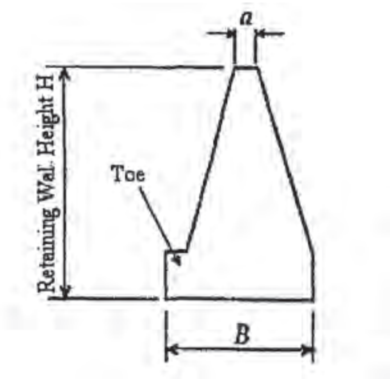


Figure 3.59 Shape of Gravity Retaining Wall (source: PWRI, 2004)

In determining size of the wall, it is desirable for the width B of the base to be about 0.5 to 0.7 times the height of the retaining wall.

c) Cantilever Retaining Wall

Cantilever retaining wall comprises a vertical wall and a bottom slab and each member resists external forces as cantilever beams. Depending on the position of the vertical wall, it is classified into the inverted-T type, L type and inversed L type. The suitable type is selected based on the site conditions although a well-balanced inverted-T type is normally used (Figure 3.60).

This type of retaining wall is adopted for a wide range of heights, partly because the stability of the wall is ensured by its reinforced concrete structure and back-filled soil above the heel plate which acts as the weight and partly because it uses less concrete than a gravity retaining wall.

Its members are designed in a cantilever style where the connecting parts of the vertical wall, toe plate and heel plate form the fixed ends.

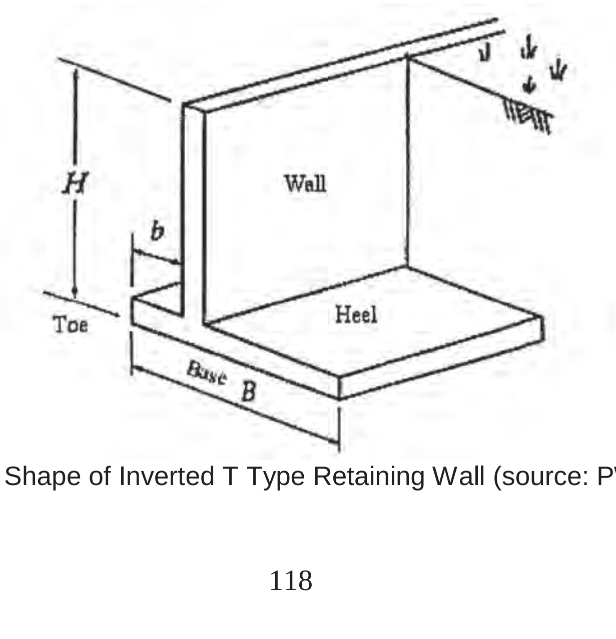


Figure 3.60 Shape of Inverted T Type Retaining Wall (source: PWRI, 2004)

(5) Design of Foundations

As a retaining wall is often constructed in a place with complex topography and geology, the foundations must be carefully designed.

Two types of foundations, i.e. spread foundations and pile foundations are feasible for a retaining wall. Spread foundations are almost always used for sites where the topography changes. One crucial aspect of such spread foundations is the embedment depth of the retaining wall and the following points must be taken into consideration.

- ✓ In the case of a concrete block retaining wall, at least the base stones should be buried in the ground.
- ✓ In the case of a concrete retaining wall, the embedment depth should be at least some 50 cm from the upper face of the toe plate.

Even if there is an outcrop of a good quality bearing stratum, a sufficiently embedment depth should be secured in view of possible scouring of the ground in the future.

(6) Design of Drainage

Another important point in the design of a retaining wall is drainage. When the water content of the soil at the back increases with water infiltration, the earth pressure rises due to the increased density, reduction of the internal friction angle and cohesion of the soil. In case of clayey soil, swelling due to added moisture. Meanwhile, when the groundwater level rises, hydrostatic pressure is added to the earth pressure, constituting a cause of the destabilisation of the retaining wall.

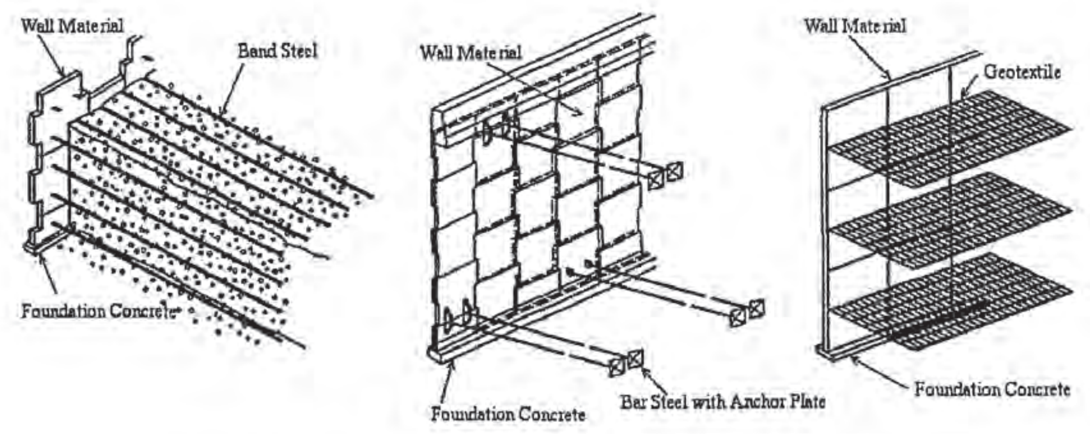
Various types of drainage, including weep holes, ditch type drainage and continuous back drainage, can be available for retaining walls. Although there are many combinations for actual application, weep holes should always be introduced. Weep holes are commonly introduced at the rate of one weep hole per 2 - 3 m^2 of retaining wall using a PVC pipe.

(7) Design of Reinforced Soil Wall

a) General

A reinforced soil wall is a soil retaining structure constructed by means of laying reinforcing materials in an embankment.

The reinforcing mechanism employed by this type of retaining wall is that the earth pressure acting on an almost vertical wall is balanced by pull-out resistance force of the tensile reinforcement materials laid inside an embankment. Many methods with different reinforcing materials and different wall structures have been proposed for practical application (Figure 3.61). Typical reinforcing materials include steel strip, grid or sheet-shaped geotextiles using polymeric materials and steel bar with an anchor plate. The former uses friction resistance to reinforce soil while the latter relies on bearing resistance to achieve the same effect.



(a) Band steel reinforced earth retaining wall **(b) Anchor reinforced earth retaining wall** **(c) Geotextile reinforced earth retaining wall**

Figure 3.61 Schematic Drawing of Typical Reinforcement Soil Walls (source: PWRI, 2004)

The characteristics of reinforced soil walls include: (i) an embankment with an almost vertical wall can be constructed at a restricted right of way in an urban or mountainous area, (ii) spread foundations can be used at a relatively soft bearing stratum where a conventional retaining wall would require pile foundations provided that sufficient technological analysis is carried out (see Figure 3.62).

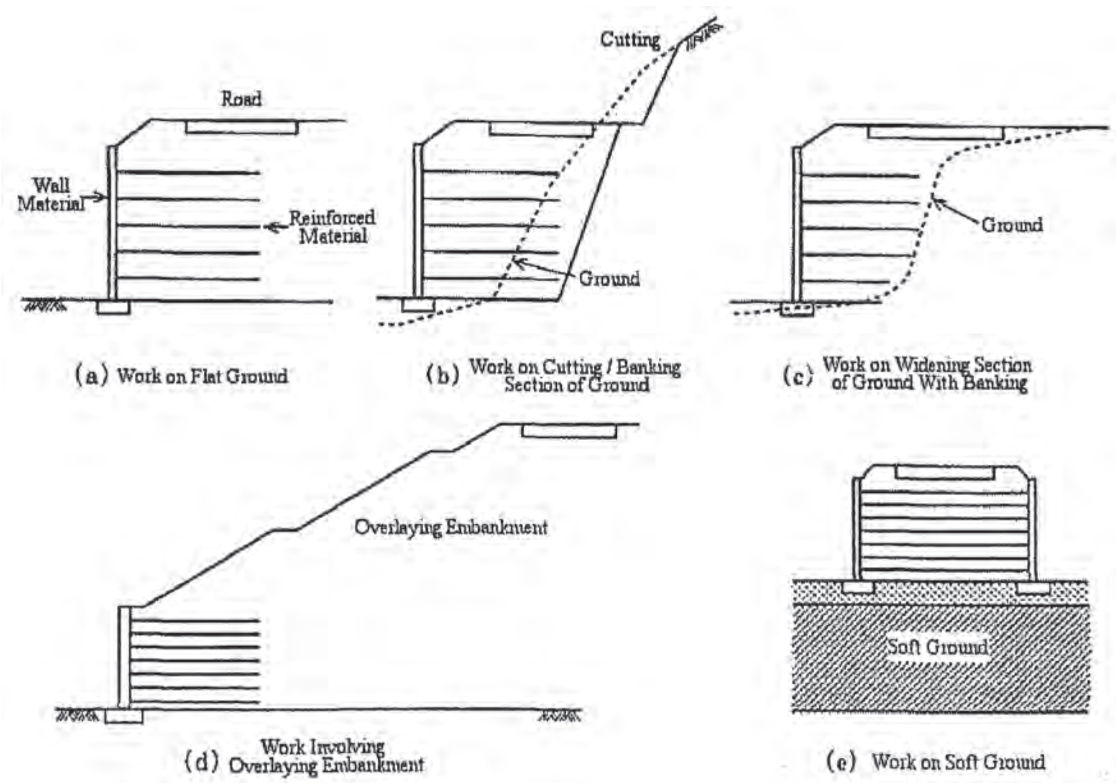


Figure 3.62 Application Examples of Reinforcement Soil Wall (source: PWRI, 2004)

Another characteristic of reinforced soil walls is that some deformation is required to achieve the reinforcing effect. Moreover, long-term durability may be defined as physical or chemical stability in the case of a geotextile reinforcing material or corrosion resistance in the case of a steel reinforcing material for example, and must be guaranteed to ensure the function of a retaining wall as a permanent structure.

b) Design Principles

Any design of a reinforced soil wall must assume the types of failure shown in Figure 3.63, analyse the items described below and secure the required design values as well as safety factor.

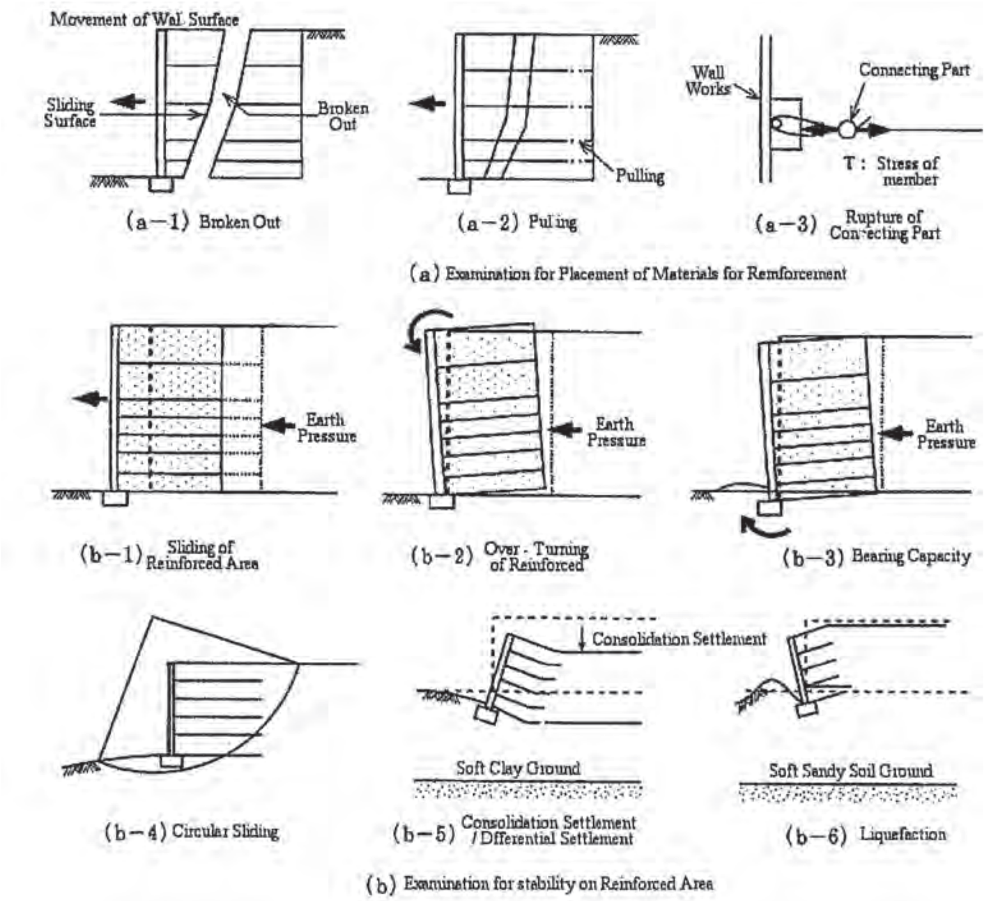


Figure 3.63 Types of Failure and Examination Items for Design of Reinforcement Soil Wall (source: PWRI, 2004)

1) Arrangement of Reinforcing Material

(a) Broken-Out of Reinforcing Material

The earth pressure acting on the wall of the reinforced soil wall is firstly calculated. Next, based on this lateral earth pressure, the required resistance for the reinforcing material is calculated in accordance with the placement position and interval of such material (see Figure 3.64). A type of reinforcing material whose design tensile strength (allowable stress) exceeds the required resistance is then selected. Stress checking for the connecting part between the reinforcing material and the wall is also necessary.

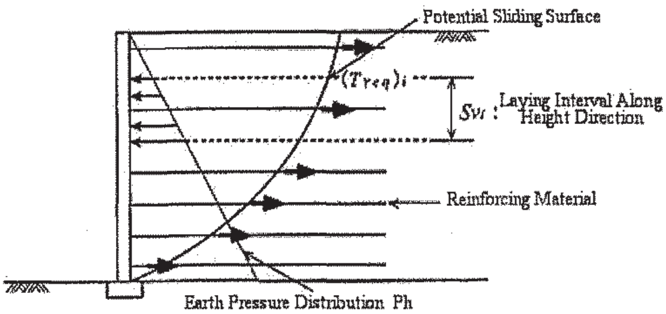


Figure 3.64 Idea of Calculating Required Resistance Force for Reinforcing Material (Example of Geotextile Reinforced Soil Wall) (source: PWRI, 2004)

(b) Pull-out of Reinforcing Material

The basic length of the reinforcing material should, in principle, be determined to ensure that the pull-out resistance force T_p to be provided by the reinforcing material in a stable soil mass (resistance area) situated at the inner side of the potential slip surface in an embankment exceeds the value calculated by multiplying the resistance force (T_{req}) required to prevent the reinforcing material from being pulled out by the earth pressure acting on the wall by the safety factor F_s (Figure 3.65).

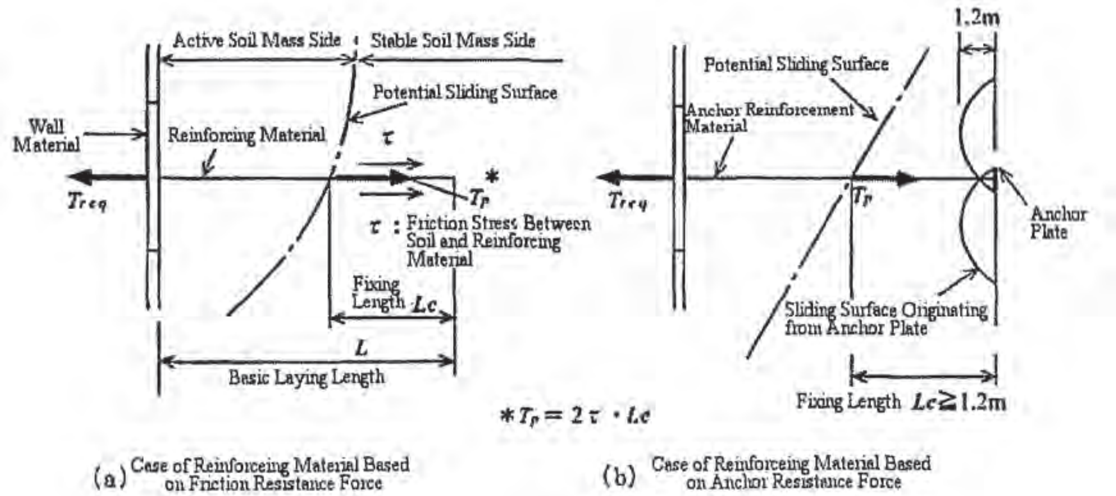


Figure 3.65 Idea of Calculating Pull-out Resistance Force and Deciding Laying Length (source: PWRI, 2004)

2) Stability of Reinforced Area

The application of multiple layers of a reinforcing material generates the effect of integrating the reinforced area and it is necessary to analyse the stability of the integrated area. One method to analyse the stability of the integrated area is to assume that such reinforced area forms a kind of retaining wall and to analyse its slide, over-turning and bearing capacity as in the case of an ordinary gravity retaining wall.

Under certain circumstances, it is also necessary to analyse the settlement of soft ground as well as the stability against circular sliding, including the foundation ground and the embankment at the back.

3.6.3 Culvert

A culvert is a structure which is introduced beneath a road, as a water channel for irrigation or drainage purposes or as a passageway for pedestrians or cars. There are many structural types, including box culverts, pipe culverts and corrugated metal culverts.

(1) Selection of Structural Type

Culverts are primarily classified as rigid culverts and flexible culverts. Rigid culverts are designed to use their own rigidity to resist the earth pressure, etc. Box culverts, portal culverts, arch culverts and pipe culverts belong to the category of rigid culverts. Meanwhile, flexible culverts have flexible thin walls. Deflection caused by the vertical earth pressure compresses the soil on both sides of the culvert. Using the reactive earth pressure generated by this compression, this type of culvert resists the external pressure acting on it by equalising such forces along its full arc from the passive earth pressure generated by compression of the soil. Corrugated metal culverts and PVC pipe culverts belong to the category of flexible culverts.

The most suitable structural type must be selected by analysing all of the relevant factors, including the inner dimensions, topography, geology, working conditions and adjacent structures at the proposed site and construction cost. Table 3.26 shows the general scope of culvert application.

Table 3.26 General Scope of Culvert Application (source: PWRI, 2004)

Type of Culvert	Applicable Overburden	Size of Cross-Sectional Area
Box Culvert 1)	Up to 10 m	1 x 1- 5 x 6.5 m
Portal Culvert	Up to 10 m	Span: 3 - 8 m
Arch Culvert 2)	10 m or more	Span: 3 - 8 m
RC Pipe Culvert	Up to 20 m	150 - 3,000 mm
Pre-stressed Concrete Pipe Culvert	Up to 30 m	500 - 2,000 mm
Corrugated Metal Culvert	0.6 - 30 m	300 - 4,500 mm
PVC Pipe Culvert (in the case of VU) 3)	Up to 4 m	150 - 800 mm

Notes
1) The subject here is a cast-in-place concrete box culvert. In the case of precast products, such as PC box culverts, the relevant standards are referred to in order to determine their scope of application.
2) Careful examination is required prior to selection.
3) Two types of PVC pipe culverts, i.e. VP (ordinary pipe) and VU (thin wall pipe) exist. VU is mainly used.

(2) Loads Used for Design of Culvert

The loads used for the design of a culvert include the dead load, earth pressure, live load, impact load and water pressure, etc. It must be noted that the relevance of the loads varies depending on the type of culvert and purpose of design. The main loads are described below. For the design of a culvert, their combination to achieve the best advantage for the purpose of the culvert under the site conditions is essential.

a) Vertical Earth Pressure

The vertical earth pressure acting on a culvert is basically given as $P^{vd} = \gamma \cdot h$ (γ: unit volume weight of soil; *h*: thickness of earth cover). However, when a box culvert supported by pile foundations is introduced above soft ground, the settlement of the culvert itself is prevented despite the settlement of the embankment. Here, the acting vertical earth pressure is given as:

$\alpha \cdot \gamma \cdot h$ as the additional coefficient α is also applicable (Figure 3.66). As such, the vertical earth pressure acting on a culvert varies depending on the bearing conditions of the culvert in addition to the type and burying method, making it necessary to consider an earth pressure suitable for the site conditions (Figure 3.67).

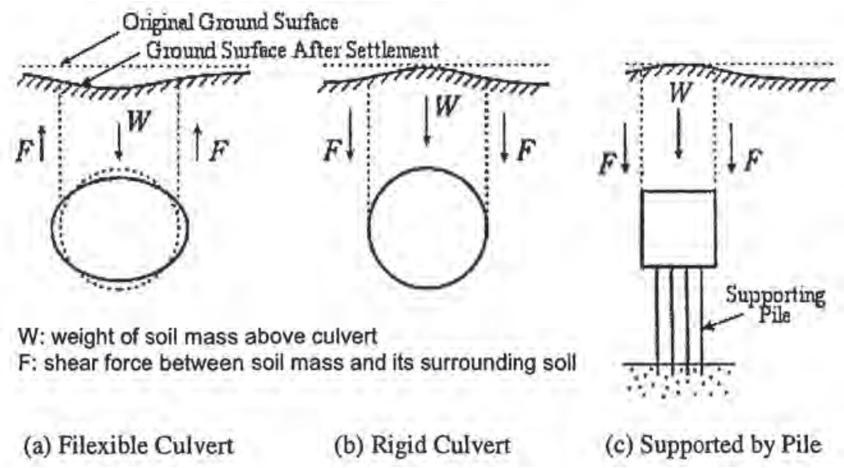


Figure 3.66 Change of Vertical Earth Pressure by Deformation of Culvert and Difference in Settlement Characteristics (source: PWRI, 2004)

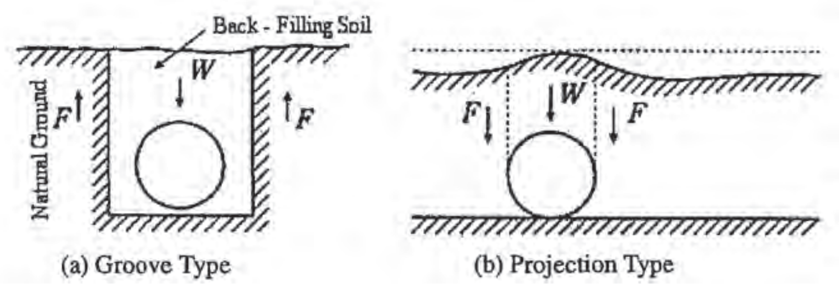


Figure 3.67 Change of Vertical Earth Pressure by Difference of Laying Method (source: PWRI, 2004)

b) Horizontal Earth Pressure

The horizontal earth pressure acting on a culvert is given as $P_{hi} = K_0 \cdot \gamma \cdot h_i$ (K_0: coefficient of earth pressure at rest, γ: unit volume weight of soil; h_i: depth at the point in question). However, the coefficient of earth pressure at rest and the distribution of earth pressure vary depending on the type of culvert. The value of this coefficient of earth pressure at rest normally used is 0.5 for a box culvert and portal culvert and 0.3 for an arch culvert.

The horizontal earth pressure is normally not considered for a pipe culvert as it constitutes a safety margin.

c) Vertical Load Originating from Live Load

The vertical load originating from the live load acting on the upper face of a culvert is generally calculated by making the rear wheel load (P = 100kN (10 tf)) act in the manner shown in Figure 3.68. In this case, the load per unit length along the longitudinal direction of a culvert is calculated by the following formula taking the impact force into consideration.

$$\text{Rear wheel: } P_{l1} = \frac{2 \cdot rear\ wheel\ load\ (100kN(10tf))}{vehicle\ width\ (2.75m)} \cdot (1 + i) \qquad (3.11.1)$$

The value of the impact coefficient 'i' is normally 0.3 for a box culvert of which the earth cover thickness is less than 4 m. In the case of a pipe culvert, a suitable constant is determined in correspondence with the earth cover thickness. The vertical load on a box culvert becomes smaller as the earth cover thickness increases more than 4 m. It is therefore, sufficient to use the single value of 10 kN/m^2(1 tf/m^2) for all box culverts with an earth cover thickness of more than 4 m.

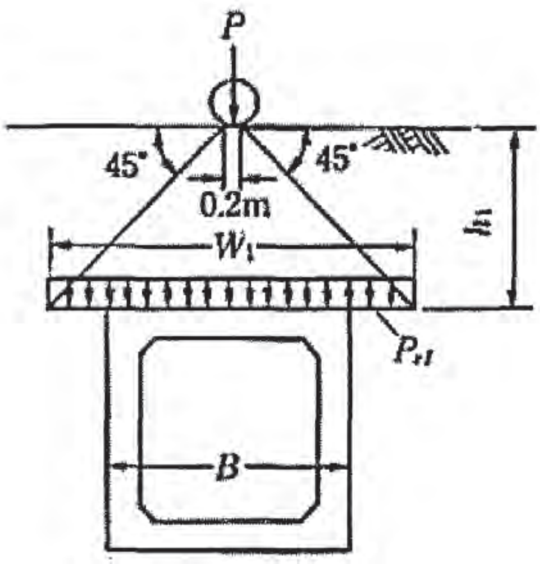


Figure 3.68 Distribution of Live Load (source: PWRI, 2004)

d) Horizontal Load Originating from Live Load

As the value of the horizontal load originating from the live load acting on both sides of a culvert, 10K_o kN/m (surcharge 10 X coefficient of earth pressure at rest K_o) is given to each side. It is a common practice not to consider the horizontal load for pipe culverts.

(3) Important Points for Design of Various Types of Culverts

A culvert which has the required strength and durability and which is economical to construct and appropriate for the construction site must be designed based on its purpose and the topographical, geological and working conditions of the site. When designing a culvert, therefore, it is essential to pay proper attention to the characteristics and design principles of each type of culvert described below.

a) Box Culvert

A box culvert is commonly constructed using cast-in-place reinforced concrete and is used as a road or water channel. In the case of a box culvert which is used as a road, the most common section is a single section which must be determined by analysing the width of the existing road, through traffic, road alignment, presence of a water channel, etc. and future plans for the site. A single section is desirable for a box culvert used as a water channel. However, dual or multiple sections may be adopted if restrictions posed by the inner height of the culvert make it impossible to secure the necessary cross-sectional area.

Figure 3.69 shows the common configuration of the members and design of a box culvert to be introduced beneath a road.

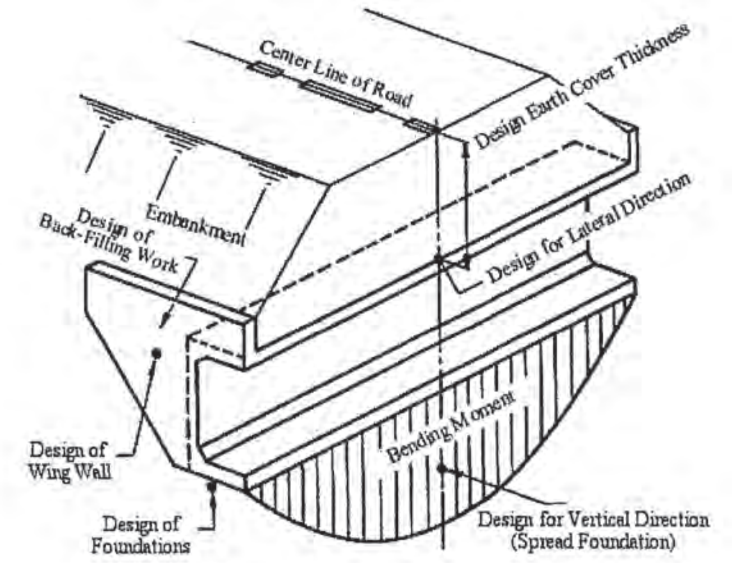


Figure 3.69 Members and Design of Box Culvert (source: PWRI, 2004)

The earth cover thickness is naturally determined by the required cross-sectional area of the box culvert, embankment height and elevation of the box culvert. In the case of shallow earth cover, as the road surface often becomes uneven due to settlement of the back-filling material, a design earth cover thickness of not less than 50 cm is desirable.

A box culvert must be designed in both the cross-sectional and longitudinal direction as shown in Figure 3.69. As a rigid-frame axis for calculation along the cross-sectional direction (span direction), the central axis dimension lines (B_o, H_o) shown in Figure 3.70 are used. In principle, expansion joints are introduced at intervals of 10 - 15 m along the longitudinal direction of a box culvert regardless of the foundation conditions. When the interval of the expansion joints is determined together with the application of distributing bars (transverse reinforcement) corresponding to the main reinforcement for the cross-sectional direction, the design for the vertical direction can generally be omitted. Nevertheless, analysis for the vertical direction is required when spread foundations are employed above poor foundation ground or when the length exceeds 15 m. In general, calculation for the vertical direction is assumed as "beams above an elastic foundation".

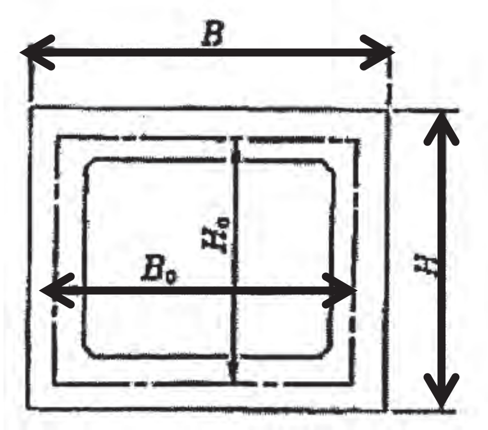


Figure 3.70 Rigid Frame Axis (source: PWRI, 2004)

b) Portal Culvert

A portal culvert has a structure where footings are introduced at the bottom of the side wall without a bottom plate. A portal culvert is generally constructed at sites with good foundation ground and is opted for when the inner cross-sectional area is large or when the construction of a bottom plate for a box culvert is difficult because of the site conditions, including the impossibility of unwatering.

The basic design requirements are similar to those for a box culvert. However, designs which take into consideration the effects of temperature fluctuation and drying shrinkage are necessary when the earth cover is shallow, or when a long span makes it necessary to treat a portal culvert as a bridge.

c) Arch Culvert

An arch culvert receives vertical earth pressure with its arching member and is generally more economical than a box culvert under the condition of a high embankment. Careful analysis must be made prior to its selection since there are some specific conditions for its use. These conditions comprise that differential settlement due to inclined ground does not occur and that unbalanced earth pressure due to the topography and/or different banking materials used does not occur.

The arching member must have a thickness with a margin which ensures its safety when exposed to load during construction work or unbalanced earth pressure. It is, therefore, desirable to determine the thickness by considering its balance with the side wall members. A member thickness of some 60 cm or more has often been adopted in past examples (Figure 3.71).

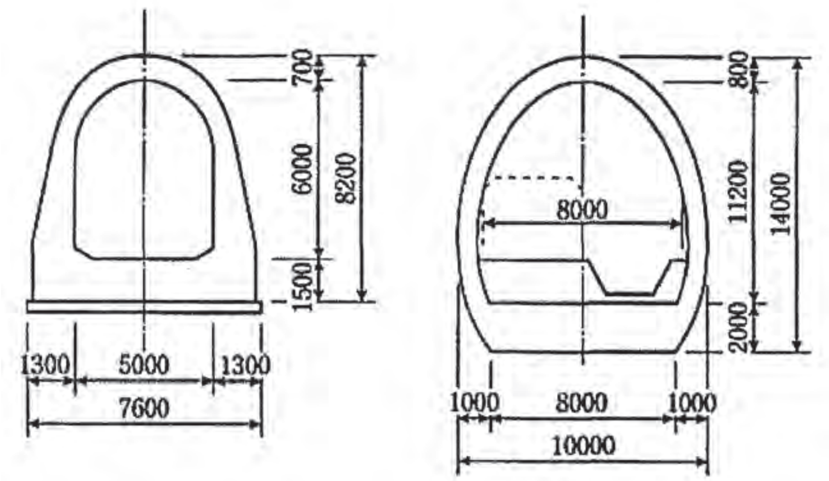


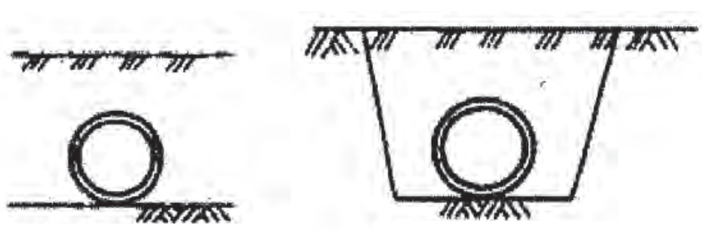
Figure 3.71 Typical Shape of Arch Culvert (source: PWRI, 2004)

d) Rigid Pipe Culvert

Pipe culverts are widely used as a permanent or temporary structure to be used as a water channel. In general, a RC pipe or prestressed concrete pipe is used to act as a concrete pipe culvert. The most popular pipe is a centrifugal RC pipe while a prestressed concrete pipe is used at sites with a thick earth cover.

For the design of a pipe culvert, the pipe diameter and burying method are first determined given that the body is a precast product. The type of foundations and the type of pipe corresponding to the required pipe culvert strength are then selected.

There are two types of pipe culvert burying, i.e. the projection type and the groove type, as shown in Figure 3.72. As each type uses a different earth pressure concept, attention should be paid to such a difference at the design stage. The projection type means that the pipe is laid directly onto the ground or well-compacted ground and is banked afterwards as shown in Figure 3.72-(a). In contrast, the groove type means that a groove is dug in the original ground or well compacted ground to bury the pipe as shown in Figure 3.72-(b). A pipe culvert which is buried after excavation of a pre-loaded and rested embankment for a long period of time is considered to be the groove type. However, pipe culverts under the conditions shown in Figure 3.73 must be considered as the projection type.



(b) Projection type (a) Ditch type

Figure 3.72 Laying Method (source: PWRI, 2004)

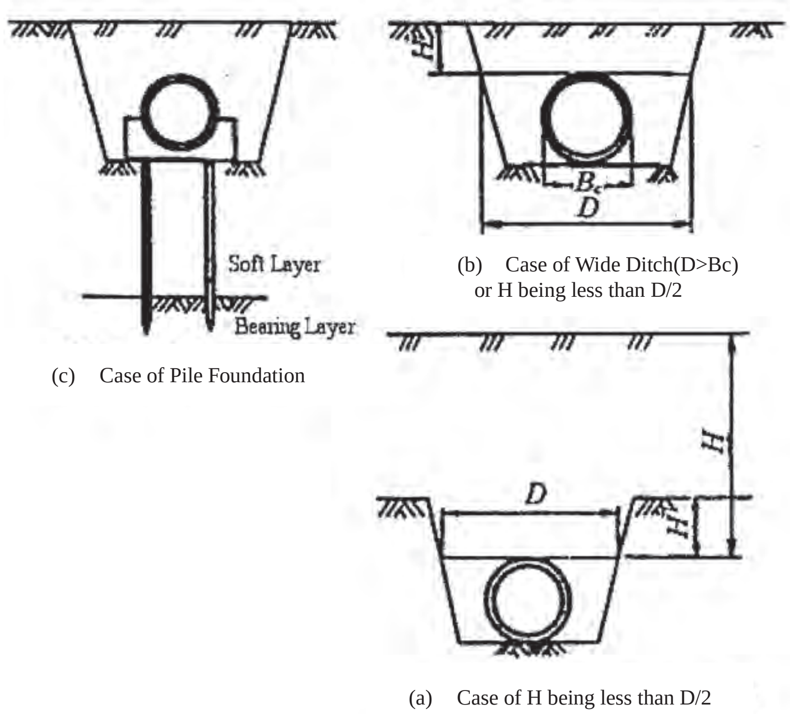


Figure 3.73 Conditions considered as Projection Type (source: PWRI, 2004)

The standard types of foundations for rigid pipe culverts are sand foundations, crusher run foundations and concrete foundations. In general, sand foundations or crusher run foundations are used in the case of relatively good ground while concrete foundations are used when large external forces act on the pipe and the foundation ground is soft.

e) Corrugated Metal Culvert

Corrugated metal culverts are used at sites where their characteristic of flexibility can be utilised. As the light weight corrugated section is advantageous for transportation and there is little demand for large construction machinery, corrugated metal culverts are often used at remote mountainous sites. Corrugated metal culverts are also often used as temporary water channels because of the ease of site work as well as conversion to other uses.

There are four types of sectional forms, i.e. circular, elongation, pipe arch and arch. Among these, the circular form is most popularly used because of its mechanical stability and ease of assembly and construction compared to other forms. In the case of the elongation form, inverse deformation of 5% is given along the vertical direction in advance and it is used for high embankments where the circular form exceeds the limit value for flexibility. The pipe arch form is mainly used when the thickness of the earth cover is small while the arch form is used when a large clearance limit is required as in the case of a footpath under a road, a vehicle road or a water channel requiring a large cross-sectional area of flow.

Design for the use of a corrugated metal culvert is required to calculate the cross-sectional rigidity during construction work, axial joint strength, buckling of the corrugated section and deflection of the corrugated metal culvert so that the calculated values satisfy the relevant allowance values.

The design of the foundations, selection of the back-filling material and acting of unbalanced earth pressure, etc. are also important to ensure the full performance of the characteristics of a corrugated metal culvert and proper attention should be paid to these aspects in the design of a corrugated metal culvert.

f) PVC Pipe Culvert

There are four types of PVC pipe culverts, i.e. round pipe, oval pipe, high rigidity round pipe and high rigidity oval pipe. Given its light weight, the unit length of PVC pipe can be quite long. In addition, PVC pipe is highly resistant to both acidic and alkaline conditions. The use of oval pipe is often associated with low water discharge or a gentle gradient.

Design for the use of PVC pipe is required to calculate the maximum bending stress and rate of deflection of the pipe so that the calculated values satisfy the relevant allowance values.

(4) Design of Foundations

The foundations for a culvert can be spread foundations using good quality soil, such as sand, replacement foundations or pile foundations, etc. as shown in Figure 3.31 depending on the actual ground conditions. For the design of foundations, the following points must be noted.

1) In principle, the foundations for a culvert should be spread foundations. When pile foundations where the structure prevents any settlement of the culvert are required to support a water channel culvert on soft ground, the possibility of an increased surcharge due to settlement of the surrounding ground and an uneven road surface must be carefully analysed followed by the preparation of suitable countermeasures.

2) When a culvert is constructed on weak ground, the ground should be improved by the surcharge method.

3) When a thin soft layer is situated near the ground surface or when the ground partially consists of a soft layer, the soft soil should be replaced by good quality soil.

Table 3.27 Criteria for Selection of Foundations (source: PWRI, 2004)

Ground	Ordinary Ground	Soft Ground
Type of Foundations	Spread Foundations	▪ Replacement Foundations ▪ Ladder Type Foundations ▪ Sand Sheet Foundations ▪ Soil Cement Foundations ▪ Pile Foundations

Note: Foundations combining different types of foundations

4 Execution

4.1 Introduction

The basic principle of execution is the slope earthwork of exactly the shape and quality specified in the design documents while ensuring its conformity with the local environment, topography and geology. The actual execution processes of the work are however subject to natural phenomena, including the weather conditions, as well as many factors which may disrupt execution of the work. Since slope earthwork is closely related to the social environment in the surrounding area, this work cannot be executed without considering such social environment. It is therefore essential to properly recognize possible factors of disruption and the social environment so that the work can be smoothly carried out.

Special attention must be paid to the following general requirements.

1) Proper understanding of the contents of the design documents and site conditions and precise control of work execution

2) Precise knowledge of the weather and climate, local geology and soil properties, and careful attention to rainwater and groundwater

3) Conscious efforts to ensure safe execution, disaster prevention and conservation of the surrounding environment

4) Constant smooth communication between the ordering side and the contractor side

4.2 Slope Work

4.2.1 Cut Slope Work

The normal procedure for cut slope work is to start with rough excavation at the section to cut, followed by shaping and finishing of the slope surface and the execution of slope protection work. Special attention should be paid to the following points for the execution of cut slope work.

1) Since it is difficult to fully understand the ground conditions of the slope to cut through a preliminary survey, it is essential to regularly check the ground conditions during excavation of the cut slope. Comprehensive judgment should be made on the slope gradient and cutting height by verifying the state of the ground with the shape of the cut slope indicated in the design drawing. If it is found that a change is required, the necessary measure should be promptly implemented.

2) A sufficient number of finishing stakes should be placed for excavation at the cut slope so that the planned excavation line is not exceeded.

3) In the case of cut slopes where retaining walls were originally planned, the gradient of the cutting slope frequently becomes steeper than the standard values, and thus slope failures often occur during or upon completion of excavation and prior to the construction of retaining wall. Safety management should be strictly carried out particularly during excavation and during successive retaining wall work.

4) When spring water or seepage water is discovered on the face of the slope, countermeasures, such as weep holes and subsurface drainage ditches, should be implemented.

5) The construction of drainage ditches to be introduced at the top of the slope and berms should be carefully executed so that the face of the slope is not scoured by the splashing of running water and/or overflow.

6) After executing the slope work, small stones which are likely to fall in the future should be carefully removed with a pick hammer or bar. If it is difficult to remove large stones completely, they should be anchored to the ground by anchor works. The Rock Fall prevention net is often implemented where the height of the slope is large and where there is the potential danger of minor Rock Falls during work.

7) Minor faults found during work should be fully examined particularly for their sizes, directions, degrees of fracture, presence of spring water and so forth, in order to investigate whether they could induce large-scale failures. Even though they seem not to trigger any large-scale failure, small local failures tend to occur frequently, so that these small faults should be properly treated, if necessary, by means of concrete block pitching or weep holes.

4.2.2 Embankment Slope Work

The execution methods for embankment slopes include the method whereby a slope section (width: 0.5 - 3 m) is separately constructed prior to or after banking of main body and the method whereby excess banking on the planned slope section is done first for subsequent cutting and shaping. The suitable method should be decided based on the site conditions. Special attention should be paid to the following points for the execution of embankment slope work.

1) The slope section must be fully compacted to prevent surface erosion by rainwater, etc.

2) Finishing stakes should be introduced to avoid an insufficient embankment cross-section due to the compressive settlement of the embankment and other reasons. These stakes should be removed as soon as the work has been completed to prevent the occurrence of scouring by rainwater.

3) Slope protection work should be promptly executed.

4) The concentrated downward flow of rainwater from the top of the embankment to the face of the slope should be prevented.

5) The construction of drainage ditches to be introduced at the face of the slope and berms should be carefully executed so that the face of the slope is not scoured by the splashing of running water and/or inundation.

(1) Compaction of Embankment Slopes

An embankment slope must be fully compacted by machinery. Once rainwater infiltrates the face of a slope, there is a danger of slope failure, mainly due to lack of uniformity near the face of the slope. Full compaction by rolling over each of the lateral thin layers is generally considered to be effective to prevent such lack of uniformity. Compaction of the face of the slope can be directly carried out by a compacting machine when the slope gradient is gentle (approximately 1:1.8). Another method in use is excess banking on the slope for subsequent cutting and shaping to achieve the required slope.

Slopes to be made with materials such as clay or volcanic ash with high water contents, which cannot be completely compacted, should be very carefully worked out by paying special attention to the stability of the whole slope. Any deformation of finishing stakes or swelling of the slope should be carefully observed during work. If any indications are found, their causes and future stability should be examined.

Earth should be replaced, or slope gabions or drainage work such as horizontal drainage layer in embankment should be provided as needed.

Where the main body of embankment is to be made with the coarse-grained soils such as gravel or sandy soil and therefore any problem is anticipated such as erosion or difficulties in vegetation, slope is often covered with top soil. In this case, the boundary between top soil and already executed fill body should be formed by properly mixing them together and be compacted without leaving a clear boundary (refer to Figure 4.1).

If possible, it is desirable to have a gentle slope ratio of about 1:1.8 for the embankment slope and to design a thickness of about 2 to 3m for blanket soil in order to make machine works possible (refer to Figure 4.2).

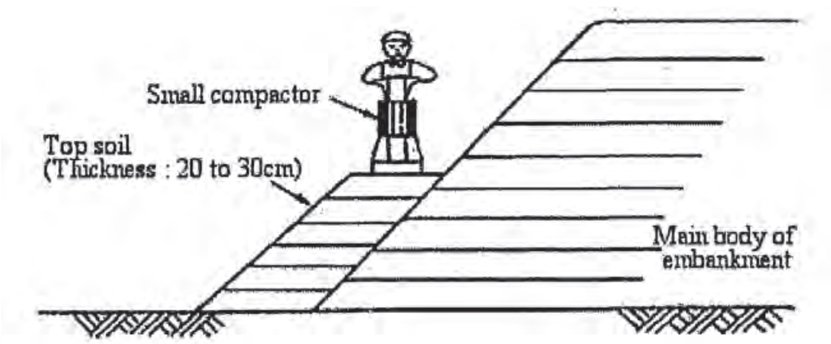


Figure 4.1 Compaction of Top Slope (source: PWRI, 2004)

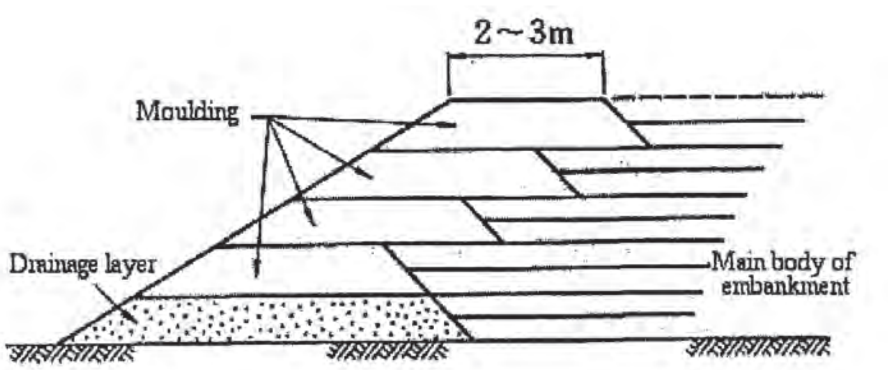


Figure 4.2 Example of Blanket Soil considering Machine Execution (source: PWRI, 2004)

Molding

(2) Slope protection during Work

Temporarily finishing slopes are most unstable until the protection work is performed, and will be easily eroded by rain water or others. Therefore, the slope protection by vegetation or longitudinal drainage facilities should be provided as quickly as possible. However, as temporary measures until the slope will be fully protected, it is recommended to employ filling work shown in Figure 4.3 in order to avoid the concentration of surface water on the surface of slope. Also, if the executed embankment is left for a long time after completion until paving work, it is desired to install a temporary ditch using a soil cement mixture as shown in Figure 4.3, if required, in order to prevent the occurrence of any problem due to concentrated flow of rain water. In the case of high embankment with erodible soil, temporary drain ditches as shown in Figure 4.4 is effective in order to prevent surface water from flowing down the slope.

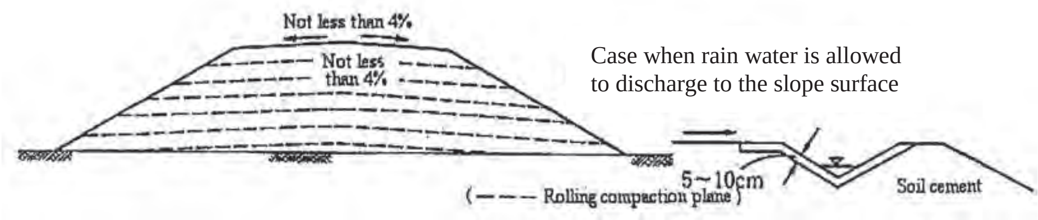


Figure 4.3 Treatment of Surface Water during Banking (source: PWRI, 2004)

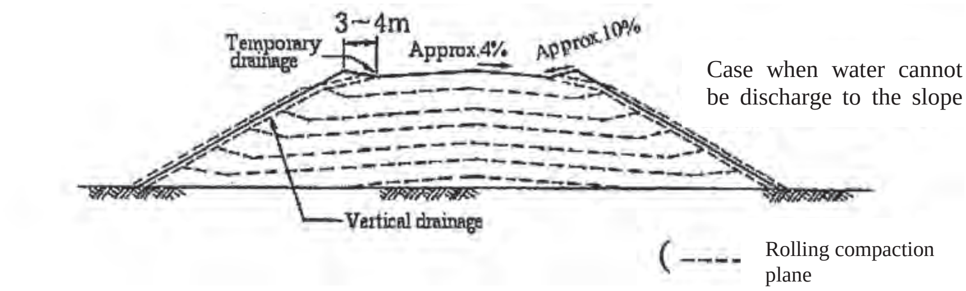


Figure 4.4 Example of Temporary Drainage during Banking with Soil Vulnerable to Erosion (source: PWRI, 2004)

4.2.3 Slope Protection Work

Slope protection works are performed to protect the slopes from erosion or weathering by covering them with vegetation or structures and also to stabilise the slope by means of drainage works or retaining structures.

- Slope protection work should immediately follow the completion of cutting or banking work. The execution timing for planting should be carefully decided.
- Slope protection work, be it planting or structural work, is essentially not capable of withstanding earth pressure. A different type of countermeasure is, therefore, required if there is a danger of facing earth pressure. If failure is anticipated at part of a cut slope, such necessary treatment as the removal of soil from that part should be carried out.
- For slope protection for full cover of slope by spraying, attention should be paid to

the drainage of spring water or seepage. And spring water from slope should be removed as much as possible for other protection work.

(1) Vegetation

Success or failure of vegetation is controlled by the growth of plants. Therefore, the species and execution method should be carefully selected in accordance with the following conditions, and the conditions capable of assuring the complete growth of the selected species should be provided.

1) Area, gradient and height of slope

2) Condition of adjacent area

3) Soil conditions (physical and chemical composition, water content and hardness of soil, unevenness, presence of spring water, etc.)

4) Weather conditions (air temperature, rainfall, slope direction, degree of sunshine)

5) Other (degree of difficulty in securing the local materials (such as earth and water), their qualities, and conditions of access road for bringing in the machinery and materials)

(2) Slope Protection Work using Structure

Special attention should be paid to the following points for the execution of slope protection work using a structure.

1) It is extremely difficult to accurately predict the ground conditions prior to excavation. Therefore, if the ground conditions discovered considerably differ from the assumptions at the design stage, the suitability of the planned slope protection work should be carefully examined. When a retaining wall or crib work is planned, it must be judged whether or not the existing ground can be used as its bearing stratum while implementing appropriate measures if necessary.

2) In the case of a long slope, it is desirable to execute protection work in line with the progress of excavation without waiting for the completion of excavation. This is because of the fact that the execution of protection work after the completion of excavation is not economical due to the need of transporting the protection materials from the bottom of the slope and also because of the fact that the face of the slope is left bare for a long period of time, resulting in loosening, weathering and erosion of the ground.

3) When sealed-type protection work, such as mortar/concrete spraying or pitching, is executed, the implementation of spring water control and drainage measures is required. In regard to crib work, sufficient compaction as well as spring water control and drainage measures are necessary to prevent the outflow of the filling materials.

4) Prior to the execution of mortar/concrete spraying or spray crib work, unwanted sediment, dust and stumps, etc. should be carefully removed from the face of the slope to prevent the detachment, unevenness or cavities behind the sprayed material. Careful attention must be paid to the timing of execution and the weather conditions at the time

of execution to prevent (i) poor adhesion to the ground during the dry season when cracks are more likely to occur and (ii) a decline of the quality of the spraying material.

5) As the yield strength and effects of rock bolts and ground anchors are considerably affected by the execution skill, careful attention must be paid to drilling, insertion of steel, fixing and grouting. In addition, drilling should be carefully carried out so as not to loosen the surrounding ground and the tension members should be given the proper treatment to prevent their corrosion.

6) Proper consideration should be given to safety control during the execution of slope protection work as it may be necessary to conduct such work at a high place or on a steep slope. The likelihood of the presence of unstable pumice stones or the instability of the bare slope during or immediately after execution also demands careful safety control.

4.3 Countermeasures for Rock Fall and Debris Flow

Slopes or mountain streams requiring the execution of countermeasures for Rock Fall and debris flow are generally steep and the construction conditions are often poor because of the proximity of housing near the site and other reasons. It is, therefore, essential to pay special attention to safety measures not only for the construction site but also for the adjacent area in the formulation of an execution plan.

At the time of execution, careful attention is particularly required during and immediately after torrential rain because of the high risk of Rock Fall, slope failure and/or debris flow. If necessary, a rain gauge, Rock Fall detector and debris flow monitoring system should be installed to ensure personal safety as well as the safety of nearby facilities during the period of execution.

4.3.1 Countermeasures for Rock Fall

Special attention should be paid to the following points for the execution of countermeasures for Rock Fall.

(1) Rock Fall Prevention Work

a) If the site for Rock Fall prevention work is characterised as a type of topography which is prone to collect rainwater or seepage water or geology which is prone to erosion, the foundation for such work becomes liable to erosion. At such a site, it is necessary to shape not only the target slope but also nearby slopes and to implement groundwater and surface water control measures.

b) Rocks which are considered to be extremely dangerous should be made to fall or should be removed at the beginning of the execution period. If this is found to be impossible, the state of penetration and cracks of such rocks should be estimated and a simple measure or temporary facility should be implemented in anticipation of their eventual fall.

c) The foundation for foot protection work, concrete pitching or cast-in-place concrete cribwork, etc. should be executed above ground with a sufficient bearing capacity.

d) A rock anchor or wire rope fixing must be fixed to a foundation which provides a sufficient bearing capacity to withstand the weight of pumice stones or boulders.

(2) Rock Fall Protection Work

Fastening of the members for such Rock Fall protection work as a Rock Fall protection net and Rock Fall protection fence should be carried out several times while ensuring a good balance.

4.3.2 Countermeasures for Debris Flow

Special attention should be paid to the following points for the execution of countermeasures for debris flow.

1) Countermeasures for debris flow are generally executed inside or near a mountain stream. The formulation of an execution plan which involves the construction of a temporary drainage channel as well as a temporary cofferdam to completely manage running water is necessary so that no disaster occurs during the work period. For this reason, the execution of countermeasures for debris flow during the dry season is desirable.

2) A survey should be carried out on the rainfall conditions at the time of the occurrence of debris flow at the subject as well as nearby mountain streams to establish the hazardous rainfall level for the occurrence of debris flow. When rainfall exceeding this level is predicted to occur during the work period, it is necessary to adopt safety measures, including temporary suspension of the work to evacuate the area sooner rather than later.

3) Dumping of the surplus soil from the work into a mountain stream should be avoided as such soil can become a new source of debris flow.

4.4 Slope Disaster Related Structures (Retaining Wall and Culvert)

4.4.1 Construction of Retaining Wall

For the construction of retaining wall, it is necessary to check at the time of excavation of the foundation ground to see whether or not the actual topography and geology is conformed to the relevant assumptions at the design stage. If the shape and/or geological composition of the slope at the back of the retaining wall or the conditions of the strata of the foundation ground differ from those in the design drawings, it may be necessary to consider a change of the shape, including the height of the retaining wall or even a change of the retaining wall type if necessary. Should any structure exist nearby, execution work must be carried out based on detailed survey results so that damage such-as settlement, shifting and/or tilting are not caused to the structure.

(1) Excavation at Back of Retaining Wall and of Foundation Ground

As the excavation gradient at the back of the planned retaining wall and of the foundation ground is often required to be a short-term stable gradient, special attention should be paid to ensuring the safety of the work. The general precautions required for this type of work are listed below.

a) Entire excavation of the ground should be avoided as much as possible and partial excavation (pit excavation) is preferred.

b) Precautions are required for excavation at the back of the planned retaining wall immediately after rain as the soil there is liable to failure.

c) Excavation should proceed while preventing failure by sheathing if necessary.

d) Careful attention should be paid to the conditions of the surrounding ground during excavation. Excavation in high risk places, such as at the bottom of a cliff, should preferably use a backhoe or similar equipment and a watchman should be assigned.

e) Foundation work should be carried out by verifying the required bearing capacity, etc. of the foundation ground.

(2) Foundation Work for Retaining Wall

There are two types of foundation for a retaining wall: spread foundation or pile foundation.

The treatment of the foundation described below is required to fully ensure the resistance of a spread foundation to sliding. In general, approximately 300 kN/m^2 of an allowable bearing capacity is required of the ground to support a retaining wall.

When the foundation ground consists of a rock mass, cutting should be carried out at the bottom position of the base produced by excavation should be completely removed and the surface of the rock mass should be thoroughly washed for direct construction of the base above it. The base should be constructed above levelling concrete or mortar layer. When the foundation ground consists of soil, cobble stone or crusher run should be laid on the excavated ground and levelling concrete should be cast if necessary above the fully compacted cobble stone or crusher run for construction of the base on top of it. When part of the ground below the base is soft, due to titled foundation ground or other reasons, such part may be replaced by concrete.

When spread foundation is applied on the soft ground and thickness of soft ground layer is thin, such soft ground may be excavated to create new foundation ground consisting of good quality replacement material. In this case, it is desirable to conduct a full soil test on the replacement material together with a plate load test, prior to execution work of the base to confirm the existence of the required bearing capacity.

(3) Main Body of Retaining Wall

It is desirable for a concrete retaining wall to be made as an integral structure of a base and vertical wall. When lateral construction joints are necessary for a plain concrete structure, such as a gravity retaining wall, keyed joints or grooves should be introduced for such joints. Alternatively, steel bar should be inserted at appropriate intervals. When concrete is cast onto already hardened concrete, loose aggregates, low quality concrete and/or laitance on the surface of the hardened concrete must firstly be completely removed before sufficient water is absorbed. Cement paste or mortar which has similar composition to that of the mortar used in the hardened concrete should be applied to the surface of the hardened concrete, immediately followed by the casting of fresh concrete for its close adhesion to the hardened concrete.

V-shaped vertical construction joints should be created on the surface of the retaining wall and their interval should preferably be less than 10m. Reinforcing bars should not be cut at these joints. The reasons for creating V-shaped vertical construction joints are the prevention of breaking at the corners and the prevention of small cracks on the wall surface.

Expansion joints should generally be introduced at intervals of less than 10 m for a gravity retaining wall and 15 - 20 m for a cantilever retaining wall, etc. and reinforcing bars should be cut at these joints. The introduction of expansion joints as discontinued sections of the foundation ground is necessary to prevent cracks, etc. due to differential settlement.

There are two types of concrete block retaining walls, i.e. dry masonry wall and wet masonry wall. Meanwhile, there are two types of masonry work, i.e. uncoursed masonry and coursed masonry. The standard practice is wet uncoursed masonry.

Weep holes must be introduced without failure at the positions indicated in the design drawings. For the execution of backfilling concrete for a concrete block retaining wall, backing forms should preferably be used and backfilling should be frequently carried out with small quantities in line with the rise of the wall, so that the wall will not fall down.

4.4.2 Construction of Culvert

Prior to the execution of a culvert construction, it is essential to confirm the conformity of its position and height with the local topography. Special attention should be paid to the elevation of the lower end of the culvert to avoid flooding.

(1) Excavation of Foundation for Culvert

Although the excavation method differs depending on the planned excavation width and depth and also on the conditions of the ground, the open cut method with sloping sides is generally used. However, when the excavation depth is deep at a small work site, the open cut method with an earth retaining wall is opted for. In either case, special attention must be paid to prevent failure during the work, especially in the case of narrow unsupported excavation because of its likelihood to failure without proper preparation.

In the case of the open cut method with an earth retaining wall, the state of the foundation ground and its relationship with the groundwater level must be thoroughly surveyed to determine the penetration depth of the sheet piles and others in order to prevent boiling (in the case of sandy ground) or heaving (in the case of cohesive soil ground) during excavation.

When excavation below the groundwater level is planned, the necessary drainage measures must be implemented, taking the state of the ground, suitable excavation method and volume of groundwater into consideration. In the case of the implementation of a large-scale drainage measure, the possible impacts of lowering of the groundwater level on the surrounding area must be analysed together with due consideration of the suitable disposal of the drained water.

(2) Foundation Work for Culvert

The most important requirement for the foundation for a culvert is to ensure the even distribution of the bearing capacity which is required by the design. For this reason, if the geological or topographical conditions are not uniform, suitable design and execution must be carried out to adapt to the local condition. For example, when a culvert is planned at the boundary between a cut slope and an embankment or at a valley with considerable changes of the geological conditions, the site conditions must be accurately understood at the time of excavation of foundation. If weak soil which does not meet the design conditions is discovered, replacement with good quality soil is required while ensuring the uniformity of the ground.

If the construction of a culvert above soft ground is unavoidable, it is preferable for preloading to be carried out for the integral settlement of the culvert with the surrounding embankment in addition to the implementation of careful investigation. Pile foundation may be used if the settlement is not acceptable in the case of a water channel culvert and others. In this case, a possible increase of the surcharge and the occurrence of an uneven road surface due to settlement of the surrounding ground should be carefully examined and countermeasures should be introduced if necessary.

In principle, the placing, spreading and compaction of sand, gravel and cobblestones and the casting of a levelling concrete should be carried out by means of dry work. However, a fixed concrete foundation for a pile culvert is structurally required unlike a levelling concrete and must be carefully executed to achieve the design shape and quality.

(3) Construction of Main Body of Culvert

The positions of reinforcing bars and forms must be in accordance with the design drawings. The most suitable concrete casting method must be selected in view of the topographical conditions and the casting positions while the supporting work for forms must be compatible with the selected concrete casting method.

Particular attention should be paid to the positions of the construction joints for concrete casting and these positions must be decided based on the design data, taking the stress distribution into consideration. From the viewpoint of structural soundness, casting in the sequence shown in Figure 4.5-(a) is desirable. However, the sequence shown in Figure 4.5-(b) may be used because of the difficulty of placing forms and/or casting concrete. In this case, the concrete for the corners and the top slab must be cast at least two hours after the casting of the concrete for the side walls. In addition, the cast concrete must be fully cured to prevent the occurrence of settlement cracks.

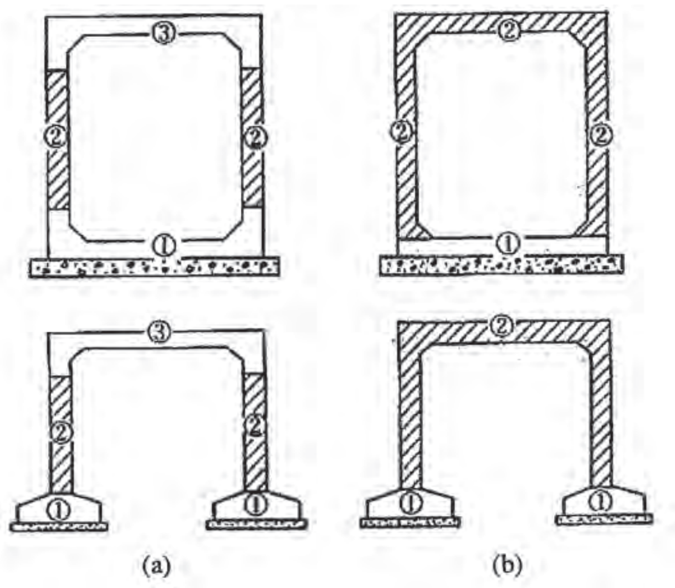


Figure 4.5 Sequence of Concrete Casting (source: PWRI, 2004)

The installation of a water stop at expansion joints must be executed with special care to prevent the occurrence of voids and/or water leakage. The material to be injected to the joints is an admixture of asphalt and rubber, etc. which must not fluidise at room temperature, must firmly adhere to the concrete and must not cause any adverse impacts on the water stop.

When constructing a culvert with precast concrete or centrifugal reinforced concrete pipes, attention must be paid to ensure its firm settlement on the foundation, careful execution of the joints and careful handling of the materials during their transportation so as not to cause any damage.

(4) Important Points for Execution of Culvert Construction

In the case of staged construction, it is desirable to execute the culvert and earthwork at the adjoining section of the culvert in accordance with the final cross-section. The work to construct a culvert, above weak ground in particular, should be executed with the final cross-section from the beginning since differential settlement may occur between the initial work section and subsequent work sections, possibly causing breaking of the culvert. If the adoption of stepped execution is unavoidable in the case of a rigid culvert, sleepers should be placed in advance. In addition, the reinforcing bars should be installed so as to avoid any problem at the joints in the future and the installation of a water stop is also desirable.

In the case of a flexible culvert, differential settlement by the initial work and differential settlement by additional work may affect each other in a complicated manner and the resulting actual settlement may differ from the predicted pattern of settlement, causing a problem for water flow. Special attention is therefore required to ensure proper water flow as planned.

4.4.3 Execution of Backfilling and Approach Cushion

(1) Problems of Backfilling Work

At the connecting section between structures such as a bridge, a culvert or a embanked road, the settlement of this section after its opening to traffic may cause faulting on the pavement surface, disrupting vehicle traffic and possibly damaging the structure involved.

Settlement at the connecting section between an embankment and structure may well be the result of the problematic construction of the said section as follows, in addition to settlement of the embankment's foundation ground, as well as compressive settlement of the backfilling material.

a) When the excavated soil to accommodate the foundation for a structure is soft, such soil may be mixed with backfilling material, causing deterioration of the quality of the backfilling material.

b) As a backfilling section is often surrounded by an erected abutment or culvert and its wing walls as well as the embankment, the drainage tends to be poor.

c) As backfilling is the final work to be executed, spreading depth tends to be higher than it should be. Compaction at the backfilling section tends to be insufficient because of the narrow space.

In view of the likelihood of these problems, the following countermeasures are often employed to prevent faulting at the connecting section between a structure and embankment.

(i) Careful execution of backfilling using good quality material

(ii) Introduction of an approach cushion at the connecting section between a structure and embankment, if necessary

(iii) Adoption of sufficient drainage measures by means of securing a drainage slope during execution and installing a subsurface drainage ditch.

(2) Important Points for Backfilling Work

Good quality material with low compressibility and high permeability should be used as the backfilling material for a structure at an embankment section and the work must be carefully executed, paying proper attention to drainage.

Table 4.1 shows the properties of soil which is suitable as a backfilling material. However, it is often difficult to use such a high quality material in a large quantity. If sufficient compaction can be carried out by a large compaction machine, the use of good quality material is unnecessary. The selection of a material with a good particle size distribution among the different banking materials available is permissible.

Important points for the execution of backfilling work are listed below.

a) The finishing thickness for backfilling and spreading should not be more than 20 cm and compaction should be carried out at a similar intensity to the compaction of the embankment.

b) The backfilling material should be evenly spread by a small bulldozer or by hand and overfilling using a dump truck or bulldozer should be avoided.

c) The machine to be used for compaction should be as large as possible while a smaller compacting machine should be used to carefully compact near the edges and wing walls of a structure.

d) As the backfilling section is liable to the inflow of rainwater or standing water, it is essential to prevent the inflow of rainwater as much as possible during the work. Seepage water should preferably be dealt with by introducing a subsurface drainage ditch.

e) A structure must not be subject to earth pressure by backfilling or embankment before it has reached the level of sufficient strength as structure. Even after a structure has reached such a level, it should not be subject to uneven pressure. For example, backfilling for a culvert or a nearby embankment should be evenly compacted in thin layers at a time from both sides of a structure to avoid an uneven load on either side.

Table 4.1 Particle Size and Properties of Suitable Materials for Backfilling (source: PWRI, 2004)

Item	Range
Maximum particle size	100 mm or less
4.760 μm sieve through	25— 100%
74 μm sieve through	0— 25%
Plasticity index (for 420 μm sieve through)	10 or less

(3) Backfilling of Retaining Wall

In principle, the same material and same compacting machine as those used for the embankment should be used for backfilling a retaining wall at the embankment slope while heeding to the important points explained in (2) above. While drainage work is required at the back of a retaining wall, the suitable type must be selected in accordance with the backfilling material. Here, special attention is required to ensuring that the execution of drainage work does not make the compaction at the back of the retaining wall become insufficient.

When rolling compaction is difficult to perform at, for example, a retaining wall at the cut slope, good quality material should be used, spread so that the finishing thickness of a single layer is not more than 20 - 30 cm and fully compacted using a vibration compactor or similar machine. Special attention is also required in regard to the execution of drainage work.

When the quality of the backfilling material and shape of backfilling are clearly indicated for a concrete block retaining wall and others, such wall must be precisely executed to achieve the design requirements.

(4) Backfilling for Culvert

The simultaneous commencement of backfilling work with banking is desirable Figure 4.6-(a). If there are any problems in terms of the procurement of material and deployment of machinery, backfilling work may be carried out prior to banking in the manner shown in Figure 4.6-(b). Meanwhile, when preloading is carried out in an area with soft ground, backfilling is carried out afterwards. Cleaning may be required to remove banking material which has outflowed due to rainwater and which has deposited at the bottom of the backfilling section. At the same time, special attention is required to avoid the thick spreading of the material (Figure 4.6-(c)).

In the case of a corrugated metal culvert, careful attention should be paid so as not to damage it by heavy machinery during backfilling work.

Significant settlement of the backfilling section after completion may be observed in the case of a culvert which is introduced at the boundary between cutting and banking or a culvert which crosses a road with a longitudinal slope. Common countermeasures include the introduction of weep holes for the side or wing walls or subsurface drainage facilities (net or porous pipes made of synthetic resin) along the walls at intervals of approximately 2 m.

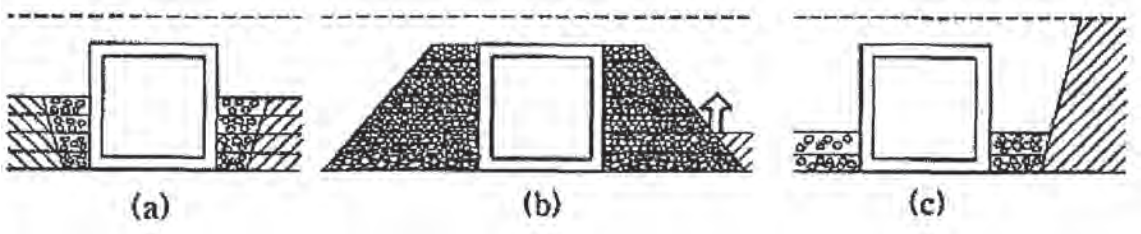


Figure 4.6 Backfill Execution Method (source: PWRI, 2004)

(5) Approach Cushion

An approach cushion means a reinforced concrete slab positioned between such a structure as an abutment and an embankment for the purpose of mitigating the adverse impacts of faulting which may occur at the connecting section between the structure and embankment. For the execution of an approach cushion, special attention should be paid to the following points.

1) The site for the approach cushion must be fully compacted.

2) The ground at the base of the approach cushion must be carefully shaped so that it is level and that the protective covering for the reinforcing bars is not damaged.

3) The concrete slab must be carefully cast as in the case of a concrete road pavement. It must also be fully cured. Since no vehicles are allowed to pass until the required strength is reached, the advance consideration of a detour is necessary.

5 Work Management and Inspection

5.1 Introduction

Slope earthwork must be properly managed so that the planned and designed structures with precise work specifications can be completed at a reasonable cost within a predetermined period while satisfying the required shape, dimensions and quality. Work inspection must be carried out to confirm that the completed structures meet the initial plan and design.

Two types of management are involved in work management. One is the management of "end factors" (schedule, quality and cost) relating to the activity functions of the body which directly conducts the work, and the other is the management of "mean factors" such-as control factors to ensure the smooth performance of the said activity functions. The former is generally called execution management while the latter is called site management.

Figure 5.1 shows the correlation between management and inspection.

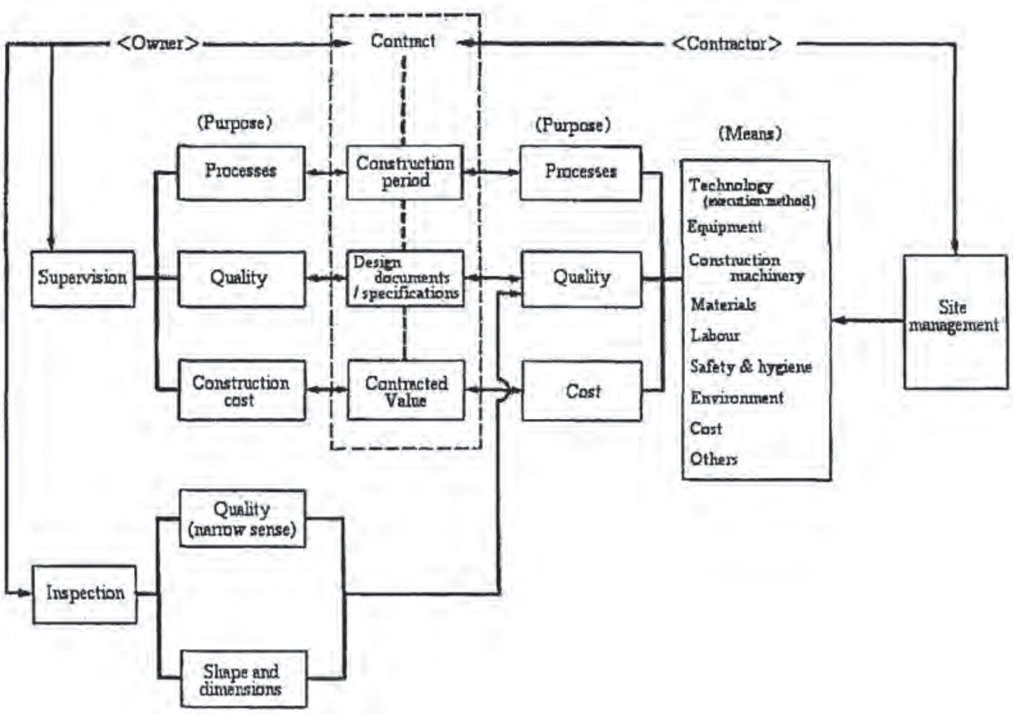


Figure 5.1 Correlation Diagram for Control and Inspection (source: PWRI, 2004)

5.2 Execution Management

5.2.1 Schedule Control

As slope earthwork is easily affected by the weather and others, it is not easy to proceed with the work as initially planned. For this reason, a detailed schedule plan should be prepared in advance and the planned schedule and actual progress should be compared at each stage of the work. Should any delay in the schedule occur, its cause must be analysed with intention to promptly prepare a suitable countermeasure as part of the strict schedule control.

5.2.2 Quality and Finished Work Control

(1) Purposes of Quality and Finished Work Control

In general, it is difficult to re-adjust inferior work which is discovered by inspection after completion. Even if re-adjustment is possible, much labour and time are required, resulting in an unfavourable economic performance. It is therefore rational to constantly control the quality and finished work during the construction period so that the subject items for construction pass the inspection without failure.

Precise quality control can economically complete the subject items for construction which satisfy the quality standards demanded by the specifications. The minimal dispersion of quality can enhance the reliability of construction work.

(2) Quality Control Methods

Quality control for slope earthwork usually centres on banking (filling). In particular, the main control items are the banking material and degree of compaction of an embankment.
Table 5.1 shows the quality control tests for embankment.

Common quality control techniques involve the execution of various tests designed to objectively evaluate the quality and statistical processing of the test results, so that if there is a chance that the work quality upon completion will not meet the predetermined targets, the necessary measures can be implemented, thereby contributing to improved quality control after these tests. In general, quality control is carried out in accordance with the steps shown in Figure 5.2. The technique (control method) for the sorting of quality control data is shown in Figure 5.3.

Table 5.1 List of Quality Control Tests (Example of Embankment) (source: PWRI, 2004)

Subject	Item	Qualitative Characteristics	Testing/Measuring Method	Remarks
Filled Up Ground	Material	Natural water content Specific gravity of soil particles Particle size Liquid limit Plasticity Limit Maximum dry density and optimal water content Cone index	Water content test for soil Specific gravity test for soil particles Particle size test for soil Liquid limit test for soil Plasticity limit test for soil Soil compaction test using a rammer Static cone penetration test	Frequency: at the beginning of the work and when the soil properties are changed
	Execution	Water content during construction	Water content test for soil	After rain or when a change of the water content is observed
		Dry density Air voidage Degree of saturation	In-situ unit volume weight test for soil	At the rate of one test/1,000 m³; at least three times for work involving an earth volume of less than 5,000 m³
		Cone index	Static cone penetration test	When the trafficability is poor
Subgrade	Material	Natural water content	Water content test for soil	After rain or when a change of the water content is observed
		Specific gravity of soil particles Particle size Liquid limit Plasticity Limit Maximum dry density and optimal water content CBR	Specific gravity test for soil particles Particle size test for soil Liquid limit test for soil Plasticity limit test for soil Soil compaction test using a rammer CBR test	At the beginning of the work and when the soil properties are changed
	Execution	Water content during construction	Water content test for soil	After rain or when a change of the water content is observed
		Dry density	In-situ unit volume weight test for soil	At the rate of one test/1,000 m³; at least three times for work involving an earth volume of less than 5,000 m³
		Bearing capacity value	Plate load test In-situ CBR test	At the rate of one test/40 m in length for each lane
		Proof rolling Degree of deflection	Measuring of deflection using a Benkelman beam as set forth in the Guidelines for Asphalt Pavement	Subjecting the entire width of the entire section after finishing of the subgrade

Figure 5.2 Quality Control Steps (source: PWRI, 2004)

For example, if the values measured during banking work do not satisfy the control values, an abnormality in terms of quality must be assumed, prompting the introduction of a suitable measure to prevent its reoccurrence by analysing the causes of such abnormality.

In this case, if the banking material is found to be responsible for an abnormality, the source of the material must be reviewed, followed by a measure to prevent the use of such material or at least to mix it with a good quality banking material. If the soil properties of the banking material have changed, a material test must be carried out. A further check should be made in regard to the suitability of the type and weight of the compaction equipment, spreading thickness of the soil, water content during construction and the work standard for the number of compaction operations and the necessary measures to rectify the situation should be implemented.

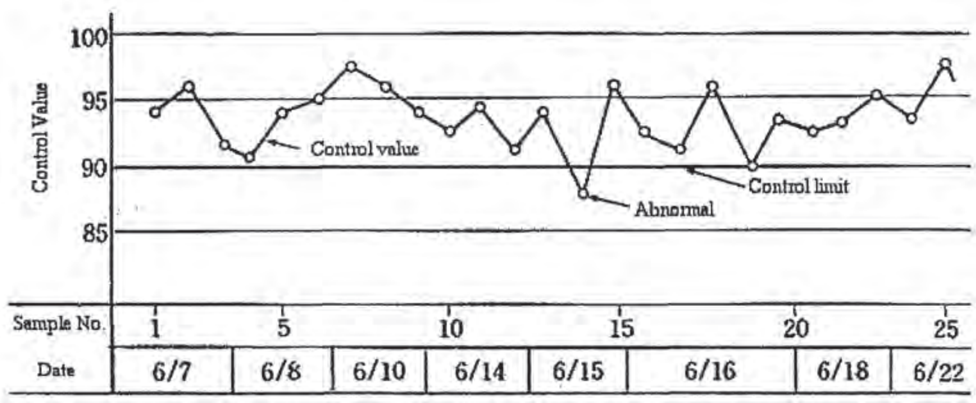


Figure 5.3 Process Control Steps (source: PWRI, 2004)

(3) Finished Work Control Methods

Finished work control means to check whether or not the shape and dimensions of the subject items for construction satisfy the shape and dimensions demanded by the design documents and specifications at predetermined interim stages of the construction work in order to ensure the completion of highly reliable subject items. In the case of those parts which cannot be visually checked after the completion of construction work, photographs, etc. should be used to record the work completed.

Many finished works related to slope earthworks can be visually checked after the completion of construction work. These include the position (especially the centre line of roads), dimensions (width and slope length), gradient (for embankments and cut slopes) and reference height (for embankments and cut slopes). Matters requiring special attention during construction are divergence of the centre line, over-cutting of cut slopes and over-banking of embankment slopes. Careful attention should also be paid to the positioning, shape and dimensions of structures which accompany earthwork as errors cannot be easily rectified.

5.2.3 Environmental Conservation Measures

The noise and vibration caused by civil engineering work, water pollution due to the discharge of sediment, scattering of soil during transportation, dust and debris, ground deformation by banking and water depletion by cutting, etc. can adversely affect the living environment around the work site and may also disrupt the execution of construction work. Careful attention should be paid to the planning and execution of construction work so that a suitable construction method, machinery and work procedures are selected to protect the living environment and to ensure the smooth implementation of construction work.

(1) General Environmental Conservation Measures Relating to Earthwork

a) To prevent water pollution due to the discharge of soil, a stable embankment gradient should be secured along with protection fences and others.

b) To prevent the scattering of soil during transportation, avoidance of over-loading and the use of a sheet cover for the truck bed should be practiced together with the introduction of vehicle washing facilities at the access point to a public road from the work site.

c) To prevent dust from the banking site, such dust prevention measures as the sprinkling of water on the embankment surface, spraying of emulsion and spraying of seeds should be carried out.

d) To prevent water depletion due to cutting, an advance survey should be carried out to prepare a suitable prevention measure(s).

(2) Countermeasures for Noise and Vibration

The scale of the adverse impacts of noise and vibration are determined by their level, duration and frequency distribution. Viable measures include lowering of the absolute values of noise and vibration and shortening of the period in which noise and vibration are generated.

Common countermeasures for noise and vibration during construction work are listed below.

a) Use of a low noise, low vibration construction method or machinery if possible

b) Careful examination of the deployment positions of machinery and equipment on the site

c) Careful examination of the working hours and work processes

d) Installation of sound insulation facilities

e) Improved operation method of machinery

Engineers involved in construction work must fully inform nearby residents of the outline of the planned construction work to obtain their understanding and cooperation and should take the opinions of such residents into proper consideration.

5.3 Work Inspection

Inspection means to check whether or not the work has been exactly executed according to the contract at the stage of completion or partial completion (or during work progress) by means of visual observation, measurement, testing or other methods with intention of giving a verdict on the pass or failure of the inspected work. Recent construction work is mainly carried out by contractors and the criterion for passing is the satisfaction of the conditions specified in the contract documents (agreement, specifications and drawings, etc.). Inspection is carried out on the finished works relating to the position, height, width, length, gradient and quantity and also on the quality, such as the degree of embankment compaction.

Inspection is carried out at the completion of construction work and also during construction work.

As it is difficult to inspect all of the quantitative items involved in construction work, sampling is usually carried out and is often accompanied by a supplementary method, such as visual observation.

In special circumstances, destructive inspection is carried out for those parts which cannot be visually checked as part of the finished work and quality inspection of construction work. It is essential for any inspection to use suitable equipment to ensure reliable test or measuring results through the proper operation of such equipment.

5.3.1 Finished Work Inspection Methods

Finished work inspection involves inspection items such-as the reference height, length (distance, width and slope length) and gradient in addition to confirmation of the cut slope and embankment positions. As far as measuring is concerned, it is time-consuming and not very efficient to conduct measuring at all of the measuring points. The common practice is therefore to conduct measuring by selecting more points at sections with many changes of the horizontal alignment, as well as longitudinal alignment while selecting fewer points at sections with fewer changes, leaving the remaining points for visual checking. Visual checking is also required at the halfway points between the measuring points since the values demanded by the design drawing must be met at these points as in the case of the measuring points. If visual inspection detects any difference at a point from the preceding or subsequent point, verification with the design drawing is required. In addition, it may also be necessary to conduct measuring in the same manner at measuring points to check for any abnormality.

(1) Inspection of Reference Height

This inspection uses a level or other suitable tool/equipment to measure the height of the centre line of the measuring point and the top of the slope and the results are compared with the corresponding heights specified in the design drawing.

(2) Inspection of Length (Distance, Width and Slope Length)

a) Inspection along Longitudinal Direction

This inspection involves measuring of the distance between measuring points, distance from a point of change of the horizontal or vertical alignment, distance between a structure and a measuring point, and distance between a point of change of a cut slope or embankment and a measuring point and the results are compared with the corresponding distances specified in the design drawing.

b) Inspection along Cross-Sectional Direction

This inspection involves measuring of the width, distance from the centre line, width of berm(s), slope length and height of the road surface at measuring points and the results are compared with the corresponding values specified in the design drawing.

(3) Inspection of Gradient

This inspection involves measuring or calculation of the gradient of the face of a cut slope and/or embankment slope at measuring points based on the horizontal distance, vertical distance, slope length and gradient meter readings and the results are compared with the corresponding values specified in the design drawing.

5.3.2 Quality Inspection Methods

The quality inspection of slope earthwork practically consists of inspection of the banking material and the degree of compaction. By the same way, the quality of vegetation work on the face of a slope and of small concrete structures is also inspected. In this section, inspection of the banking material and the degree of compaction is described.

Quality inspection of the banking material commonly involves a judgment on whether or not the quality test results meet the quality set forth in the specifications using the construction management records. Given the extreme difficulty of rectifying the quality of the banking material when it fails inspection, it is essential to confirm the quality of the soil at the initial stage as well as interim stages of execution in addition to a borrow pit survey.

The practical way to conduct inspection of the degree of compaction is to make a judgment based on the quality control documents, recording the measured values. However, inspection of the finishing surface of the embankment, etc. can be carried out in the form of the necessary tests upon completion of the embankment, etc. Special attention should be paid to the sufficiency of compaction at the road edges and near structures.

Quality inspection is commonly carried out by the owner using reference data submitted by the contractor in accordance with the specifications. In addition to this, the owner may also conduct his own quality tests as part of the quality inspection process. In any case, the reliability of the tests and measuring which provide reference data is a precondition and these tests and measuring must be properly carried out under the guidance of skilled supervisors.

5.3.3 Acceptance Judgment

There are two methods as described below to judge whether or not slope earthwork-related results are acceptable.

(1) Method using Standard Values

In principle, when all of the measured values of the total inspection satisfy the standard values (within the allowable error range of the design values specified in the design documents and specifications), the inspected item is judged to have passed the inspection. This method is commonly used for inspection of the external dimensions of structures.

(2) Method using Acceptance Values

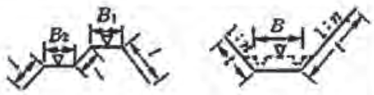
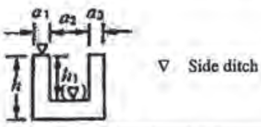
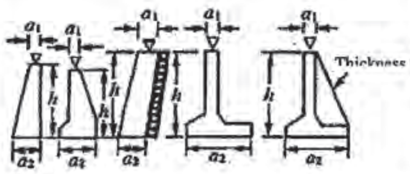
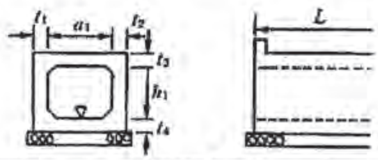
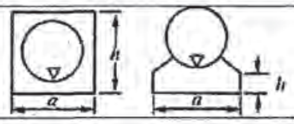
In regard to sampling inspection, when the measuring results of samples where the quantity is determined for each lot together with the size of lot satisfy the following equation, the inspected item is judged to have passed the inspection.

Higher acceptance value ≥ Mean value of measured values ≥ Minimum acceptance value

An acceptance value is commonly set at a level where 95% of the samples meet the standard value. This method is generally used for quality inspection. Table 5.2 shows examples of the standard values and acceptance values used for inspection.

Table 5.2 Standard Value and Approval Value (Examples) (source: PWRI, 2004)

(Unit: mm

Subject for Inspection		Standard Value	Remarks
Type of Work	Item		
Road Earthwork	Reference height	±50	
	Width B, B1, B2	-100	
	Slope length l < 5 m	Embankment -100 Cut slope -200	
	Slope length l ≥ 5 m	Embankment -2% Cut slope -4%	
	Degree of compaction (filled up ground; subgrade)		Approval value (individual measured value) (1) Maximum dry density: 85% or higher for filled up ground, 90% or higher for subgrade (2) Degree of saturation: 85 – 95% (air voidage: 10 – 2%) (3) Above the value specified in the special specifications in the case of using the strength characteristic (K value, etc.)
Concrete Site Ditch	Reference height	±30	
	Width a_3	-30	
	Height h, h_1	-30	
	Thickness a1, a_3	-20	
	Total length L	-200	
Concrete Retaining Wall	Reference height	±50	
	Width a_1	-30	
	Width a_2	-30	
	Height h < 3 m	-50	
	Height ≥ 3 m	-100	
	Thickness of t Counterfort	-20	
	Total length L	-200	
Stone Masonry, Block Masonry, Stone Pitching and Block Pitching	Thickness t	-50	
	Slope length l < 3 m	-50	
	Slope length l ≥ 3 m	-100	
	Reference height	±50	
	Total length L	-200	
Box Culvert	Reference height	±30	
	Thickness t_1, t_2, t_3, t_4	-20	
	Width (inner dimensions) a_1	-30	
	Height h_1	±30	
	Length L < 20 m L ≥ 20 m	-50 -100	
Concrete Pipe Culvert	Reference height	±30	
	Width a	-50	
	Height h	-30	
	Total length	-200	

6 Maintenance of Earth Structures

6.1 Introduction

6.1.1 Necessity for and Components of Maintenance

The purpose of maintenance is to ensure safety and soundness of the slopes through the constant preservation of the good conditions as well as efficient operation of structures which are important social assets. As roads are constantly exposed to varying traffic conditions and harsh weather conditions, they become deteriorated or weakened with time. They may be deformed or damaged by changing conditions which are beyond anticipation at the time of their construction. Meanwhile, the social demands for slope structures become more advanced and diversified each year and there has been a noticeable increase of cases where defective structure management is questioned, making maintenance ever more important. The maintenance, repair and disaster restoration of earth structures must be carried out against such a background.

The actual maintenance work of earth structures has the following components:

(1) Inspection

Inspection is carried out to accurately establish the conditions of earth structures under management, such-as cut slopes and embankments, and their surrounding areas so that any abnormality or damage can be quickly detected.

(2) Maintenance and Repair

Maintenance or repair work is carried out to maintain or to repair the functions of earth structures.

(3) Countermeasures

Countermeasures are implemented to prevent any further worsening of abnormalities found with earth structures, or to restore the damage or failure of such structures.

6.1.2 Important Points for Maintenance

(1) Early Detection of Abnormality or Damage

The early detection of any abnormality or damage through routine inspection is important for maintenance. Early detection enables the planning of an effective countermeasure, making it easier to secure slope safety.

For the effective implementation of inspection, it is essential to keep reference materials and data at the time of construction and records of subsequent maintenance for the key structural points of various land areas in an easily accessible manner.

Damage to a slope structure and road structure and/or disruption of the traffic flow can be caused by the failure of a hillside slope or other events outside the right of way. In such cases, while those responsible for the management of areas outside the road section must principally formulate suitable countermeasures, it is desirable for those responsible for slope management to pay proper attention to those situations.

(2) Prohibition or Restriction of Traffic

When an abnormality or damage is detected on the road, it is important to implement measures to prevent traffic accidents and/or to stop the further spread of the damage. For this purpose, the prohibition or restriction of traffic must be adopted in a flexible manner in response to the extent of the abnormality or damage.

Prior to the introduction of traffic restrictions, full consideration should be given to the traffic arrangements, including the restriction method, designation of a detour and traffic safety measures. When an emergency countermeasure is implemented, careful planning must be conducted to prevent any hindrance and/or duplicated work at the time of executing full-scale restoration work.

(3) Investigation of Causes and Countermeasures

For the examination of countermeasures, the causes must firstly be accurately established. In reality, however, it may not be easy to establish the exact causes because of the overlapping of many causes or the danger associated with the on-site investigation of causes under abnormal weather conditions. Accordingly, it is necessary to urgently proceed with a viable investigation in response to the nature of abnormality or damage to formulate countermeasures, including emergency measures, in a flexible manner.

In the case of structural abnormality of a structure, continuous observation of the abnormality and regular investigation must be carried out.

The most important point for the formulation of countermeasures is the “disposal of water” as water is a factor for the maintenance of earth structures which is as crucial as during the design and execution stages.

Secondly, the key points of the planning and design of earth structures must be properly understood. Every design has its own preconditions and a proper understanding of such preconditions is essential for maintenance.

Thirdly, the characteristics and scope of application of each construction method and technology must be properly understood for the selection of a suitable countermeasure.

A flexible response must be made to the possible disruption of traffic and impacts on the social environment when implementing a countermeasure.

6.1.3 Disaster Restoration Measures

When slopes are affected by extraordinary natural phenomena, they are often rendered impassable or road traffic and land use are restricted. It is essential to investigate the current situation of a disaster and intend to quickly decide a restoration policy.

The types of disasters which frequently occur to earth structures are slope failure, embankment or retaining wall collapse due to poor drainage and the outflow of sediment due to the clogging of drainage ditches.

For the restoration of damaged earth structures, it is necessary to fully examine whether restoration of the original shape or restoration with fresh reinforcement is more desirable.

6.2 Maintenance of Slopes

The maintenance of slopes is carried out in the manner described in 6.1. The actual maintenance work consists of the planning of disaster prevention, inspection and disaster prevention maintenance work. Figure 6.1 shows the general flow of maintenance work.

Disaster prevention maintenance work is carried out in response to the situation of a slope as identified by inspection. Disaster prevention maintenance work for slopes is largely classified into the maintenance management of structures and disaster prevention management. The former involves work to repair the aged deterioration of vegetation and structures to maintain the good status while the latter involves work to monitor abnormalities or failure and work to implement countermeasures to avert risks.

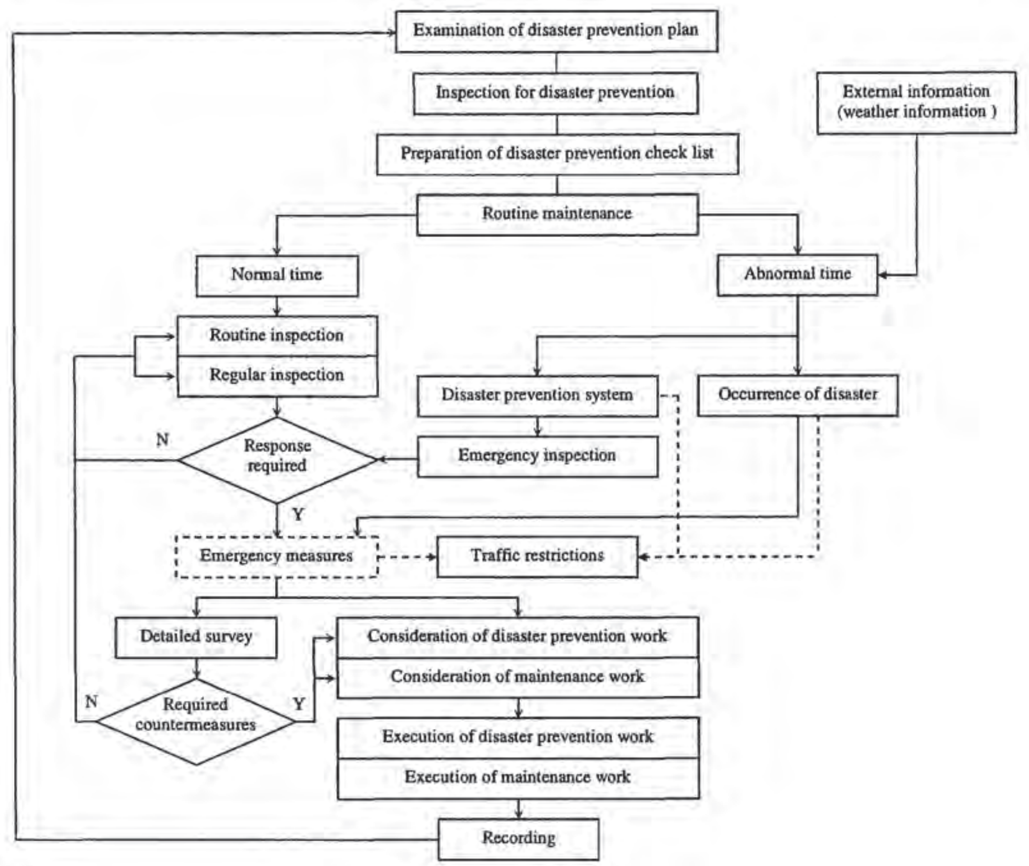


Figure 6.1 Flow of Maintenance (source: PWRI, 2004)

6.2.1 Inspection of Slopes

The inspection of slopes (abnormality investigation) is carried out to maintain safety as well as amenity. It is extremely difficult to accurately predict the level of slope stability (affected by declined strength of the ground due to weathering, improved stability due to repair or improvement of slope protection work, unpredicted external forces generated by extraordinary rainfall, changes of land use in adjacent areas, changes of groundwater behaviour due to transformation of the landforms and others) and the form of slope disaster (travelling distance of failed soil, failure above a slope and others) on a land and road as well as the surrounding area.

Accordingly, the abnormality investigation of a slope is quite important in the sense that it may clarify the uncertain factors described above or, to be more precise, it may accurately identify potential sites of disaster at an early stage to prevent the occurrence of a disaster or accident. This investigation is also important to efficiently and rationally conduct repair, etc. with a limited budget and other restrictions.

(1) Types of Inspection

a) Disaster Prevention Inspection

Disaster prevention inspection is a detailed inspection which is carried out by specialist engineers to check the geomorphological and geological conditions of a slope, the effects of existing countermeasures and the history of disasters, etc.

b) Routine Inspection

Routine inspection involves the visual inspection of visible areas from a patrol vehicle, etc. and intends the early detection of any abnormality. It also checks the situation of everyday road use and reports from the residents.

c) Periodic Inspection

Periodic inspection involves the detailed checking of a slope by approaching the subject slope on foot and is carried out at relatively long intervals, such-as once a year.

d) Special Inspection

Special inspection is carried out after heavy rain, etc. whenever such inspection is deemed to be necessary to supplement routine or periodic inspection.

(2) Important Points

One of the most basic issues which are important for inspection is the inspection of water. It is well-known that the scouring and failure of a slope occurs with a large quantity of surface water running down the slope in a concentrated manner or the ground or an embankment fails due to the weeping of seepage water. Because of such a risk, it is important to conduct the careful inspection of water, including the situation of water concentration at the top of a slope, the situation of clogging of drainage ditches and the position, volume and changes of spring water.

When phenomena which are believed to be signs for the large-scale failure of a slope body or the face of a slope are detected, displacement gauges and extensometers should be installed if necessary to observe abnormalities or distortions. In addition, it may be necessary to conduct a drilling survey to analyse the phenomenon of failure so that a prudent judgment can be made. Table 6.1 shows the important points for slope inspection by type of slope. Depending on the degree of seriousness, abnormalities or inferior sites detected by inspection may require ordinary maintenance work or more fundamental countermeasures to prevent failure through the observation of abnormalities and a geological survey as described above.

6.2.2 Maintenance and Repair of Slopes

Maintenance and repair work is essential to maintain the proper functioning of a slope. Planting in particular can only achieve its positive effects through the normal growth of plants. Careful consideration is therefore required in regard to the management of planting work.

Such facilities as a Rock Fall prevention fence and Rock Fall protection net require removal of the deposited soil, repair of any cut rope or net and foot protection of the loosened foundation.

6.2.3 Countermeasures for Post-Completion Abnormalities

Even if the inspection and maintenance described in 6.2.1 and 6.2.2 are properly carried out, failure can still occur at the time of extraordinary weather, making emergency countermeasures necessary.

The general principles for the implementation of countermeasures are as follows:

1) Countermeasures to deal with water, such as inflow water and spring water.

2) Installation of protection works to deal with the failure of a shallow surface layer or re-cutting to make the slope gradient gentler.

3) Removal of soil from the top part of a slope by excavation, prevention pile work and/or anchor work to deal with the deep failure of a cut slope.

4) Creation of a counterweight embankment or reinforcement of the bottom of a slope to deal with the failure.

Table 6.1 Important Points for Slope Inspection (source: PWRI, 2004)

Type of Slope / Inspection Item		Rock Fall Prevention Work		Rock Fall Protection Work			Slope Surface with Structural Protection			
	Natural Slope	**Concrete/ Masonry Foot Protection Work**	**Rock Bolt/Rock Anchor/Wire Rope Work**	**Rock Fall Prevention Net/Fence**	**Rock Fall Protection Retaining Wall/ Rock Shed**	**Vegetated Slope Surface**	**Block Masonry Cribwork, etc.***	**Concrete/ Mortar Spraying**	**Rock Fall Prevention Net/Fence**	**Net Hurdling; Gabion**
History of Failure	▪ Survey on history of failure during and after slope earthwork ▪ Any relation between rainfall and failure as well as scale of failure									
Topography Geology	Is the topography likely to gather water? Is the geology liable to weathering; Is there a dip slope?					As left	As left when a slope or vegetated slope surface exists above the slope formed by a structure		Is the topography likely to gather water? Is the geology liable to weathering; Is there a dip slope?	
State of Spring Water	Location and amount of spring water, change of state of spring water				-	Location and amount of spring water, change of state of spring water	Situation of dewatering pipes; change of state of spring water		Location and amount of spring water, change of state of spring water	
Drainage Ditch	-	-	-	-	-	Clogging of ditch; scouring around vertical ditch	Clogging of Ditch	Clogging of Ditch	Clogging of Ditch	Clogging of ditch; scouring around vertical ditch
Abnormality of Slope Surface or Body	Presence of Pumice and/or cracks	Presence of Pumice and/or cracks; Presence of failure/scouring		Presence of Pumice and/or cracks	Presence of Pumice and/or cracks	Presence of cracks	(See below)	(See below)	Presence of Pumice and/or cracks	(See below)
Abnormality of Slope Surface or Slope Protection Work	-	Cracking or breakage of concrete; loosening or failure of masonry work; loss of backfilling material	Looseness, damage to and/or corrosion of metal parts	Corrosion or cutting of rope or net; loosened anchor; deposited sediment; damage to or corrosion of steel; storage of sediment	Settlement of foundations of Rock Fall protection works; corrosion or deformation of members; loss of cushioning material; sedimentation of fallen soil; cracking or breakage of concrete	State of Vegetation Growth	Cracking, bulging, settlement of foundations; scouring; loosened filling material; loss of backfilling material	Cracking; bulging; partial separation; cavity between slope and the ground	Corrosion or cutting of rope or net; loosened anchor; deposited sediment	State of corrosion, state of sliding or lifting

Note: * Stone pitching, concrete pitching, block pitching and retaining walls are included in this column.

(1) Slope Protection with Vegetation

a) Cut Slopes

When a sign of failure appears or when a failure takes place, its scale and scope should be quickly established. If a failure is localised with no risk of becoming a major failure for the time being, net hurdling constitutes the easiest emergency countermeasure to apply. If the scale of the failure is large, it is necessary to re-cut the slope to make its gradient gentler for long-term stabilisation.

As an emergency countermeasure at the time of failure, it is important to cover a cracked portion with sheeting to prevent enlargement of the damage by preventing the permeation of rainwater.

b) Embankment Slope

Failure on an embankment slope may occur when water overflows from drainage ditches due to localised heavy rain or the poor maintenance of drainage ditches as described in 6.3, running down the slope in a highly concentrated manner. In such a case, restoration work should firstly be carried out with the full compaction of good quality soil. If necessary, net hurdling, the use of crushed stones to create a drainage conduit or the installation of gabions at the bottom of the slope should prove to be effective.

(2) Countermeasures for Protected Slopes by Structures

Typical countermeasures to deal with damage to concrete or mortar spraying and cribwork are described below.

a) Concrete or Mortar Spraying

In the case of slopes sprayed with concrete or mortar, the sprayed concrete or mortar may partially peel off and scatter due to weathering. In such a case, Rock Fall prevention net should be applied as an emergency countermeasure. When the further deterioration of spray works requires a full-scale countermeasure, re-spraying should be carried out.

In the case of the progressive weathering of the ground, concrete crib works or others may be required depending on the degree of weathering.

b) Crib works

A frequently observed abnormality of crib works is uplifting and the eventual falling of cobblestones filling the crib works onto the road surface. In such a case, a common countermeasure is the installation of Rock Fall prevention net or the injection of concrete to fix the cobblestones together with a measure to deal with spring water.

Next, when spring water is observed through sandy soil at the back of the crib works, the caving in of the crib works and/or loss of the filling soil could occur due to scouring. In this case, the re-installation of the crib works and/or foot protection work with concrete, together with a measure to deal with spring water is required.

(3) Slope Stabilisation

From the viewpoint of slope stabilisation, when boulders and gravels are situated on the face of a slope, the first action is to consider their removal. If removal is difficult, the following countermeasures should be adopted.

a) Boulders and gravels which are likely to fall at some stage are gathered to a safe place on the slope or are fixed by concrete or anchor bolts.

b) Either Rock Fall prevention fence or Rock Fall prevention net is installed so that any Rock Falling unexpectedly does not pose a danger to residents and road traffic.

c) If none of the above countermeasures are believed to be sufficient, Rock Fall shed to cover the entire road should be constructed.

The above countermeasures are designed to deal with dangerous boulders. If dangerous soil simultaneously exists, re-cutting to produce a slope with stable gradient or slope protection work involving a structure should be carried out in addition to the second or third countermeasure described above.

6.3 Slope Disaster Related Structures (Drainage, Retaining Wall and Culvert)

6.3.1 Maintenance of Drainage Facilities

In addition to routine cleaning, the maintenance of drainage facilities should include periodic inspection to regularly check whether or not these facilities are properly performing their functions. If necessary, repair or improvement work should be carried out to preserve their functions. As damage to the road surface or slopes often originates from poor drainage, the maintenance of drainage facilities is particularly important. Special attention should be paid to preventing the excessive permeation of surface water or groundwater to the embankment in order to avoid any adverse impacts, including damage to the embankment surface.

(1) Inspection of Drainage Facilities

Drainage facilities must be periodically inspected. An inspector should carry a drainage system map and an inspection sheet to accurately establish the conditions of each drainage facility. Inspection during or immediately after rain is effective as drainage defects tend to be more easily found. Inspection must be very carefully carried out after a cyclone and during the rainy season. The important points for inspection are listed below.

1) Situation of drainage from the road surface and slope drainage facilities and situation of surface water and soil flowing onto the right of way from the surrounding area

2) Situation of soil as well as boulder deposits inside and at the entrance as well as exit of transverse drainage facilities

3) Situation of water flow at the entrance and exit of subsurface drainage facilities

4) Situation of damage to drainage facilities

5) Situation of the connection points (catch basins and manholes, etc.) of drainage facilities

and situation of terminal treatment

6) Situation of drainage through weep holes in the retaining wall of an embankment and tunnel, etc.

7) Situation of drainage facilities at the shoulders

(2) Maintenance and Repair of Drainage Facilities

a) Surface Drainage Facilities

In general, drainage from the ground surface is extremely important to prevent a decline of the bearing capacity of the embankment, to ensure a safety of residents and traffic and to maintain a good environment and sanitation in areas.

a-1. Side Ditches

The periodic inspection of simply dug side ditches, U-shape side ditches and L-shape side ditches is necessary to remove any deposited fallen leaves and collapsed soil in mountain areas or rubbish in inhabited areas. Inspection should be carried out to check for any fallings of the side walls or any gap at the joints between the side walls and bottom plate in the case of concrete side ditches or any damage to the joints in the case of pre-cast U-shape side ditches. If any damage is found, it must be immediately repaired.

a-2. Drainage Pipes

The water flow function of drainage pipes may be lost due to clogging by rubbish or soil or due to settlement of the ground. Particularly in mountain areas, boulders from the hillside or debris flow may clog a water channel and the failure of the road itself may result in such clogging, demanding special attention for the prevention or clearing of clogging.

a-3. Connecting Points of Drainage Facilities

The connecting points or changing points of the cross-section of side ditches, culverts and drainage pipes tend to have a fairly complicated structure. As these points often constitute the contact points between pre-cast products and in-situ construction work, they are often marked by structural weakness. In addition, the fact that the water flow changes at these points also leads to frequent problems. In short, special attention is required for these points as shrinkage of the cross-sectional area for water flow due to the deposition of soil and rubbish or gaps can easily occur at these points.

b) Subsurface Drainage Facilities

Subsurface drainage facilities are created by either porous pipes or filling with a coarse material. In either case, careful attention should be paid to preventing the gathering of soil, etc. at the outlet of drainage pipes so that water can be smoothly discharged.

The structure and location of subsurface drainage facilities often become unknown with time and therefore, it is desirable to clearly indicate their structure in the road inventory and to clearly mark their location on the spot. As it is practically impossible to conduct the routine or periodic inspection of subsurface drainage facilities except at their outlets, it is necessary to check their proper functioning by observing their run-off, etc. after rain.

c) Slope Drainage Facilities

Most slope failures are caused by water. Rainwater can cause slope failure as it becomes surface water which erodes the top soil or seepage water which erodes a slope from inside.

Drainage ditches for the berms of a high embankment and drainage ditches constructed at the top of an embankment or cut slope must be periodically inspected with intention to remove collapsed soil, fallen rocks and weeds from these ditches so that the water collected in the ditches does not flow anywhere except in the vertical drainage ditches.

Special attention is required for pre-cast, U-shape vertical drainage ditches as the joints may separate due to differential settlement or other reasons, resulting in slope failure caused by the discharge of soil, in turn caused by scouring by water.
In such a case, the foundation material or similar material should be supplemented and well compacted to reposition the ditches. Attention should also be paid to the connecting points between the drainage ditches at the top of a slope and vertical drainage ditches and any damaged areas must be immediately repaired. Any wetting or spring water at a cut slope, embankment or slope must be carefully checked and it is advisable to adopt slope gabions, lateral drainage holes or other suitable methods depending on the cause of wetting or spring water. Slope protection work, such as concrete spraying, should also be properly inspected and, if necessary, weep holes or other suitable work should be performed.

d) Other Drainage Facilities
Other drainage facilities include those designed to drain water from the back of a retaining wall and from tunnels, underpasses, bridges and box culverts. Proper attention must be paid to the inspection and cleaning of these drainage facilities since neglecting such requirements can lead to the destruction of a structure or the failure of embankment. In regard to facilities to drain water from the back of a retaining wall, special attention should be paid to the situation of surface water and the drainage situation through weep holes with intention to prevent an inflow of surface water into the back of a retaining wall. Any clogged weep hole must be thoroughly cleaned. When standing water behind a structure is believed to exist in view of the amount and turbidity of leaking water through weep holes or cracks or at a location(s) of water leakage, a countermeasure, such as the introduction of additional weep holes, should be implemented depending on the situation to reduce the load of standing water acting against the structure.

6.3.2 Maintenance of Retaining Walls and Culverts

Although retaining walls and culverts are essentially permanent structures, they might be distorted due to external forces which are beyond their design conditions caused by extraordinary weather. The detection of such distortion at an early stage by means of inspection is therefore necessary to investigate the causes and to introduce a suitable countermeasure.

The distortion of retaining walls and culverts can be caused by the settlement of the ground, lateral flow of the ground, poor drainage of surface water and groundwater and scouring of the foundation. These cause a variety of distortions, ranging from settlement and differential settlement to bulging, dislocation and cracking.

(1) Inspection of Retaining Walls and Culverts

In addition to routine inspection, periodic inspection should be carried out for retaining walls and culverts. Further inspection must also be carried out at the time of extraordinary weather. If the timing of inspection is not right, it is difficult to determine the details of extraordinary weather and the causes of problems. It is therefore essential for inspection to be carried out as quickly as possible.

Another important point is to keep relevant data and information, including the original design conditions, stress calculation results, design drawings, construction records and maintenance and repair history.

The important points for the inspection of retaining walls and culverts are described in more details below:

a) Retaining Walls

In regard to retaining walls, special attention should be paid to the proper functioning of weep holes and the existence of residual water at the back of the wall.

As the distortion of a retaining wall tends to appear in the form of settlement or tilting as described earlier, special attention should be paid to the crown and expansion joints to check for any dislocation, opening or slippage. Peeling of the concrete, exposure of the reinforcing bars and cracks should also be checked to determine their extent, shape, distance and nature of progress, if possible.

In general, these distortions tend to be accompanied by cracks and/or settlement at the backfill part or at the back of a retaining wall and/or adjacent areas. By focusing on these irregularities, inspection can help to discover the distortion of a retaining wall and void in the backfill part.

Moreover, in the case of retaining walls which work as river bank protection, scouring of the foundation and the distortion of foot protection works should be inspected.

b) Culverts

In the case of culverts, primordial attention should be given to any faulting or cracking of the road surface as such abnormalities are frequently caused by settlement of the backfill part.

In regard to the distortion of the main body of a culvert, the trend of settlement or tilting can be established by focusing on opening or slippage. The inspection of cracks, peeling of the concrete and exposure of the reinforcing bars should be carried out in a similar manner to the inspection of retaining walls. Particular attention should be paid to the state of deformation in the case of a corrugated metal culvert or a PVC pipe culvert.

Another inspection item is the existence of suction of the backfilling material depending on the situation of water leakage into culvert.

(2) Countermeasures for Distortion of Retaining Walls and Culverts

a) Retaining Walls

When the distortion of a retaining wall occurs, the introduction of an emergency countermeasure with primary emphasis on safety for inhabitant and traffic safety is preferable. Reinforcement of only the main body of a retaining wall may prove not to be a permanent solution if distortion is caused by the ground or external conditions. Careful consideration is required in regard to proper analysis of the cause(s) of distortion in order to determine whether a permanent countermeasure is required or whether an emergency countermeasure is sufficient.

Possible countermeasures for the distortion of retaining walls are listed below:

- Reinforcement of retaining wall
- Reinforcement of foundation
- Reduction of external force acting on retaining wall
- Renewal

a-1. Reinforcement of Retaining Wall

Concrete methods to reinforce a retaining wall include the injection of resin into the cracks in the case of a concrete retaining wall and re-stocking of the blocks in the case of the partial bulging of a concrete block retaining wall. When the bulging or cracking of a concrete block retaining wall is very severe, causing uncertainty in regard to the strength of the wall, widening of the original concrete block retaining wall with a new concrete retaining wall (Figure 6.2) or anchor works (Figure 6.3) are employed to reinforce the original retaining wall.

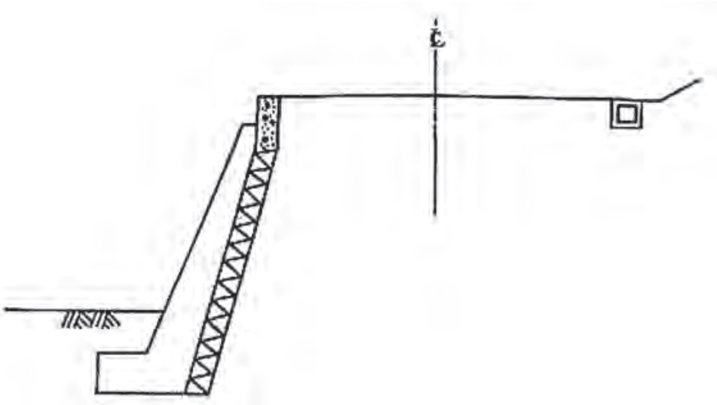


Figure 6.2 Example of Reinforcing Concrete Block (Stone) Retaining Wall by Concrete Retaining Wall (source: PWRI, 2004)

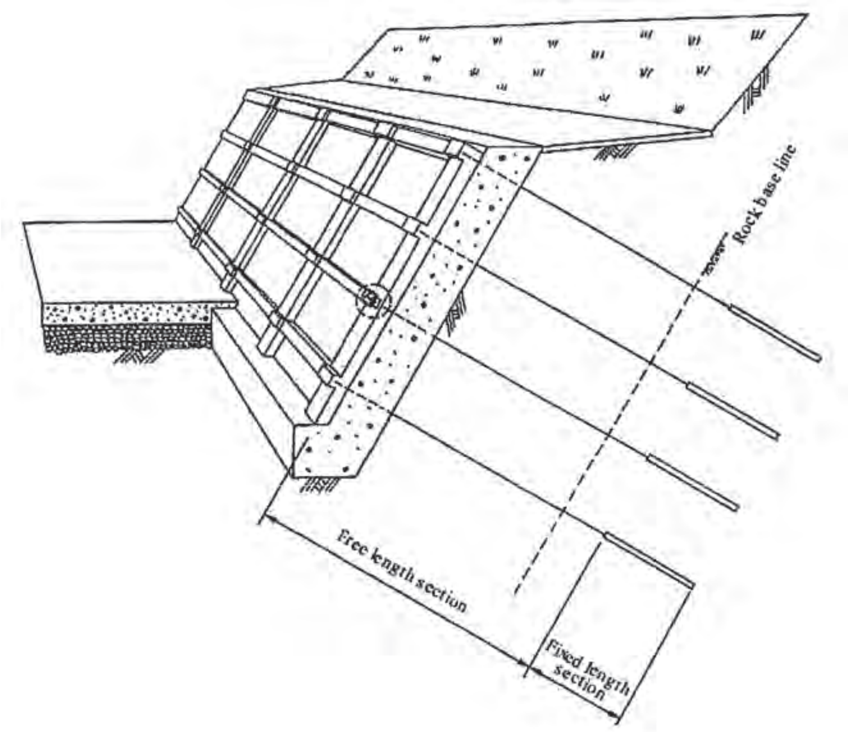


Figure 6.3 Example of Anchor Works (source: PWRI, 2004)

a-2. Reinforcement of Foundation

There are many foundation reinforcement methods, including (i) the use of sheet piles, steel piles, cast-in-place concrete piles or a diaphragm wall to reinforce the area around the foundation and to increase the bearing strength of the foundation and (ii) chemical injection to strengthen the ground. The most appropriate method for the site should be adopted after proper analysis of the cause of retaining wall distortion and the conditions of the ground as well as neighbouring environment.

As all of the construction methods mentioned above involve a huge cost, it may be necessary to carefully consider whether or not a more economical method, such as counterweight fill or reduction of the external force acting on the retaining wall, may be sufficient to achieve the objective of reinforcement work.

a-3. Reduction of External Force Acting on Retaining Wall

The methods to reduce the earth pressure at the back of a retaining wall are cutting (Figure 6.4), prevention of the permeation of surface water to the back of a retaining wall (Figure 6.5) and the cleaning of weep holes or the introduction of new weep holes.

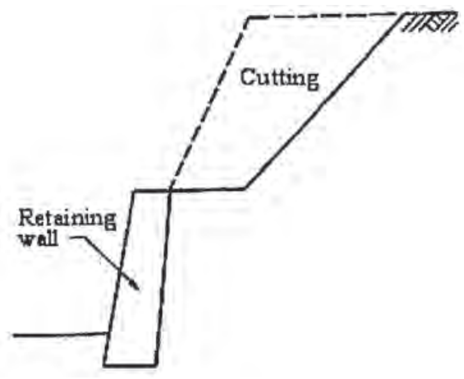


Figure 6.4 Example of Reducing Back Earth Pressure by Cutting (source: PWRI, 2004)

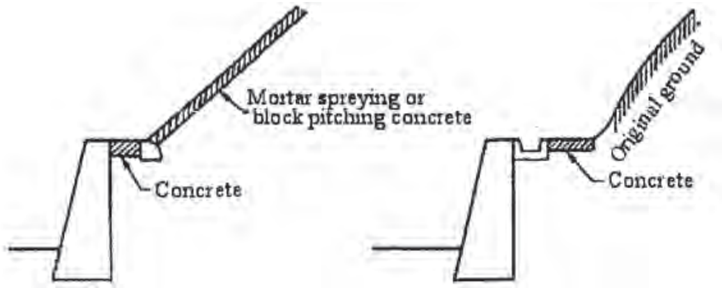


Figure 6.5 Examples of Preventing Surface Water Permeation (source: PWRI, 2004)

a-4. Renewal

A damaged retaining wall may be replaced by a new retaining wall. As this is a very costly fundamental countermeasure, the decision must be very carefully made. In general, the renewal of a retaining wall is required in the following cases.

(i) Case where the repair of a deteriorated or damaged retaining wall by means of reinforcement is impossible

(ii) Case where sufficient reliability cannot be guaranteed despite very costly reinforcement work for the foundation

b) Culverts

Countermeasures for the settlement of culverts include (i) lowering of approach roads in the case of an underpass and (ii) smoothing by means of lowering the water channels on both sides of a culvert by means of excavation, installation of incidental equipment (for example, installation of a drainage pump at the underpass) and raising of the water channel in the case of an irrigation canal or drainage channel.

Water leakage through the joints may be dealt with by the introduction of a conduit below the leakage point. Where the phenomenon of destruction, such-as considerable cracking, which suggests the loss of the culvert function, is discovered, investigation of the causes should be carried out. If necessary, a crack gauge and other equipment should be used to determine the situation of progress so that a suitable countermeasure can be selected. The decision on any countermeasure must take the scale of cracking, original design conditions, actual state of execution and environmental conditions, etc. into consideration.

If the cracks are of a minor nature without visible progress after initial discovery, grout may be used to seal them. If further progress is detected, it may be necessary to remove the root cause or to reinforce the culvert.

ANNEX 1

Manual for Rock Fall Inventory

at

Signal Mountain Road

September 2017

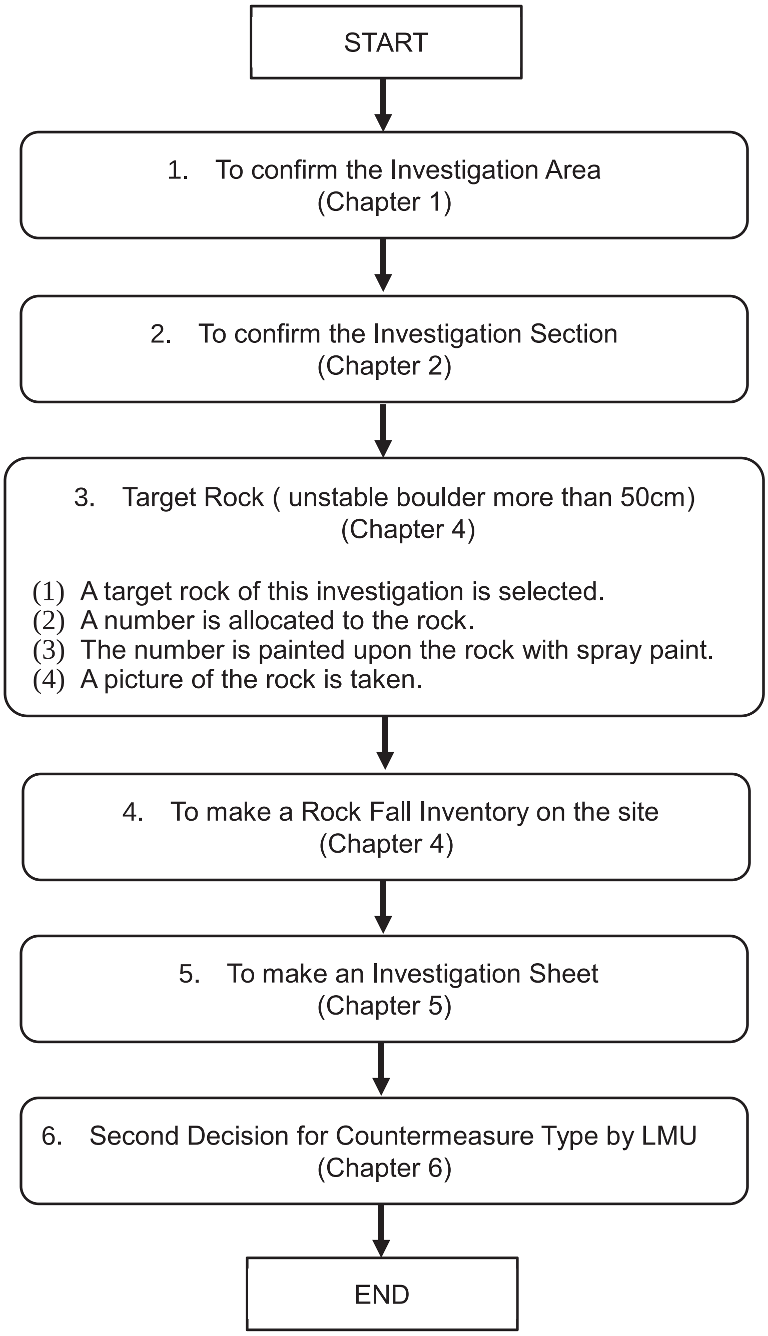


Figure 1 Work Flow of the Site Investigation for Rock Fall Inventory

1. Investigation Area

The investigation area is the slope along Signal Mountain Road, from ch 250 to ch 2830, as shown in Figure 2.

Figure 2 Location Map for Investigation Area at Signal Mountain (Base map: Google earth)

2. Investigation Section (25m width)

The investigation area should be divided into a number of smaller sections of 25m in width. Each loose rock on in the smaller section of the slope is allocated a specific number as shown in figure 3.

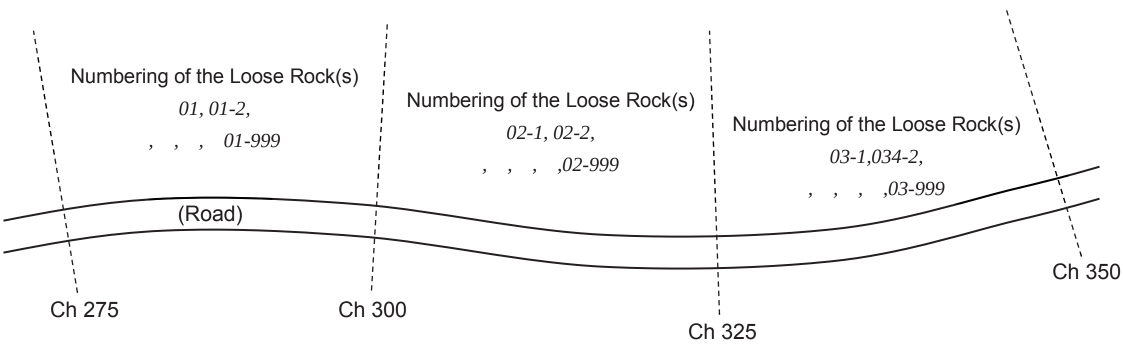


Figure 3 Sample of numbering of loose rock(s) for every section

Table 1 Investigation section and numbering of loose rock(s) for every section

Investigation section from	Investigation section to	Numbering of rock(s) for each section		
Ch275	Ch300	01-1	to	01-999
Ch300	Ch325	02-1	to	02-999
Ch325	Ch350	03-1	to	03-999
Ch350	Ch375	04-1	to	04-999
Ch375	Ch400	05-1	to	05-999
Ch400	Ch425	06-1	to	06-999
Ch425	Ch450	07-1	to	07-999
Ch450	Ch475	08-1	to	08-999
Ch475	Ch500	09-1	to	09-999
Ch500	Ch525	10-1	to	10-999
Ch525	Ch550	11-1	to	11-999
Ch550	Ch575	12-1	to	12-999
Ch575	Ch600	13-1	to	13-999
Ch600	Ch625	14-1	to	14-999
Ch625	Ch650	15-1	to	15-999
Ch650	Ch675	16-1	to	16-999
Ch675	Ch700	17-1	to	17-999
Ch700	Ch725	18-1	to	18-999
Ch725	Ch750	19-1	to	19-999
Ch750	Ch775	20-1	to	20-999
Ch775	Ch800	21-1	to	21-999
Ch800	Ch825	22-1	to	22-999
Ch825	Ch850	23-1	to	23-999
Ch850	Ch875	24-1	to	24-999
Ch875	Ch900	25-1	to	25-999
Ch900	Ch925	26-1	to	26-999
Ch925	Ch950	27-1	to	27-999
Ch950	Ch975	28-1	to	28-999
Ch975	Ch1000	29-1	to	29-999
Ch1000	Ch1025	30-1	to	30-999
Ch1025	Ch1050	31-1	to	31-999
Ch1050	Ch1075	32-1	to	32-999
Ch1075	Ch1100	33-1	to	33-999
Ch1100	Ch1125	34-1	to	34-999
Ch1125	Ch1150	35-1	to	35-999
Ch1150	Ch1175	36-1	to	36-999
Ch1175	Ch1200	37-1	to	37-999
Ch1200	Ch1225	38-1	to	38-999
Ch1225	Ch1250	39-1	to	39-999
Ch1250	Ch1275	40-1	to	40-999
Ch1275	Ch1300	41-1	to	41-999
Ch1300	Ch1325	42-1	to	42-999
Ch1325	Ch1350	43-1	to	43-999
Ch1350	Ch1375	44-1	to	44-999
Ch1375	Ch1400	45-1	to	45-999
Ch1400	Ch1425	46-1	to	46-999
Ch1425	Ch1450	47-1	to	47-999
Ch1450	Ch1475	48-1	to	48-999
Ch1475	Ch1500	49-1	to	49-999
Ch1500	Ch1525	50-1	to	50-999
Ch1525	Ch1550	51-1	to	51-999
Ch1550	Ch1575	52-1	to	52-999
Ch1575	Ch1600	53-1	to	53-999
Ch1600	Ch1625	54-1	to	54-999
Ch1625	Ch1650	55-1	to	55-999
Ch1650	Ch1675	56-1	to	56-999
Ch1625	Ch1650	55-1	to	55-999
Ch1650	Ch1675	56-1	to	56-999
Ch1675	Ch1700	57-1	to	57-999
Ch1700	Ch1725	58-1	to	58-999
Ch1725	Ch1750	59-1	to	59-999
Ch1750	Ch1775	60-1	to	60-999
Ch1775	Ch1800	61-1	to	61-999
Ch1800	Ch1825	62-1	to	62-999
Ch1825	Ch1850	63-1	to	63-999
Ch1850	Ch1875	64-1	to	64-999
Ch1875	Ch1900	65-1	to	65-999
Ch1900	Ch1925	66-1	to	66-999
Ch1925	Ch1950	67-1	to	67-999
Ch1950	Ch1975	68-1	to	68-999
Ch1975	Ch2000	69-1	to	69-999
Ch2000	Ch2025	70-1	to	70-999
Ch2025	Ch2050	71-1	to	71-999
Ch2050	Ch2075	72-1	to	72-999
Ch2075	Ch2100	73-1	to	73-999
Ch2100	Ch2125	74-1	to	74-999
Ch2125	Ch2150	75-1	to	75-999
Ch2150	Ch2175	76-1	to	76-999
Ch2175	Ch2200	77-1	to	77-999
Ch2200	Ch2225	78-1	to	78-999
Ch2225	Ch2250	79-1	to	79-999
Ch2250	Ch2275	80-1	to	80-999
Ch2275	Ch2300	81-1	to	81-999
Ch2300	Ch2325	82-1	to	82-999
Ch2325	Ch2350	83-1	to	83-999
Ch2350	Ch2375	84-1	to	84-999
Ch2375	Ch2400	85-1	to	85-999
Ch2400	Ch2425	86-1	to	86-999
Ch2425	Ch2450	87-1	to	87-999
Ch2450	Ch2475	88-1	to	88-999
Ch2475	Ch2500	89-1	to	89-999
Ch2500	Ch2525	90-1	to	90-999
Ch2525	Ch2550	91-1	to	91-999
Ch2550	Ch2575	92-1	to	92-999
Ch2575	Ch2600	93-1	to	93-999
Ch2600	Ch2625	94-1	to	94-999
Ch2625	Ch2650	95-1	to	95-999
Ch2650	Ch2675	96-1	to	96-999
Ch2675	Ch2700	97-1	to	97-999
Ch2700	Ch2725	98-1	to	98-999
Ch2725	Ch2750	99-1	to	99-999
Ch2750	Ch2775	100-1	to	100-999
Ch2775	Ch2800	101-1	to	101-999
Ch2800	Ch2825	102-1	to	102-999
Ch2825	Ch2850	103-1	to	103-999

3. Target Rock

(1) As a target rock of this investigation, an unstable boulder which is more than 50cm is selected. The stability of boulder on the slope is defined in following table 2, and Status 1, 2 and 3 are the target rock of this investigation.

(2) A number is allocated to the rock.

(3) The number is painted upon the rock with spray paint.

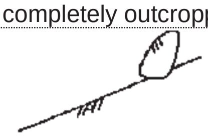
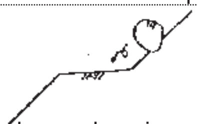
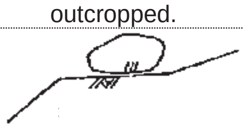
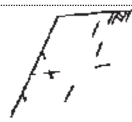
(4) A picture of the rock is taken (refer to Annex: Sample of the investigation sheet).

(5) And the rock fall inventory is filled in as shown in Chapter 5.

Table 2 Status of Stability for Loose Rocks

Status 1, 2 and 3: Target rocks of this investigation

Status 4 and 5: These rocks are not taken into consideration during this investigation.

Status of Stability	Stability	Fallen Rock	Detached Rock
1	Rock fall will occur in near future.	 Stopped by tree.	 Completely detached.
2	Although it is difficult to predict the failure time, rock fall will occur at this site.	 Stopped at a steep cliff, or completely outcropped.	 Erosion is occurring at the lower part.
3	The possibility for rock fall is high.	 The lower slope is gentle, or more than 2/3 is outcropped.	 Unstable topography.
4	The possibility for rock fall exists.	 The lower slope is near horizontal, or 2/3 -1/2 is outcropped.	 Intensive cracks.
5	There is no possibility for rock fall.	 Stopped at a horizontal field or less than half is outcropped.	 Almost sand.

* Target rocks of countermeasure works: State of Stability 1, 2 and 3.

4. Rock Fall Inventory

A Rock Fall Inventory records information about loose rocks on the site. It considers of item (1) to (8) as shown in the table below.

Table 3 Rock Fall Inventory

(1)	(2)		(3)	(4)		(5)			(6)	(7)	(8)	
Site Name	Section (ch)		Rock No.	Coordination		Size (cm)			State of Stability	Type of Countermeasure	Site Investigation	
	From	to		Latitude	Longitude	Length	Width	Height			Date	Inspector
Signal Mountain	525	550	11-1	S 20 10 30.5	E 57 29 39.0	500	700	500	1	A	25/10/2016	S. Anadachee
Signal Mountain	525	550	11-2	S 20 10 30.3	E 57 29 38.7	1350	980	810	3	B	25/10/2016	S. Anadachee
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Signal Mountain	525	550	11-999	S 20 10 30.8	E 57 29 38.1	2500	1750	1420	2	C	25/10/2016	S. Anadachee

(1) Site Name: Site name and/or Site location;

(2) Section: "ch" (distance mark) of a start and the end;

(3) Rock No.: It consists of start "ch" of the section and the continuous number (refer to Chapter 2);

(4) Coordination: Latitude & Longitude by handy GPS;

(5) Size: Length & Width & Height, Unit : cm;
   * In the case that plural unstable rocks are recorded as an area, length and width and the rough number of the rock are recorded

(6) State of Stability: The stability is rated with a number from 1 to 5. (refer to Table 2);

(7) Type of Countermeasure: It is chosen among three types, A, B and C;
   A: To remove a loose rock
   B: To stabilize a loose rock by concrete and anchor
   C: To stabilize a loose rock by net and/or wire

(8) Site Investigation: Date of the investigation & Name of the investigation person.

5. Investigation sheet for Rock Inventory

Following a site investigation, an investigation sheet is created for all recorded rock.

Rock No.	11-1	25/10/2016

[Photo]

(1) Site Name		Signal Mountain
(2) Section (ch)	(From)	525
	(to)	550
(3) Rock No.		11-1
(4) Coordination	Latitude	S 20 10 30.5
	Longitude	E 57 29 39.0
(5) Size (cm)	Length	500
	Width	700
	Height	500
(6) State of Stability		1
(7) Type of Countermeasure		A
(8) Site Investigation	Date	25/10/2016
	Inspector	S. Anadachee

Figure 4 Sample of the Investigation sheet for Rock Fall Inventory

6. Second Decision for Countermeasure Type by LMU

As a second decision, a countermeasure type of rock fall inventory should be reviewed again by LMU, designer of countermeasure works, and it is revised as needed.

7. Equipment for site investigation

- Helmet (for safety)

- Boots (for hike on mountain slope)

- Glove(for safety)

- Spray paint, white color (for numbering)

- Handy GPS

- Camera

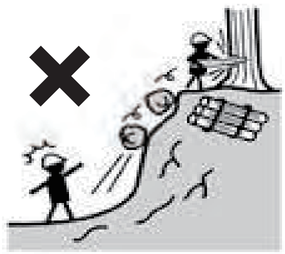
- Convex

- Mobile phone (for emergency call)

8. Safety Measures during investigation on site

(1) All individuals working on the site should wear gloves and helmet for personal protection.

(2) Investigation officers should avoid being a simultaneously on the upper and lower parts of the slope so as to prevent injury damage by rock fall.



(3) Security officers (or police officer) should be present on the road next to the slope being investigated to ensure the safety of passing traffic.

ANNEX 2

Sample of the Rock Fall Inventory

September 2017

Rock Fall Inventory

Site Name	Section (ch)		Rock No.	Coordination		Size (cm)			State of Stability	Type of Countermeasure	Site Investigation	
	(From)	(to)		Latitude	Longitude	Length	Width	Height			Date	Inspector
Signal Mountain	1100	1200	11-1	S 20 10 30.5	E 57 29 39.0	500	700	500	1	A	25/10/2016	S. Anadachee
Signal Mountain	1100	1200	11-2	S 20 10 30.3	E 57 29 38.7	1350	980	810	3	B	25/10/2016	S. Anadachee
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Signal Mountain	1100	1200	11-999	S 20 10 30.8	E 57 29 38.1	2500	1750	1420	2	C	25/10/2016	S. Anadachee

< State of Stability >

1 : Rockfall will occur in near future.
2 : Although it is difficult to predict the failure time, rockfall will occur at this site.
3 : The possibility for rockfall is high.
4 : The possibility for rockfall exists.
5: There is no possibility for rockfall.

< Type of Countermeasure >

A : To remove a loose rock
B : To stabilize a loose rock by concrete and anchor
C : To stabilize a loose rock by net and/or wire