JAPAN INTERNATIONAL COOPERATION AGENCY

THE DEPARTMENT OF PUBLIC WORKS AND HIGHWAYS

THE STUDY ON RISK MANAGEMENT FOR SEDIMENT-RELATED DISASTER ON SELECTED NATIONAL HIGHWAYS IN THE REPUBLIC OF THE PHILIPPINES

FINAL REPORT
GUIDE III

GUIDE TO ROAD SLOPE PROTECTION




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GUIDE III
ROAD SLOPE PROTECTION

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CHAPTER 1

INTRODUCTION

1.1 General

Technical Guides have been prepared in three volumes to provide technical guidance on implementing the Inventory Survey to establish an optimum Risk Management Plan for the National Highways of the Philippines. Guide III focuses on designing protection and prevention methods for road slope disasters on the existing National Highways. This Guide will be an important reference to plan countermeasure alternatives in Sheet 3 of the Inventory Format and is also applicable to the stabilization of road slopes in planning for new road projects.

Moreover, in Planning and designing countermeasures relevant to road slope disasters, reference should be made to ‘’Standard Specifications Volume II Highways, Bridges and Airports , DPWH 2004” and the Technical Standards and Guidelines for Planning and Design, *Project for the Enhancement of Capability in Flood Control and Sabo Engineering of DPWH*, March 2002.

1.2 Policy on Editing this Guide

The main objective of this Guide is to assist DPWH Engineers concerned with the planning and designing of road slope disaster management activities by providing countermeasure options for road slopes along with design examples for handling various types of road slope disasters. This Guide has been prepared for a wide and effective application to plan countermeasures for slopes on the national highways consistent with the following policies:

a) Focus on providing planning of rehabilitation works and road slope maintenance works;

b) Collection of examples of countermeasures applied in the Philippines;

c) Arrangement of basic principles and policies applied in Japanese manuals on slope protection;

d) Introduction of advanced protection and prevention methods for adverse situations to select the best solution; and

e) Collection and arrangement of countermeasure examples from the Philippines and Japan.

1.3 Outline of the Guide

This Guide comprises 11 chapters. The arrangement and division of these chapters is based on the different types of road slope disasters and the requirements for countermeasures.

Chapter 1 gives the background, purpose, and preparation policy for the Guide. Chapter 2 gives the general classifications, characteristics and main causes of triggering road slope disasters on the national highways. The basic approaches and considerations for each disaster type are also described in this chapter.

Chapters 3 to 9 provide the general criteria for selection of countermeasures and design considerations of the main countermeasures for the seven types of road slope disasters; Soil Collapse (SC), Rock Slope Collapse (RC), Landslide (LS), Road Slip (RS), Debris Flow (DF), River Erosion (RE), and Coastal Erosion (CE). In Chapter 3, the design for standard cut slopes and surface drainage is also introduced. Detailed methods for stability analysis of Landslide disasters in planning countermeasure works are discussed in Chapter 5.

In Chapter 10, examples of countermeasures for various disaster types in the Philippines and Japan are arranged for reference in actual countermeasure planning.

The road slope management activities require simple, quick, and cost-effective treatments for urgent situations in road slope disasters. These methods based on Japanese experience are described in Chapter 11.

CHAPTER 2

BASIC APPROACHES TO THE MITIGATION OF ROAD SLOPE DISASTERS

2.1 Classification of Road Slope Disasters

Previous classifications of road slope disasters were provided in the year 2000 in the "Study on the Preparation of Technical Guidelines for Flood Control". These classifications have been accepted by DPWH for the mitigation and management of road slope disasters.

On the basis of these classifications, each type of road slope disaster is defined below:

a) Landslide - Tends to occur on gentle slopes and is related mainly to weak geology, stratification, faulting and ground water. Rainfall and earthquakes are the main triggers. The movement mass generally starts at the weakest layer and involves a very wide area.

b) Slope Failure - Occurs mostly on steep slopes deteriorated by extensive surface water infiltration. Rainfall and earthquakes usually trigger the falling or crumbling, which characterize slope failures.

c) Rock Fall - No definition or features described at present.

d) Debris Flow/Sedimentation - No definition or features described at present.

e) Embankment Erosion - No definition or features described at present.

f) Bridge Abutment Erosion — No definition or features described at present.

These classifications are generally used for the management of road slope disasters in Japan, and are thus suitable in the Philippines, since both countries share similar geological, topographical and meteorological conditions.

After the first field trip was carried out in April 2006, the JICA Study Team revised and updated the above-mentioned classifications following discussions with the Counterpart Team. The revised classifications are aimed at giving a better understanding of road slope disaster types and selection of countermeasures suitable for each.

The revised classifications establish seven principal disaster types as follow: (1) Soil Slope Collapse (SC), (2) Rock Slope Collapse (RC), (3) Landslide (LS), (4) Road Slip (RS), (5) Debris Flow (DF), (6) River Erosion (RE), and (7) Coastal Erosion (CE). Comparisons between the revised and previous classifications are given in Table 2.1.

Table 2.1 Comparisons between the Revised and Previous Classifications

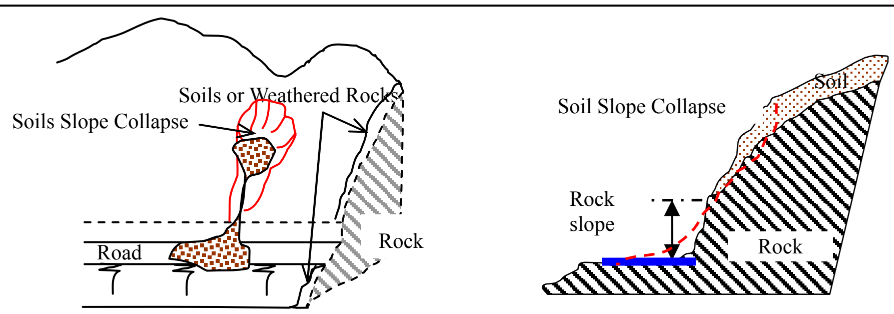
Revised Classification	Previous Classification
Soil Slope Collapse (SC)	Slope Failure
Rock Slope Collapse (RC)	Rock Fall
Landslide (LS)	Landslide
Road Slip (RS)	Similar to Embankment Collapse
Debris Flow (DF)	Debris Flow or Sedimentation
River Erosion (RE)	Similar to Embankment Collapse
Coastal Erosion (CE)	No type assigned

Bridge Abutment Erosion described in the previous classification is excluded in the revised classification, because this phenomenon is dealt with in the BMS.

The seven types of road slope disasters are defined below:

2.1.1 Soil Slope Collapse (SC)

On relatively steep slopes, both natural and artificial, the soil mass becomes unstable and collapses suddenly and quickly into the foot of the road slope. Such sudden and fast failure of soil mass is termed Soil Slope Collapse (Figure 2.1).



(a) Orthographic b) Cross Section

Figure 2.1 Schematic Illustration of Soil Slope Collapse

Soil Slope Collapse can be described as follows:

a) Collapses occur mostly in loose materials such talus deposits, colluvial deposits, residual soil, weathered rock and so on;

b) They are generally precipitated by increasing groundwater and infiltration of run off due to heavy rains or loosening of slopes by earthquakes;

c) The movement is very rapid, and the material is scattered and spread widely, the characteristics of which are quite different from landslides; and

d) Its size is generally small because only the area of loosened soil collapses.

2.1.2 Rock Slope Collapse (RC)

In contrast to soil slope collapse, blocks of solid rock or small-scale rock masses on steep rocky walls or slopes become loosened and fall or collapse to the foot of the road slope. Such a rapid movement of rock blocks or rock mass is referred to as Rock Slope Collapse. It ranges in size from individual rock fall to small-scale rock mass failure (Figure 2.2).

This phenomenon results from structural discontinuities and seepage of water, where the structural discontinuities within the rock mass, such as faults, bedding planes, joints, cracks and so on, control the type and size of the rock slope collapse.

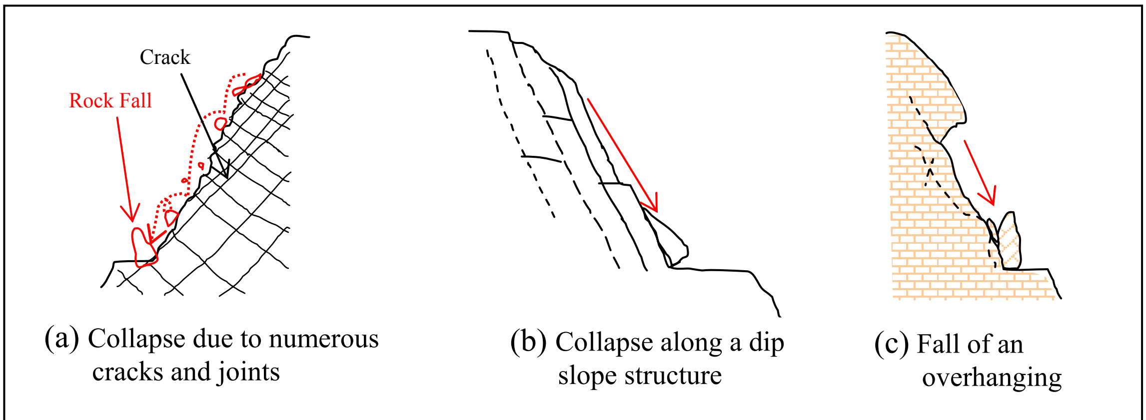


Figure 2.2 Schematic Illustration of Rock Slope Collapse

2.1.3 Landslide (LS)

Landslides, in a narrow sense, are slow, long-term, continuous deformation of slopes underlain by soils or strongly weathered rocks along recognizable sliding surfaces. Landslides have the following general characteristics (Figure 2.3):

a) Landslides occur on gentle slopes and the movements are relatively slow, mostly with continuous and recurrent characteristics;

b) Susceptible geology includes colluvial sediments, weathered rocks and soft rocks;

c) Topographically, the upper part of the landslide slope exhibits a horseshoe-shape or rectangular scarp, and the middle part is a flat and gentle slope. There are concavities, depressions, cracks, etc. or a long and narrow depression in the hill slope or at the top of the mountain.

d) They are triggered by an increase in ground water level as a result of heavy rains or by earthquakes;

e) Prior to occurrence, some signs of deformation on the ground surface are shown, such as cracks, subsidence, bulging, toe collapse, springs and so on; and

f) Its size is generally large in volume and ranges from several thousand to hundreds of thousands of cubic meters.

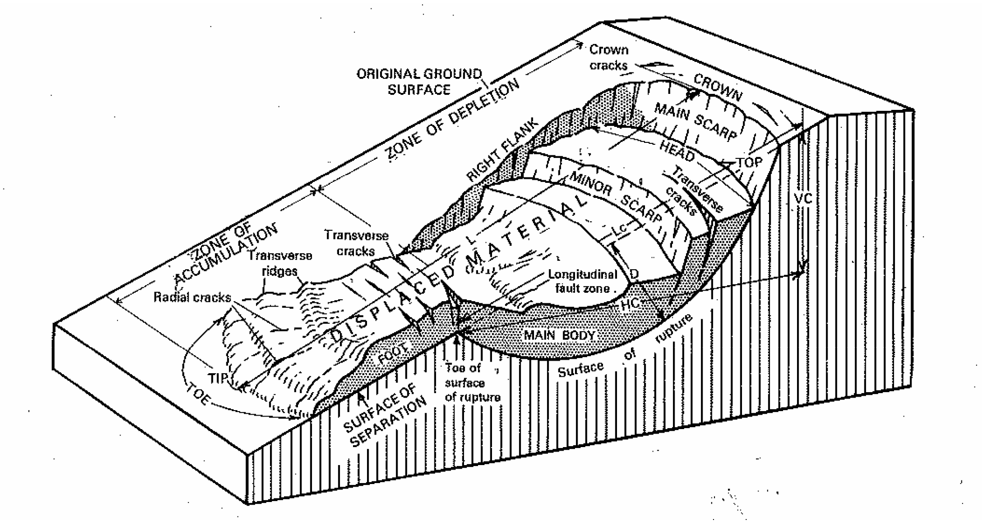


Figure 2.3 Schematic Illustration of Landslides (Varnes 1978)

2.1.4 Road Slip (RS)

Road slips include all types of road shoulder collapses, such as soil slope collapse, embankment erosion and settlement of road surfaces by various causes, scouring of the toe and so on (Figure 2.4).

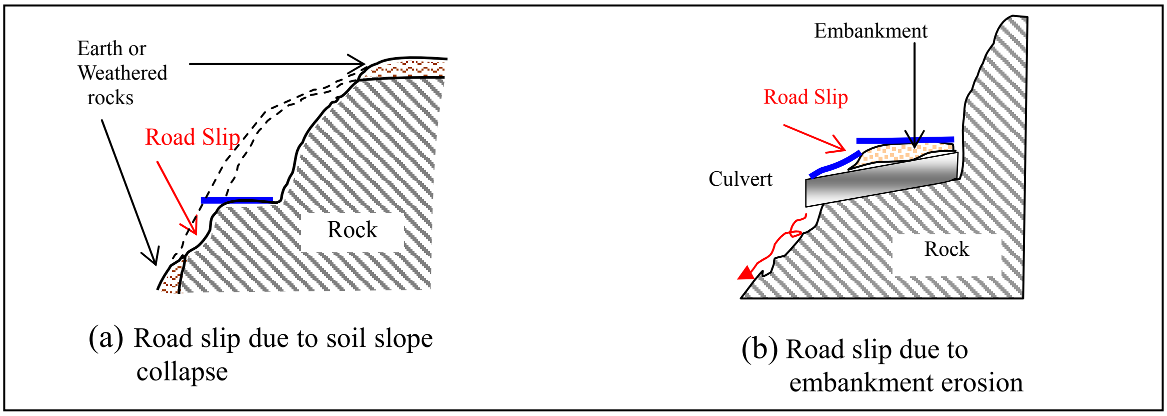


Figure 2.4 Schematic Illustration of Road Slips

2.1.5 Debris Flow (DF)

Debris Flow is the fast movement of rock fragments, earth and mud mixed with water, along a valley or a river (Figure 2.5).

Debris Flow can be characterized by the following descriptions:

a) Debris flows originate from steep slopes and have the following necessary conditions, steep gradient, heavy rain and unstable debris;

b) Source area is upstream of the road slope.

c) Debris flows are caused by heavy rain or earthquakes;

d) Surface water and ground water, to a large extent, influence the speed of debris flow;

e) Speed of debris flow depends on water content, slopes and so on; and

f) The most common form of debris flow is connected with collapse at the head of torrents.

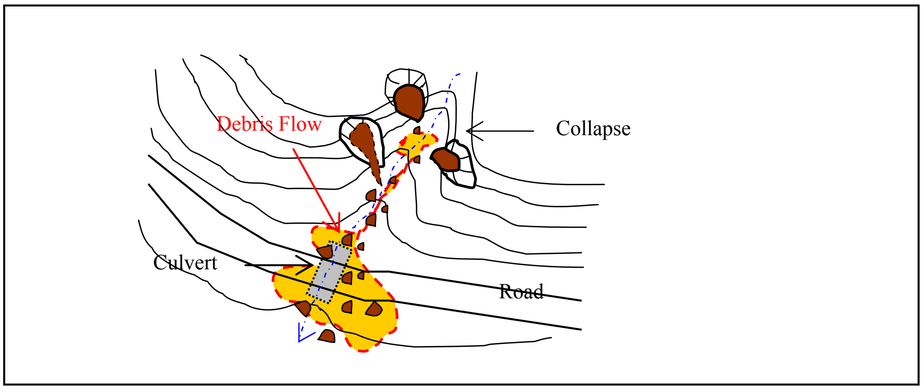


Figure 2.5 Schematic Illustration of Debris Flow

2.1.6 River Erosion (RE)

A lateral erosion and subsequent river bank collapse due to river flow is designated as River Erosion. This phenomenon initiates scouring of the road foundation and enlarges or widens into a riverbank collapse (Figure 2.6).

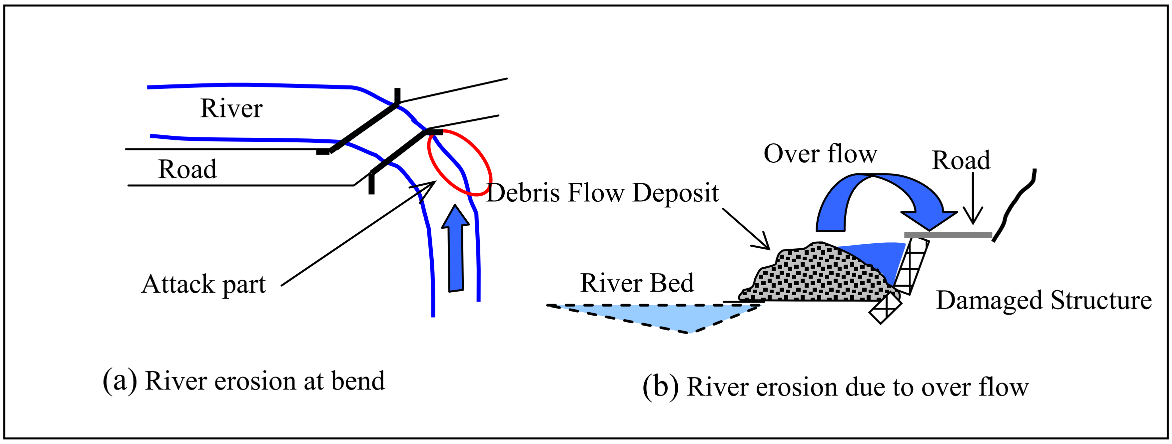


Figure 2.6 Schematic Illustration of River Erosion

2.1.7 Coastal Erosion (CE)

Similar to river erosion, coastal erosion is the erosion and subsequent collapse of coastal cliffs on national highways by the action of ocean waves and currents (Figure 2.7). This phenomenon is especially severe during storms.

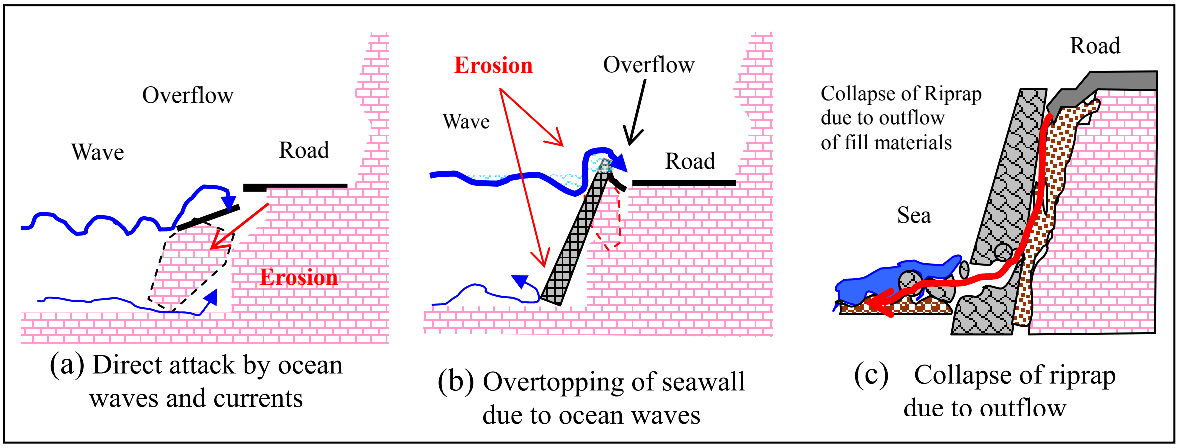


Figure 2.7 Schematic Illustration of Coastal Erosion

2.2 Characteristics of Road Slope Disasters

2.2.1 Soil Slope Collapse

Soil slope collapse is one of the main road slope disaster types along the national highways in mountainous and hilly regions. They occur mostly on road cut slopes, especially on the upper part. Figure 2.8 shows the conditions of soil slope collapses along Mahaplag- Sogod Road, Cebu-Balamban Road and Baguio-Bontoc Road.

The main features of soil slope collapse are summarized below:

a) Soil slope collapse frequently occurs on high cut slopes that are not protected by structures and have a slope gradient of over 50 degrees.

b) The geology of soil slope collapse is mainly loose and erodable sediments, such as residual soil, talus and topsoil.

c) The size of the soil slope collapse is relatively small, generally 10 to 20 m in width and length, 1 to 3 m in depth and less than 100m^3 in volume. Soil slope collapses mostly concentrate on road slopes.

d) Soil slope collapse occurs suddenly and quickly during and after heavy rainfall. Besides loose soil structure, the occurrence trigger is erosion and the infiltration of rainfall, and earthquakes.

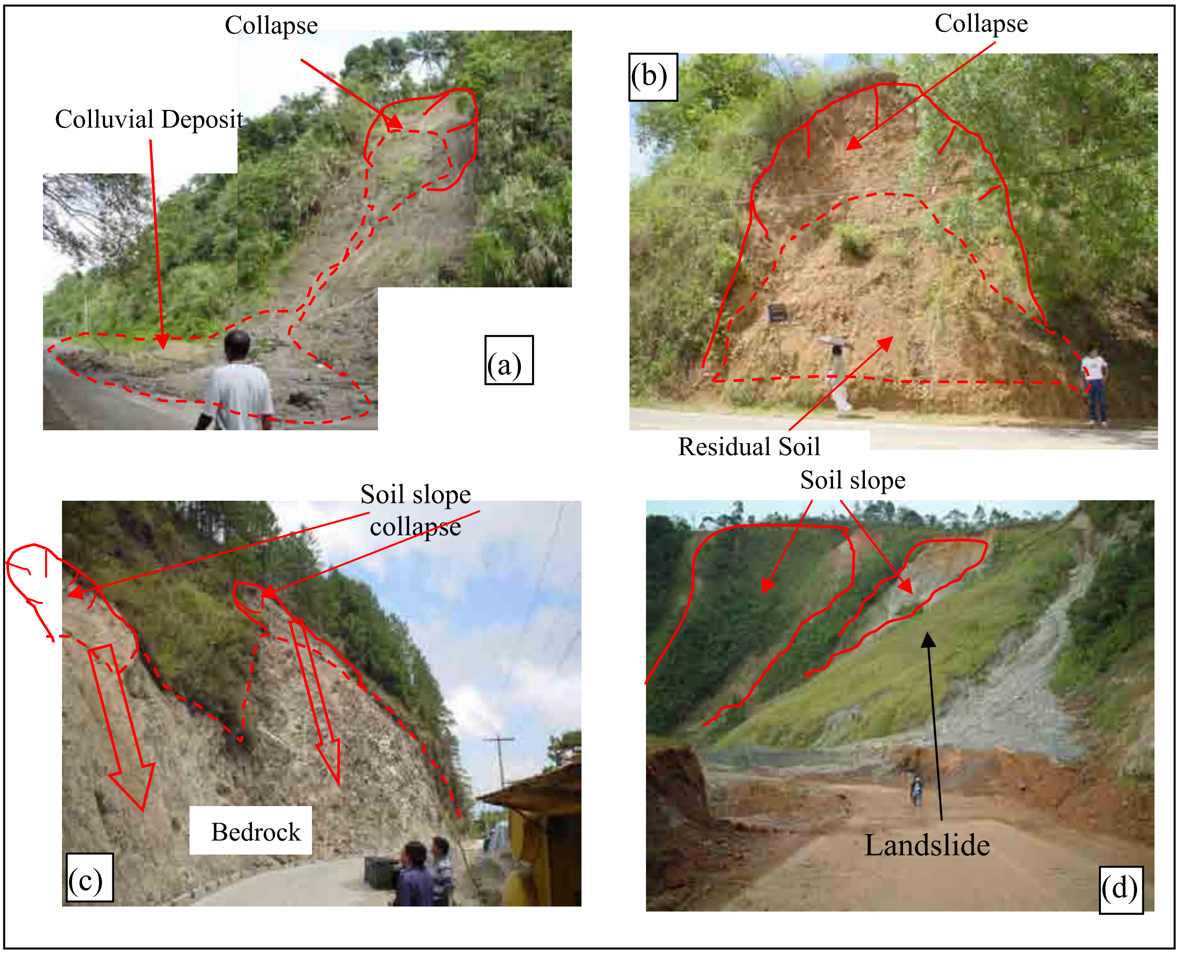


Figure 2.8 Soil Slope Collapses Occurring along the National Highways
(a) Mahaplag-Sogod (km 1006+500), (b) Cebu-Balamban Road (Km 1007+100),
(c) Baguio Bontoc Road (km 281+780), (d) Mahaplag -Sogod Road at Agas-agas.

2.2.2 Rock Slope Collapse

Rock slope collapse occurs mainly on high cut slopes of highly fractured and jointed hard rocks, for example, Kennon Road, Marcos Highway, Lagawe-Banaue Road, Dalton Pass, Cebu-Balamban Transcentral Highway and Wright-Taft Road (Figure 2.9).

The main features of rock slope collapse are summarized below:

a) Rock slope collapse occurs chiefly on steep and high rock slopes, either cut or natural.

b) The majority of rock slope collapses are associated with highly fractured and jointed hard rocks, such as limestone, volcanic rock and phyllite.

c) Its size is generally less than 10 m^3, occasionally over 100 m^3 in volume.

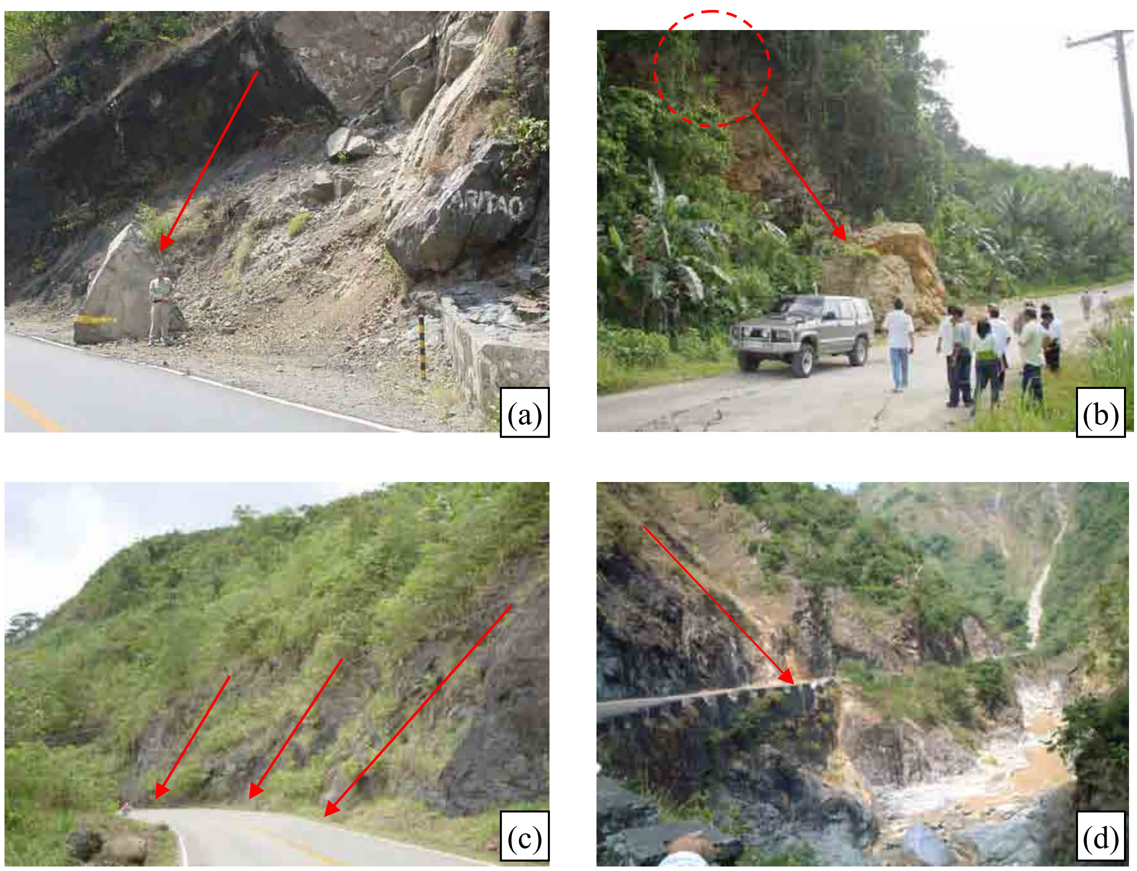


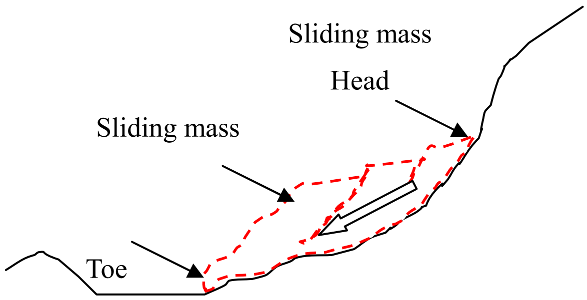
Figure 2.9 Rock Slope Collapses Occurring along the National Highways
(a) Kenon Road (Km 846+050), (b) and (d) Kennon Road, (c) Cebu- Balamban Transcentral Highway (Km 1027)

d) Failure modes are free fall, rolling down the slope or sliding along the slope.

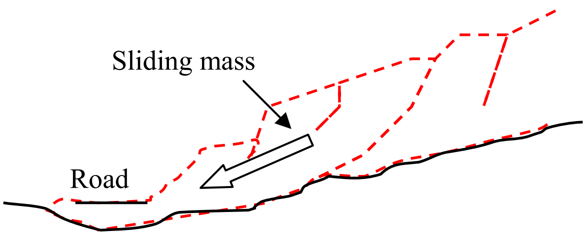
e) The toe erosion and weathering of steep slopes, causing the gradual opening of tension cracks, is believed to be the mechanism by which most rock slope collapses are produced. Rock slope collapses occur mostly during intense rainfall and/or earthquakes, which appear to be the major triggers.

2.2.3 Landslides

Landslides are the most frequently observed road slope disasters along the national highways, especially on the Banaue-Lagawe and Mahaplag-Sogod Roads. These landslides severely threaten or damage the traffic function as shown in Figure 2.10.



(a) Landslide on the Banaue-Lagawe Road
(Km334+157)



(b) Landslide on the Banaue-Lagawe Road
(Km301+200)

Figure 2.10 Examples of Actual Landslides

Besides the general features described above, landslides have the following characteristics:

a) Landslides occur chiefly on relatively gentle slopes, both natural and cut, of less than 30 degrees.

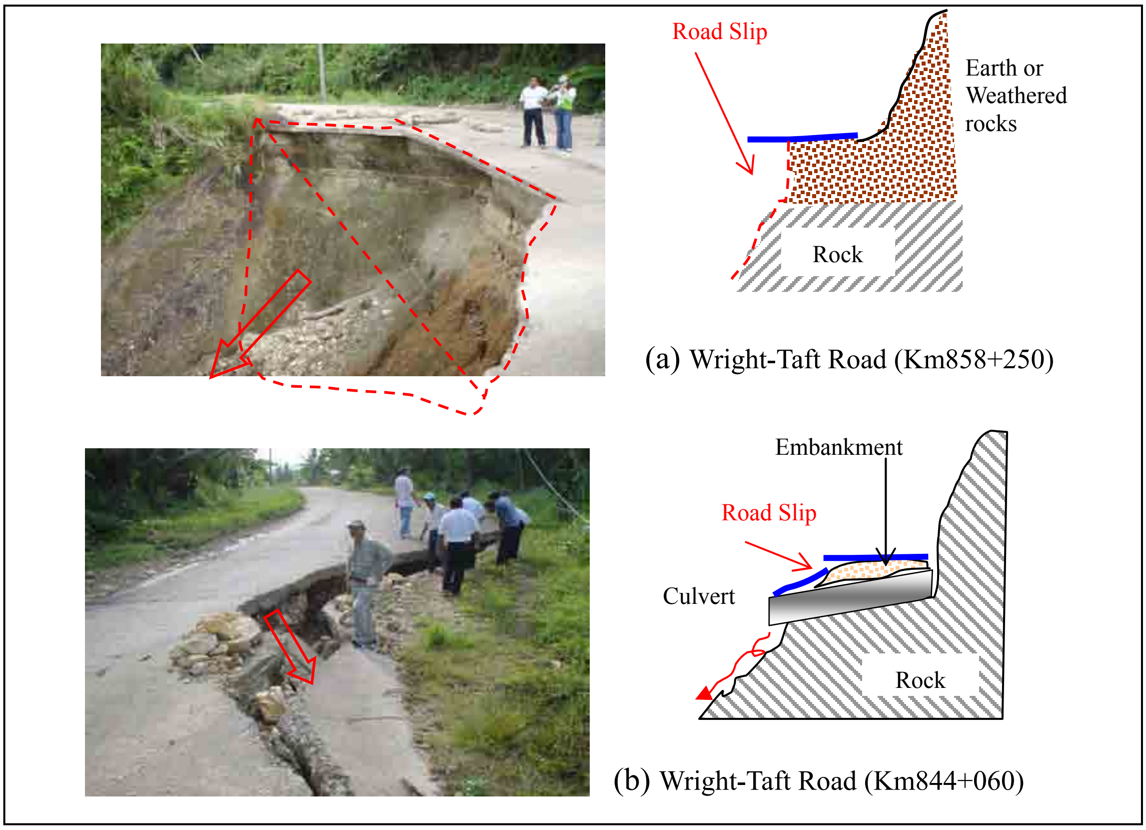
b) Landslides are concentrated mainly on soil slopes and soft rock slopes.

c) Landslides, in most cases, occur over relatively wide areas and are estimated to be 10^4 m^3 to 10^6 m^3 in volume.

d) They frequently occur or are activated during a rainfall. The infiltration of rainfall, causing a temporary rise in pore water pressure and the resulting reduction in shear resistance, is considered to contribute to occurrence of landslides.

2.2.4 Road Slips

Road slips are also common along the national highways and they severely affect the traffic function, as shown in Figure 2.11.



(a) Wright-Taft Road (Km858+250)

(b) Wright-Taft Road (Km844+060)

Figure 2.11 Examples of Actual Road Slips

The main features of road slips are summarized below:

a) Road slips have the following three failure modes: 1) Collapse of the valley side slope, 2) Scouring of the valley side slope due to inappropriate drainage, and 3) Road body settlement.

b) Road slips may occur abruptly after heavy rainfall, but such indications as local deformation or settlement of the road shoulder are observable prior to complete collapse.

c) Road slips, in most cases, are less than 50m in width and occur on steep slopes on the valley side.

d) Road slips mostly occur in places where surface water concentrates during heavy rainfall, in some cases this is due to inappropriate design or construction of the wall foundation, subsurface drainage (leakage of water), insufficient road compaction, or insufficient drainage facilities.

2.2.5 Debris Flow

Debris flows are infrequent along the national highways. Some have occurred in hilly regions as shown in Figure 2.12.

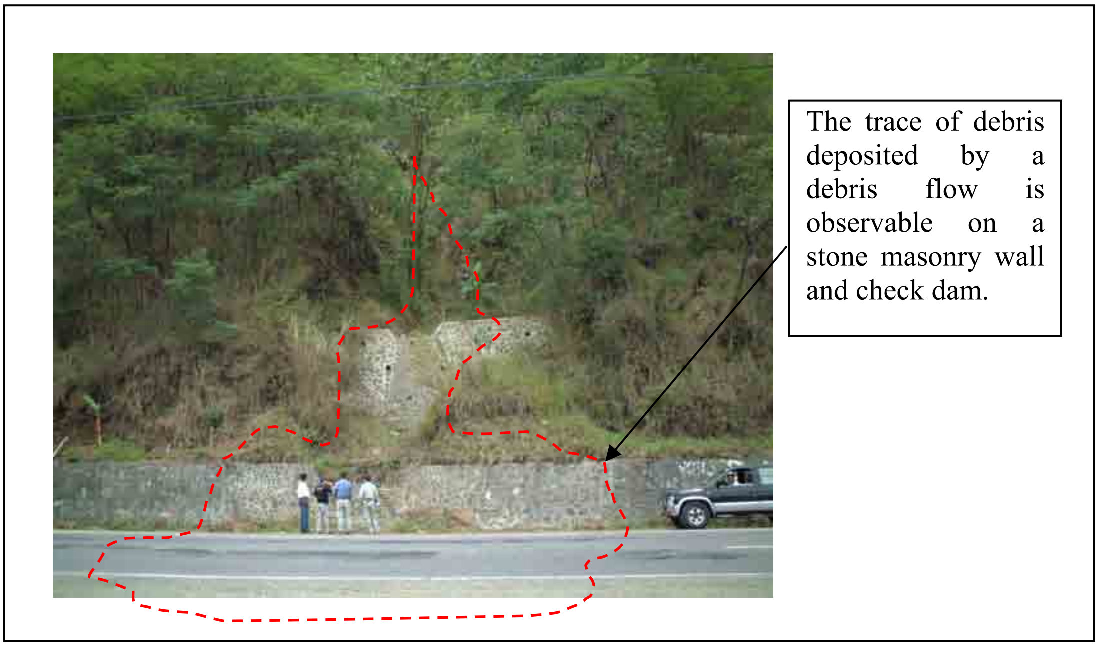


Figure 2.12 Example of Debris Flow on Dalton Pass in Nueva Viscaya

2.2.6 River Erosion

River erosions occur on embankments or natural bank slopes along the national highways (Figure 2.13). The main features of river erosions are summarized below:

a) River erosions are concentrated on outer bends, especially where the river meanders through the slope.

b) The occurrence of river erosions is due firstly to bank erosion, secondly to riverbed erosion, and thirdly to the change of river course towards the bank and the rising of the river water level as a result of the accumulation of debris flow sediments.

c) River erosions are of a smaller scale, generally less than 50 meters in length.

Kennon Road 215km＋132

Mahaplag-Sogod Section

Figure 2.13 Examples of River Erosion

2.2.7 Coastal Erosion

Coastal erosions are observable, especially along the Ginalitan-Alegria Road between 143km and 180km, as shown in Figure 2.13.

The main features of coastal erosions are summarized below:

a) Coastal erosions initiate scouring of the foundation or out flowing of backfill material by the action of ocean waves and currents, consequently leading to road slip, road body settlement, or wall collapse.

b) The phenomenon is associated mainly with soil slopes, strongly weathered rocks and highly fractured limestone.

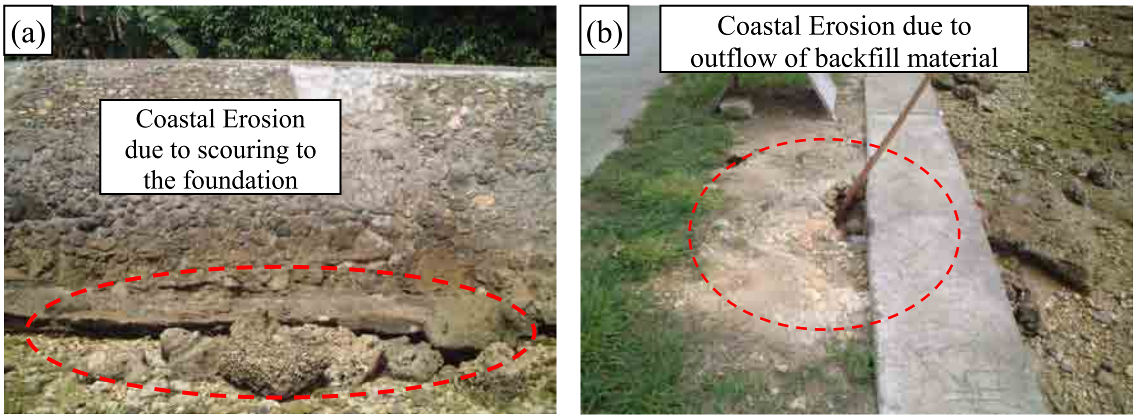


Figure 2.14 Examples of Coastal Erosion on the Ginalitan-Alegria Road
(a) at Km177+700, (b) at Km 177+910

2.3 Main Factors Causing Road Slope Disasters

Slope instability is a result of both causative factors and slope characteristics, such as slope height, slope gradient, geology, topography, surface water, groundwater, etc. Many factors influence the development of road slope disasters, as listed in Table 2.2. These factors cause slope instability either by increasing shear stress or by reducing shear strength.

Table 2.2 Factors Causing Slope Instability

Types		Typical Factors
Increase of Shear Force	1. Removal of lateral support	- Stream undercut, rainfall, sea waves, or glacial erosion - Weathering, wetting/drying, and frost action - Slope gradient increased by slope collapse, uplift of land, volcanic and fault activities - Artificial soil work: Quarries, pits, cutting, etc.
	2. Overloading	- Weight of rainfall infiltration, new talus deposit, collapse mass. - Embankment structures.
	3. Transitory stresses	- Earthquake. - Vibration.
	4. Lateral pressure	- Pore pressure in cracks, fissures, etc. - Freezing of water. - Swelling by hydration of clay and clay minerals.
Reduction of Shear Strength	1. Reduction of strength	- Weak and sensitive materials such as volcanic tuff and sedimentary clays. - Easily weathered materials or jointed materials such as mudstone, shale, and so on. - Loosely consolidated materials such as talus. - Easily liquefied materials such as sand or silt deposits.
	2. Physico-chemical reaction	- Cation exchange. - Hydration of clay. - Drying of clays.
	3. Vegetation	- Removal of trees, reducing normal loads and apparent cohesion of tree roots.

CHAPTER 3

COUNTERMEASURES AGAINST SOIL SLOPE COLLAPSE

3.1 General

Soil slope collapse, as defined in Chapter 2, is failure of a soil slope. They tend to occur suddenly on relatively steep slopes. This chapter provides general policy and basic procedures for the stabilization of soil slopes, mitigation of soil slope collapse, and design considerations for main countermeasures against soil slope collapse.

In addition, the design procedures and considerations of countermeasures against landslides given in Chapter 5 of this Guide III may also be applied to the stabilization of soil slope collapses.

3.2 General Policy for Stabilization of Soil Slopes

Soil slope collapses, especially soil cut slope collapses, are common along the national highways. Frequent occurrences of soil slope collapse are due mainly to inappropriate design and construction of cut slopes and slope protection works in addition to steep topography, fragile geology, heavy rainfall and frequent earthquakes.

Of all of these causes, the greatest cause of soil slope collapses is the action of water. The collapse of soil slope induced by water can be subdivided roughly into two types: surface erosion due to slope surface water and collapse due to the increase in pore water pressure or the decrease in shearing strength of soils forming the slope by scouring and water seepage. It is thus extremely important to take appropriate measures against water to secure slope stability.

In order to prevent the road slope disasters related to soil slope collapse, the general policies for the stabilization of soil slopes are structured in consideration of (a) degree of safety, (b) construction cost, (c) appearance, and 4) construction workability, and are as follows:

a) Design of standard slope (cut and fill);

b) Drainage (surface water); and

c) Slope protection (structural).

3.3 Design of Standard Slope (Cut Slope)

This section focuses on the design of standard cut slopes because soil slope collapses frequently occur in cut slopes along the national highways, and, compared to cut slopes, it is easier to determine the proper design section of fill slopes, which are generally formed by homogeneous fill materials.

3.3.1 Standard Gradients of Cut Slopes

A stable cut slope is generally designed according to the standard values of the gradient of slopes, as listed in Table 3.1, due to the following:

a) Natural ground is extremely complicated and not uniform in its properties;

b) Cut slopes tend to gradually become unstable over time after completion of work; and

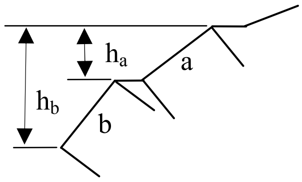
c) It is difficult to determine the proper design section of cut slopes by stability calculations.

Table 3.1 Geometric Standards for Cut Slopes

Character of soil or bedrock		Cut slope height (m)	Gradient (i=V:H)
Hard rock			1:0.3 ~ 1:0.8
Soft rock			1:0.5 ~ 1:1.2
Sand	Sand that is not solid or dense and has poor grade distribution.		1:1.5 ~
Sandy soil	Soils that are dense and solid.	Less than 5 m	1:0.8 ~ 1:1.0
		5~10 m	1:1.0 ~ 1:1.2
	Soils that are not dense and solid.	Less than 5 m	1:1.0 ~ 1:1.2
		5~10 m	1:1.2 ~ 1:1.5
Sandy soil mixed with gravel or rock	Soils that are dense and solid or of good grade distribution.	Less than 10 m	1:0.8 ~ 1:1.0
		10~15 m	1:1.0 ~ 1:1.2
	Soils that are not dense or solid or are of bad grade distribution.	Less than 10 m	1:1.0 ~ 1:1.2
		10~15 m	1:1.2 ~ 1:1.5
Cohesive soil		Less than 10 m	1:0.8 ~ 1:1.2
Cohesive soil mixed with rock or cobble stones		Less than 5 m	1:1.0 ~ 1:1.2
		5~10 m	1:1.2 ~ 1:1.5

Notes: (1) Silt is included in the category of cohesive soil.
(2) Individual consideration is given to soils not indicated in the above table.
(3) When a single gradient can not opted for because of the soil composition or other reasons, the cut slope height and gradient are determined on the basis of the following considerations.

Source: Modified from Reference No.1 Highway Earthwork Series, MANUAL FOR RETAINING WALLS, Published by Japan Road Association, March 1999.



h_a: Cut slope height for slope surface a

h_b: Cut slope height for slope surface b equals the height of a plus the height of b

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

The standard values of the gradient of slopes, as shown in Table 3.1 have been empirically determined on the basis of geological conditions and at the standard values, cut slopes remain stable over the long-term with simple slope protection works such as vegetation.

As shown in Table 3.1, the gradient of cut slopes varies depending on the geology of the cut slope. Where the geology and soil of a cut slope varies considerably and is complicated, a single gradient of cut slope suited to weaker soil is used even though this is somewhat uneconomical. Figure 3.1 gives a schematic diagram of a cut slope relating to different geology.

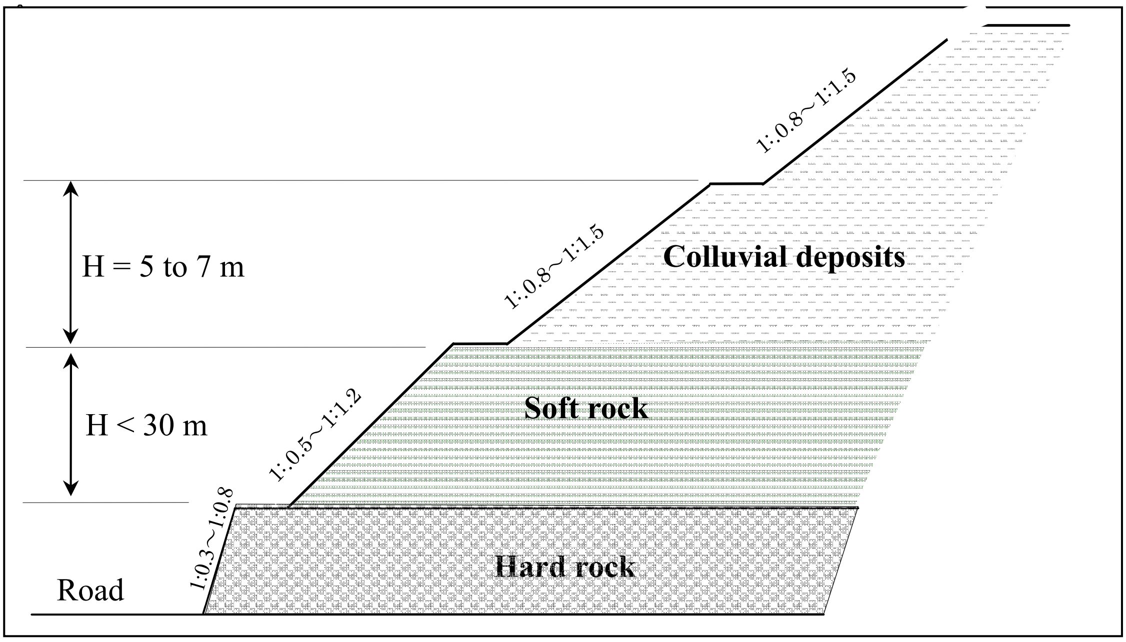


Figure 3.1 Conceptual Illustration of a Cut Slope

3.3.2 Berms of Cut Slopes

On the cut slopes, berms 1.0 to 2.0 m wide are generally provided for every 5.0 to 7.0 m in height for the following purposes:

a) To reduce speed of the surface water flow on the cut slopes, thereby decreasing scouring force on the cut slopes;

b) To provide a place for the installation of drainage ditches; and

c) To be used as sidewalk for inspection or as scaffolding for repair works.

A wider berm is recommended where the slope is long and large or where rock fall protection fences are to be installed.

3.3.3 Survey Checkpoints for Cut Slopes

Careful surveys on the stability of back slopes should be conducted prior to cutting. When the potentially unstable areas above the cut sites are large, cutting should be abandoned.

The main checkpoints of the surveys for cut slopes are as follows:

a) Stability of cut slope;

b) Average gradient of adjacent natural slopes;

c) Danger of landslide, soil slope collapse, or rock fall from the top of cut slopes;

d) Change of groundwater level in adjacent areas due to excavation; and

e) Geotechnical properties of the ground to be excavated.

A survey plan should be made for reviewing and determining measures for each item listed above.

3.3.4 Cut Requiring Caution

In designing cut slopes, the following geological conditions are to be considered with the utmost care:

a) Colluvial deposit slopes. Colluvial deposits such as talus or trace of volcanic mudflow have a low solidification and, usually form a slope with a critical angle of stability. When excavated, such cut slopes will become unstable. For this reason, a wide step near the boundary line between bedrock and the upper colluvial deposit should be planned (Figure 3.2).

b) Erodible sandy soil. Sandy soils such as weathered granite and terrace gravel layers are easily eroded by surface water, resulting in small shallow collapses.

c) Weatherable soft rocks. Cut slopes of soft rocks such as mudstone and tuff, will become unstable after cutting because of stress release, etc.

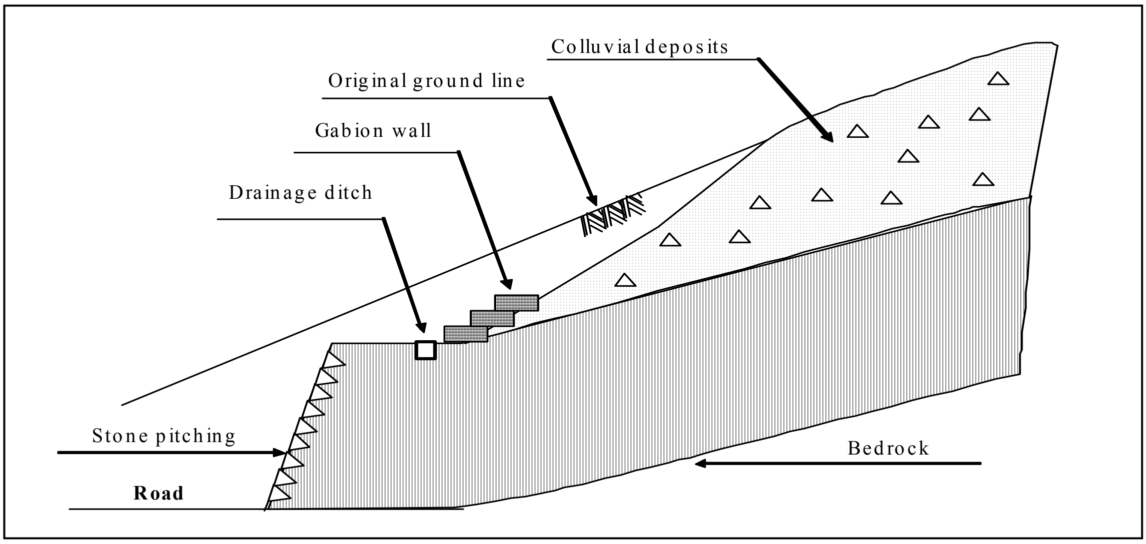


Figure 3.2 Countermeasures against Soil Slope Collapse

To prevent erosion subsequent to cutting, protection for the foot of the slope as well as for the cut slope itself should be considered. When it is unavoidable to form a cut slope with a gradient steeper than the standard gradient, the slope must be protected by a retaining wall or anchor works.

3.4 Surface Drainage

If the road slope drainage or associated road drainage systems are not properly designed and maintained, then the surface runoff will overflow onto the roads. If this surface runoff is not drained in time, water may overflow to the downhill areas and cause serious road slope disasters. Slope drainage facilities should be designed to prevent both surface erosion and the collapse of soil slopes.

3.4.1 Design Conditions

The surface drainage shall be designed with the following considerations: rainfall intensity, topography, ground surface conditions, soils, groundwater conditions, and existing drainage systems. The main factor in determining the capacities of drainage facilities is generally the runoff due to rainfall. The selection of the kind and sizes of the drainage facilities is based on hydraulic calculations.

The design conditions for surface drainage are as follows:

a) The calculation of runoff due to rainfall is based on the following Rational Method:

$$Q\ (m^3/sec) = 0.2778 \times 10^{-6} \times f \times I_T \times a \quad \cdots\cdots (3.1)$$

Where, Q: Runoff (m^3/sec)

f= Coefficient of runoff (referring to Tables 3.2 and 3.3),

I_T= Rainfall intensity within time of concentration (mm/h),

a= Catchment area (m^2),

Table 3.2 Coefficients of Runoff by Ground Surface Conditions

Ground surface condition		Coefficient of runoff
Road surface	Pavement	0.70 ~ 0.95
	Gravel road	0.30 ~ 0.70
Shoulder, slope, etc.	Fine-grained soil	0.40 ~ 0.65
	Coarse-grained soil	0.10 ~ 0.30
	Hard rock	0.70 ~ 0.85
	Soft rock	0.50 ~ 0.75
Grass on sandy soil	Gradient 0 to 2%	0.05 ~ 0.10
	Gradient 2 to 7%	0.10 ~ 0.15
	Gradient more than 7%	0.15 ~ 0.20
Grass on clayey soil	Gradient 0 to 2%	0.13 ~ 0.17
	Gradient 2 to 7%	0.18 ~ 0.22
	Gradient more than 7%	0.25 ~ 0.35
Ridges		0.75 ~ 0.95
Intermediate areas		0.20 ~ 0.40
Parks with abundant lawns and trees		0.10 ~ 0.25
Mountainous areas with gentle slopes		0.30
Mountainous areas with steep slopes		0.50
Paddy fields, water surface		0.70 ~ 0.80
Fields		0.10 ~ 0.30

Source: Modification from reference No.2 Highway Earthwork Series, MANUAL FOR DRAINAG WORKS, Published by Japan Road Association, June 1987.

Table 3.3 Standard Probable of Rainfall Return Period to be Applied

Degree of drainage capacity to be anticipated	Rainfall Return Period	
	(a)	(b)
High	3 years	More than 10 years
Normal	2 years	7 years
Low	1 year	5 years

Notes: (a) is applied to ordinary drainage structures such as the ones on road surfaces and on small-scale slopes.
(b) is applied to important drainage structures, for example, drainage structures crossing roads and draining water from large natural slopes.

b) The rainfall intensity within the time of concentration is empirically obtained from the following Monobe equation or from the rainfall intensity versus rainfall duration curve:

I_T (mm/h) = R24/24 $\times$ $(24/T)^{2/3}$ ·························· (3.2)

Where, R_{24}= Daily rainfall (mm),

I_T (mm/h)=the mean rainfall intensity in a period of time T,

T= Rainfall concentration time (hour)

c) The rainfall concentration time T can be estimated by the following Rziha formula:

T_a (sec) = 1/20 $\times$ $L/(H/L)^{0.6}$ ·························· (3.3)

Where, L= Length of the rainfall path (m),

H= Difference of the elevation between the top of the catchment area and the end of the flood path (m).

d) The design section of the drainage structures should be more than 120% of the sectional area required to discharge the design storm in order to compensate for a reduction of cross-section area due to soil sedimentation in the drainage structures:

3.4.2 Design of Surface Drainage

(1) Classification of surface drainage facilities

The classification of the surface drainage facilities relevant to road cut slopes are as follows, and as shown schematically in Figure 3.3.

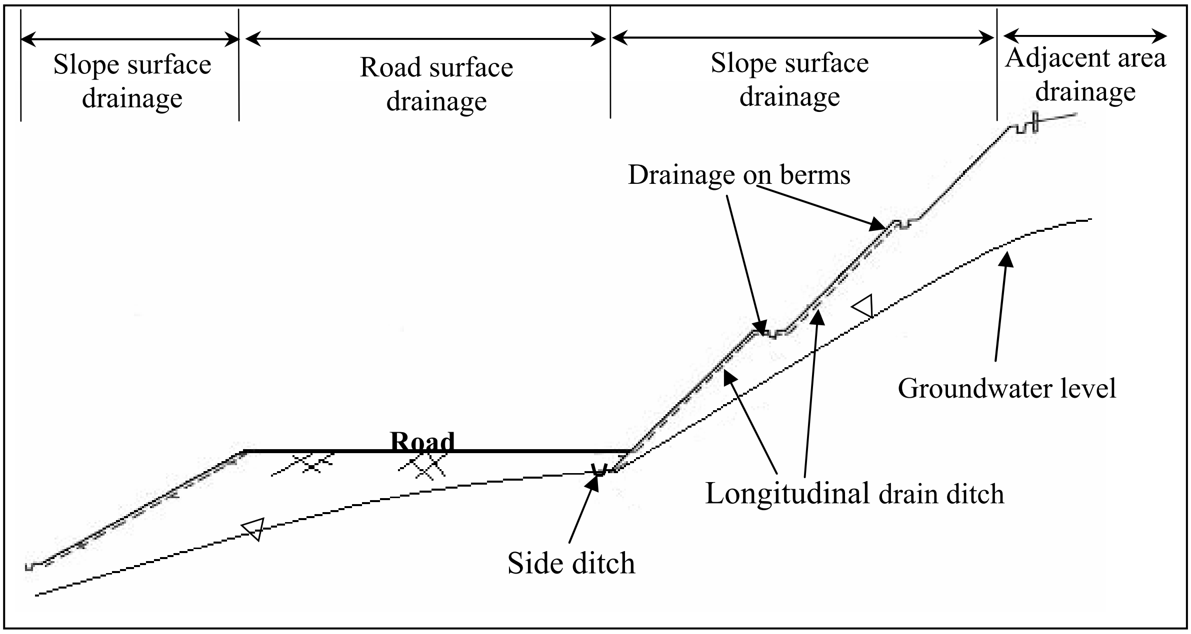


Figure 3.3 Classifications of Surface Drainage Facilities

(2) Horizontal drainage ditches

Horizontal drainage ditches or berm drainage ditches shall be designed to prevent slope surface erosion caused by rainfall or spring water.

The drainage ditches shall be constructed using soil cement mixtures, reinforced concrete U-shaped gutters or be of the unsupported types. Figure 3.4 gives the structural image of a horizontal or berm drainage ditch.

These ditches shall be installed close to the toe of the slope to prevent the flow of water at the back or sides of the ditch.When berm drains are provided, the width of the berm should be greater than 1.5m.

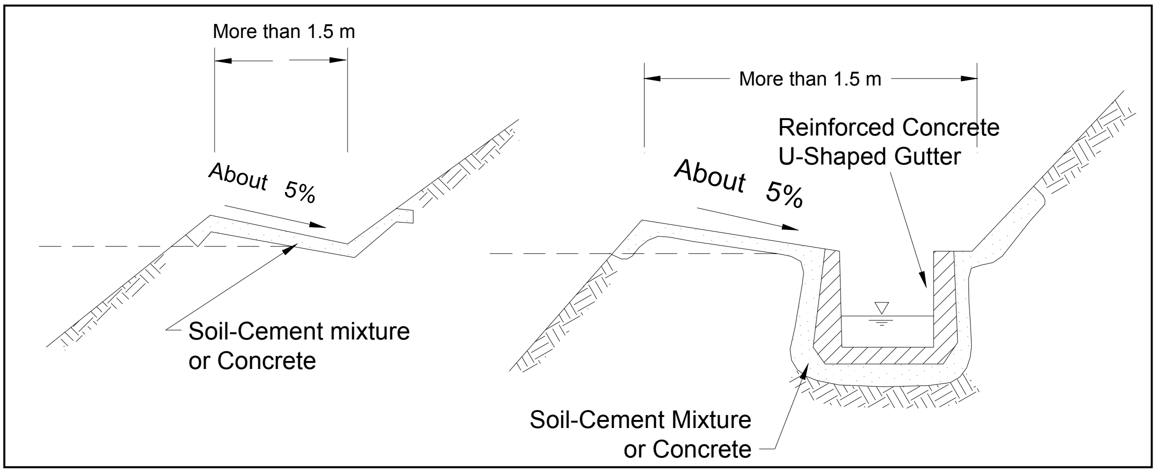


Figure 3.4 Details of Berm Drainage Ditches

Source: Reference No.8 Technical Standards and Guidelines for Planning and Design, Volume IV, NATURAL SLOPE FAILURE COUNTERMEASURES, Project for the Enhancement of Capability in Flood Control and Sabo Engineering of DPWH, March 2002.

(3) Longitudinal drainage ditches

Longitudinal drainage ditches shall be designed to guide the water from a ditch at the top of a slope or berm to a proper channel at the toe of the slope.

The longitudinal drainage ditches are generally constructed using reinforced concrete U-shaped gutters, reinforced concrete pipes, or are stone-pitched (ladder type) channels. An example is shown in Figure 3.5.

At places where the direction of the flow changes drastically or where the longitudinal drainage ditch meets other waterways, a collecting basin with covers and simple sediment pit should be installed to reduce the energy of the running water. In principle, longitudinal drainage ditches are installed under the following conditions (Figure 3.6);

a) Slopes are wider than 100 meters; and

b) On valley-shaped slope, rainfall water is expected to flow in from the upper slope.

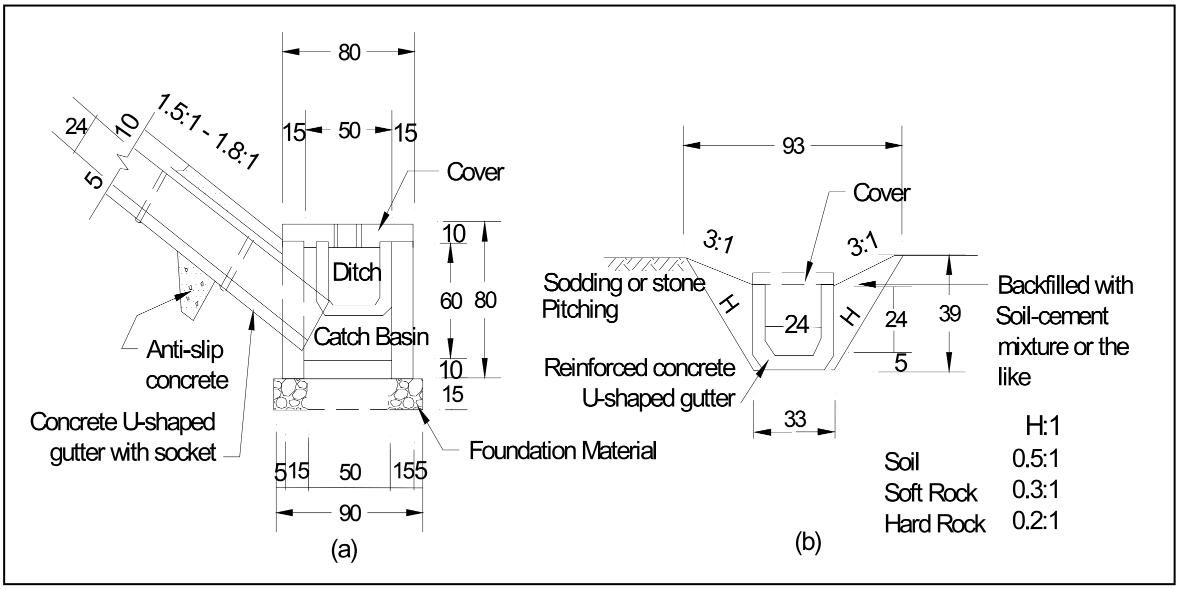


Figure 3.5 Structural Image of Drainage Ditch

Source: Reference No.8 Technical Standards and Guidelines for Planning and Design, Volume IV, NATURAL SLOPE FAILURE COUNTERMEASURES, Project for the Enhancement of Capability in Flood Control and Sabo Engineering of DPWH, March 2002.

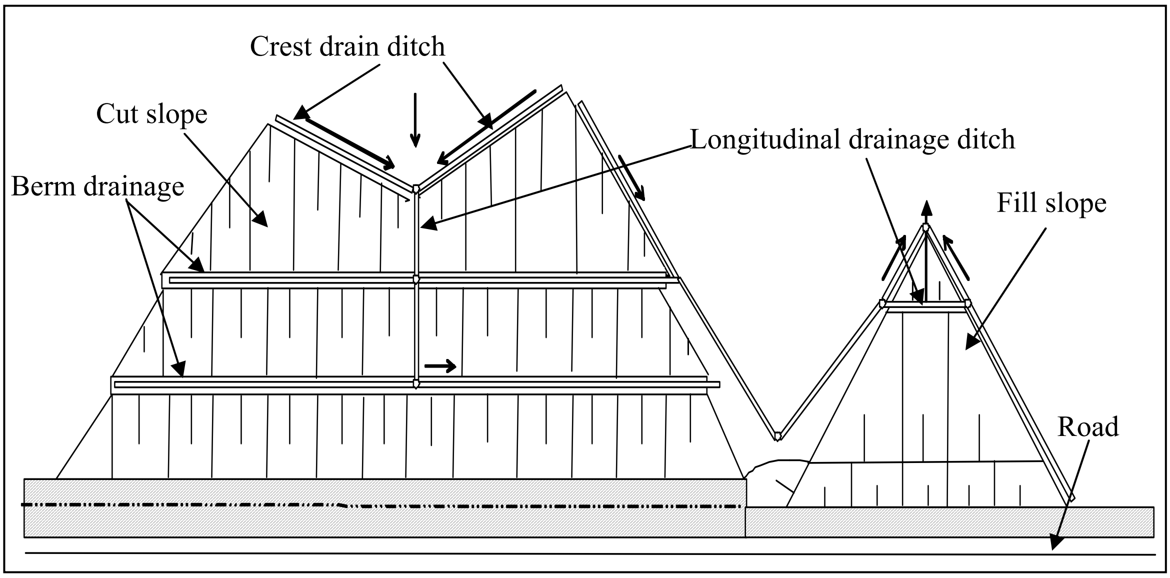


Figure 3.6 Example of Drainage Ditch Layout

(4) Drainage ditches at the top of a slope

Drainage ditches for the top of the slope shall be installed along the top of the slope to prevent flow of surface run-off from adjacent areas onto the slope.

The size of the ditch along the top of the slope shall be determined according to the amount of runoff due to rainfall. The ditches shall be constructed using soil cement mixture, stone pitching, etc. Figure 3.7 gives a structural image of a drainage ditch made with a soil-cement mixture.

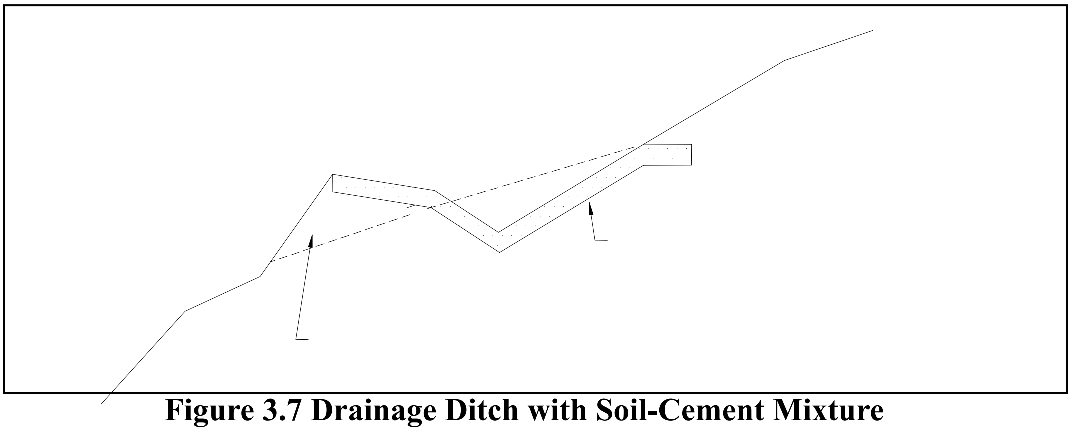


Figure 3.7 Drainage Ditch with Soil-Cement Mixture

Source: Reference No.8 Technical Standards and Guidelines for Planning and Design, Volume IV, NATURAL SLOPE FAILURE COUNTERMEASURES, Project for the Enhancement of Capability in Flood Control and Sabo Engineering of DPWH, March 2002.

3.5 Selection of Countermeasures

3.5.1 Classification of Countermeasures

The main countermeasures against soil slope collapse are classified into seven categories in terms of their functions and purposes, as listed in Table 3.4.

Table 3.4 Classification of Countermeasures against Soil Slope Collapse

CLASSIFICATION		TYPE OF WORK
1. EARTH WORK	Earth Work	Cutting and Recutting
		Filling and Refilling
2. VEGETATION	Vegetation	Hydroseeding
		Vegetation
3. DRAINAGE	Surface Drainage	Drainage Ditches and Channels
	Subsurface Drainage	Culverts
		Horizontal Drain Holes
		Drainage Wells
4. SLOPE WORK	Pitching Work	Stone Pitching
	Shotcrete Work	Shotcrete (mortar and concrete)
	Crib Work	Crib Work (Precast)
5. ANCHORING	Anchoring	Rock Bolts with Concrete Crib Work
		Ground Anchors
6. WALL AND RESISTING STRUCTURES	Retaining Walls	Gabion Walls
		Stone and Concrete Block Masonry Walls
		Concrete Retaining Walls
	Catch Work	Catch Walls and Catch Embankments
7. PILING WORK	Piling Work	Steel Pipe Piles
		Concrete Piles

3.5.2 Criteria for Selection of Countermeasures

Figure 3.8 shows a flowchart for the selection of adequate and effective countermeasures to prevent soil slope collapse. Considerations include the anticipated causes, shape, mechanism, and size of the collapse, as well as the appearance of the structure.

Drainage works, especially surface drainage works, shall be given priority regardless of the results of the stability analyses.

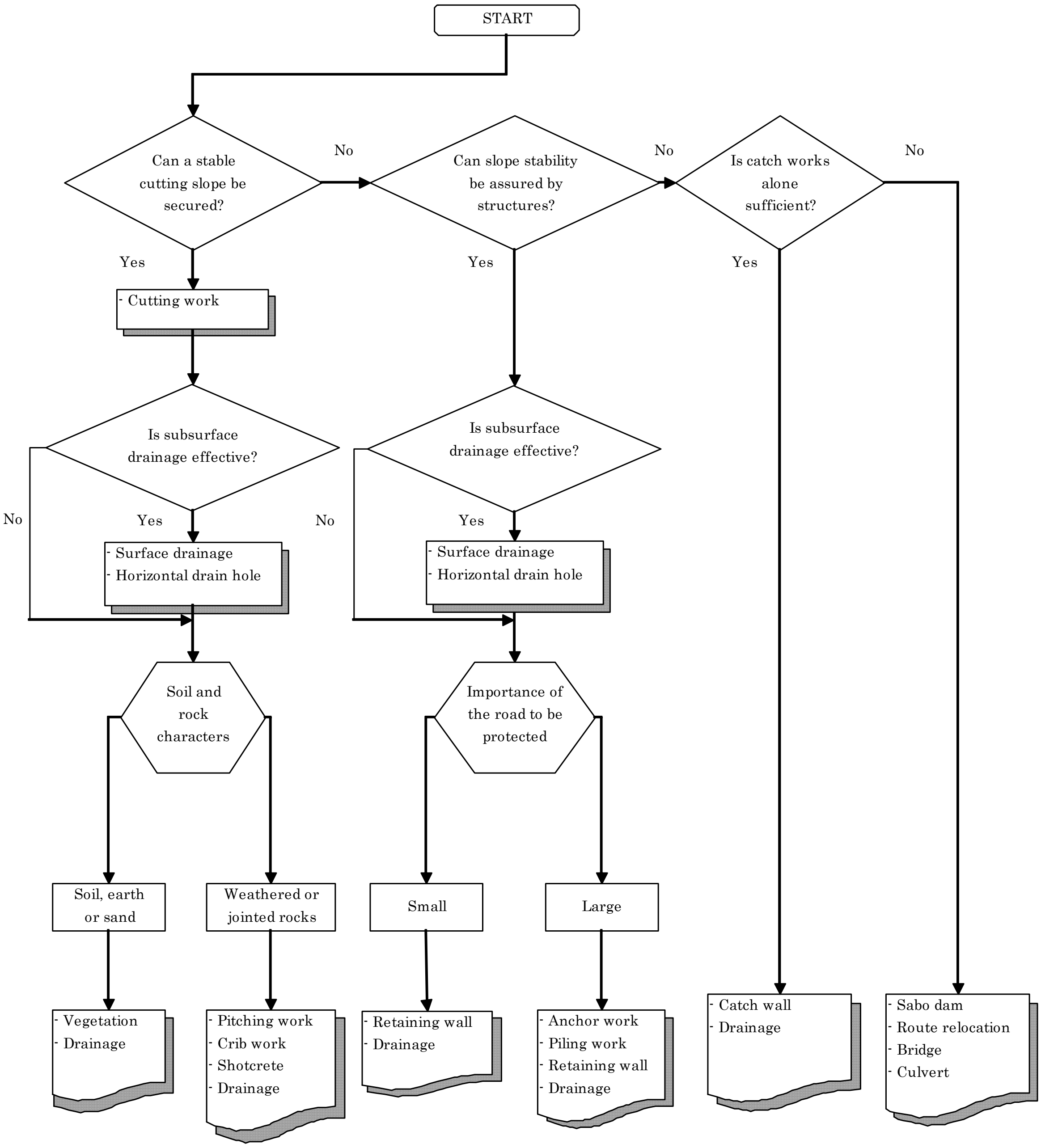


Figure 3.8 Selection Flowcharts for Countermeasures against Soil Slope Collapse

Generally, the following criteria shall be used for the selection:

a) Wherever possible, cutting or re-cutting work is prefered. In planning cutting work, slope stability and harmony with the surrounding environment should be considered (Figure 3.9);

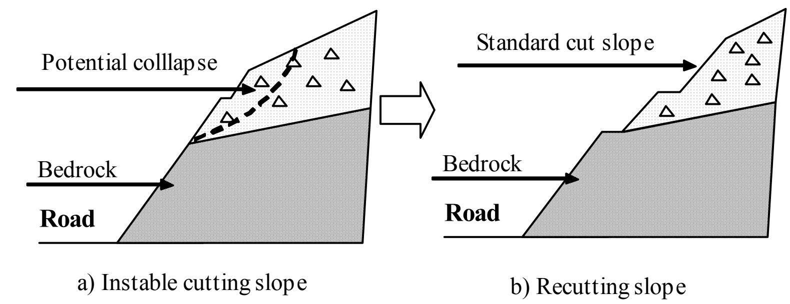


Figure 3.9 Schematic Diagrams for Re-cutting Slope

b) In principle, surface drainage work is considered positively. Subsurface drainage work is adopted if spring water exists during normal times and/or rainfall, or a depression exists near the top of the slope;

c) Whenever the slope gradient and soil conditions will allow vegetation to grow, it shall be used to prevent erosion due to rainfall. Where slopes are unsuited to vegetation, pitching work, shotcrete work, and crib work shall be considered;

d) Retaining walls are selected if the foot of a slope must be stabilized or if it is to be used as the foundation for other measures (Figure 3.10);

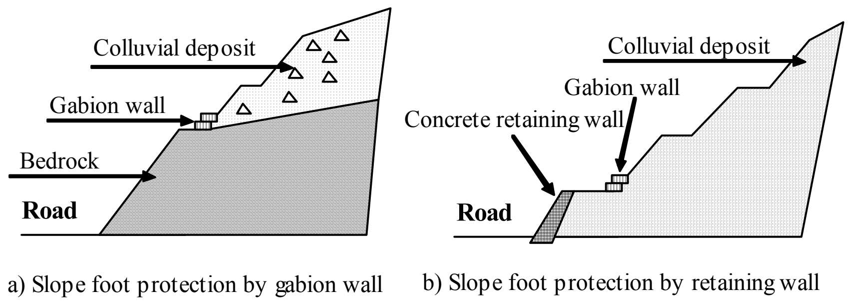


Figure 3.10 Schematic Diagram of Slope Foot Protection

e) Even though costly, anchoring or piling should be planned if other methods are not expected to control soil slope collapse (Figure 3.11);

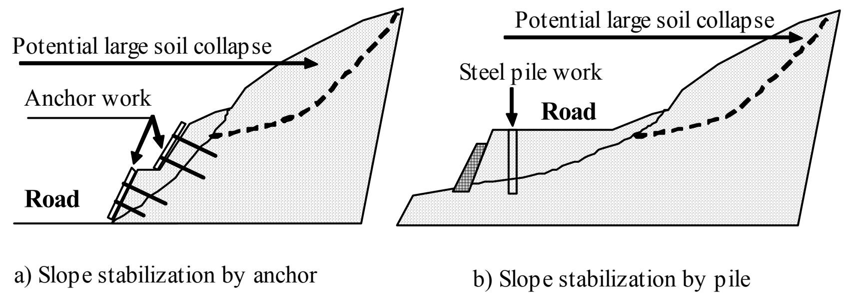


Figure 3.11 Schematic Diagrams of Anchor and Pile Works

f) When a potential soil slope collapse is large, avoiding the unstable area by using an alternate route or by the construction of a bridge or similar structure shall be considered.

3.6 Design of Main Countermeasures

3.6.1 Vegetation

A dense vegetation cover can prevent the formation of unstable debris on bare hillsides such as collapsed surfaces and bare slopes. This method is one of the most important countermeasures and is normally cost-effective.

(1) Purposes

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

(2) Design Considerations

In principle, slope vegetation is employed when the slope is to be stabilized by installation of other countermeasures.

In selecting the type of vegetation to be planted, careful attention is to be paid to rainfall, plant growth conditions, soil properties of the slope, and the timing of construction as well as the area of the protection works. Table 3.5 gives the general selection criteria for the various vegetation placement methods.

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

Table 3.5 General Selection Criteria for Vegetation

Soil and rock properties		Methods
Sand		Hydroseeding, seed mud spraying or vegetation mats
Sandy soil, gravely soil, sandy soil containing rocks and cobble stones	Loose	Sodding, hydroseeding, seed mud spraying, vegetation mats or vegetation nets.
	Dense	Hydroseeding, seed mud spraying, vegetation bags, vegetation holes, vegetation blocks or vegetation packets.
Clay, clayey soil, clay or clayey soil containing rocks and cobble stones	Soft	Sodding, hydroseeding, seed mud spraying or vegetation mats.
	Stiff	Hydroseeding, seed mud spraying,, vegetation bags, vegetation holes, vegetation blocks or vegetation packets
Soft rock		Hydroseeding, seed mud spraying, vegetation bags or vegetation holes.

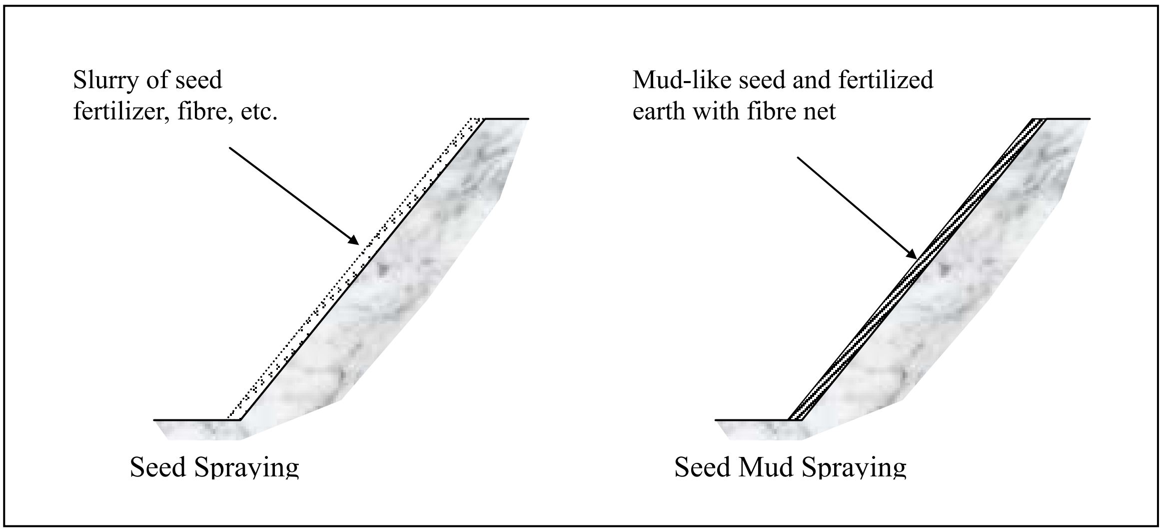


Figure 3.12 Typical Vegetation Works

Closed turfing: This is the conventional method in which sod is laid directly on the face of the slope. This is suitable for erodable soils. In laying sod, it should be laid flat in tight contact with the face of the slope without joints in order to prevent scouring.

Hydroseeding: A mixture of seed, fertilizer, fibres and water is sprayed over the face of the slope with a pump. This method is suitable for gentler slopes or low lands.

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

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

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

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

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

3.6.2 Retaining Walls

(1) Purposes

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

(2) Design Considerations

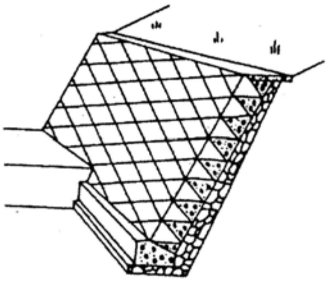
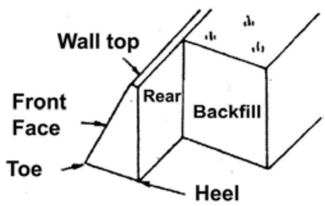
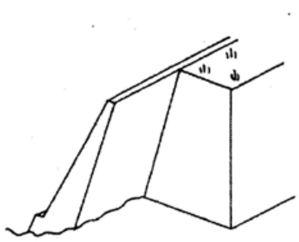
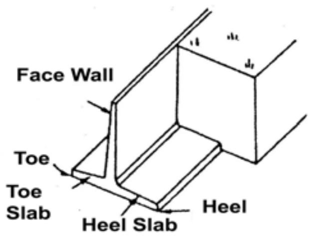
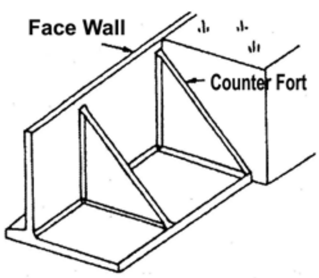
Retaining walls are generally classified into 5 types in terms of their design criteria, applications, etc. Selection of the type of retaining wall is generally based on the topographical and geological conditions at the place of the wall construction, work conditions, purpose of retaining wall, height of wall and so on. Table 3.6 summarizes retaining wall types and their characteristics.

Retaining wall design includes analysis of (a) sliding, (b) overturning, typically about the toe of the walls, (c) bearing capacity of the foundation ground, and (d) overall stability. For (d), stability analysis must not only consider the stability of the wall itself, but also the overall slope of which the wall may be a part.

Moreover, loads acting on the retaining wall are normally considered as (a) deadweight, (b) surcharge and (c) earth pressure, for design purposes.

Further, design calculations against earthquakes are generally not required for ordinary retaining walls because the load increase due to the seismic force can be compensated by a slightly increased factor of safety for the normal design calculations and by a resisting force which can not be considered in the calculations. However, the effects of earthquakes need to be considered when designing retaining walls higher than 8 meters which are not easily restored after a collapse.

Table 3.6 Types and Characteristics of Retaining Walls (Modification from Reference No. 3)

Type	Shape	Height and Gradient	Characteristics	Technical Note
Block (Stone) Masonry		• Normally less than 7.0 m in height. • Up to 15.0 m in height for large block masonry. • Front slope is 1:0.3 to 1:0.6 (V:H)	• Frequently used to prevent small scale collapse at the foot of the slope or to protect the slope.	• Mainly applicable for light earth pressure loads where the soil behind the wall is dense or good soil sediment. • Structurally weak to resist the effects of an earthquake.
Gravity		• Less than 5.0 m in height. • The width of wall base is about 0.5 to 0.7 times the height of the wall.	• Supports the earth pressure by its deadweight.	• Applicable on good ground foundations because of great ground reaction. • Inapplicable for pile foundations.
Leaning		• Less than 10.0 m in most cases. • Up to 15.0 m in some cases. • Front slope is 1:0.3 to 1:0.6 (V:H)	• Supports the earth pressure by its own deadweight while being supported by the earth at the rear or by the backfill.	• Applicable for widening the existing road in mountainous terrain. • Frequently used in places with land and topographical constraints.
Cantilever		• 3.0 to 10.0 m in height. • The width of wall base is about 0.5 to 0.8 times the height of wall.	• Vertical wall resist the lateral load or earth pressure. • The weight of backfill over the heel slab can be used to support the earth pressure.	• Applicable for pile foundations. • Precast concrete is frequently used.
Counterfort		• More than 10.0 m in height. • The width of wall base is about 0.5 to 0.7 times the height of wall	• Vertical wall and bottom slab as slab is supported on three sides. • Counterfort type is more beneficial than cantilever type for higher walls.	• Construction of wall body and backfill is difficult. • Applicable for pile foundations.

(a) Gabion walls

Gabion walls are fabricated from gabion baskets that are typically 1 meter × 1 meter in cross-section and from 2 to 5 meters in length. The rock fill for the gabion is graded from a maximum of 250 mm diameter to 100 mm diameter in size. The gabion structures are flexible and the nature of the gabion fill provides good drainage conditions in the vicinity of the wall. Filtration protection between the gabion and the wall backfill should be considered (Figure 3.13).

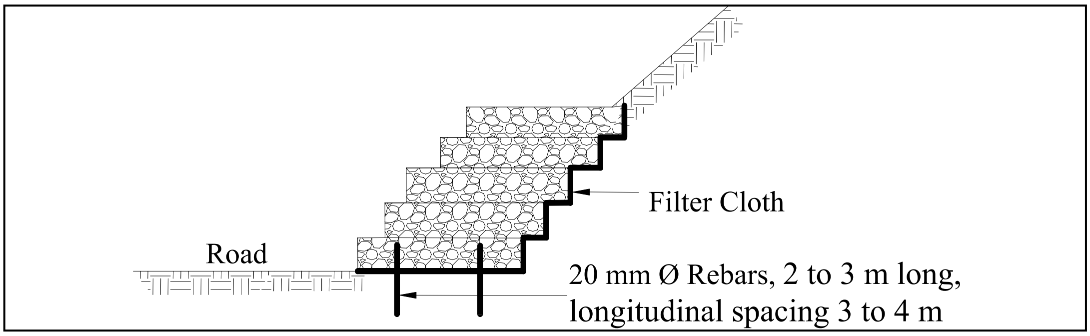


Figure 3.13 Example of Gabion Wall on the Foot of a Slope

Source: Reference No.8 Technical Standards and Guidelines for Planning and Design, Volume IV, NATURAL SLOPE FAILURE COUNTERMEASURES, Project for the Enhancement of Capability in Flood Control and Sabo Engineering of DPWH, March 2002.

(b) Stone (or concrete block) masonry retaining walls

Stone (or concrete block) masonry retaining walls must be made of wet masonry. Wall stability, especially the critical height, is examined (refer to the depth from the wall top edge to the critical point 1/3 outside of the force line centre). The foundation is embedded by at least 60 centimeters. One drain hole (generally φ100 mm) is installed every 2 to 3 m^2, usually in a zigzag pattern, because of the poor drainage of the walls.

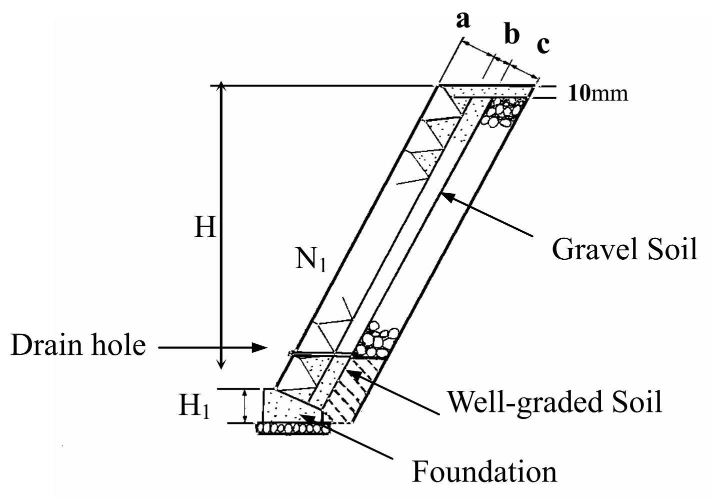
The details of stone (or concrete block) masonry retaining walls are shown in Figure 3.14, while their standard dimensions are given in Table 3.7.

Table 3.7 Standard Dimensions of Stone or Concrete Block Retaining Walls

Height (m)	Gradient	Wall thickness (cm)	Backfill thickness (cm)	Concrete Backfill thickness (cm)
H	**N1**	**a**	**c**	**b**
0 to 1.5	1:0.3	35	30 to 40	5
1.5 to 3.0	1:0.3	35	30 to 40	10
3.0 to 5.0	1:0.4	35	30 to 40	15
5.0 to 7.0	1:0.5	35	30 to 40	20

Note: This table is only preliminary. Further detailed analysis should be carried out by engineers.

Source: Modification from
Reference No. 3 Highway Earthwork Series, MANUAL FOR RETAINING WALLS, Published by Japan Road Association, March 1999.
Reference No. 5 DESIGN GUIDE －EARTHWORKS, Published by Japan Highway Public Corporation, May 1998.



Note: Wall thickness **a=35 cm,** Concrete backfill thickness **b=0 to 20 cm**,
Top edge thickness of backfill **c=30 to 40 cm**,
Wall height H=**1.5 to 7.0 m**, Foundation height **H_1=25 to 40 cm**,
Gradient N_1=1V: 0.3H to 1V: 0.5H.

Figure 3.14 Detail of Stone or Concrete Block Retaining Wall

(c) Leaning retaining walls

When concrete crib work or concrete shotcrete work is not applicable, leaning retaining walls are usually used to prevent small-scale collapse on relatively steep slopes.

Leaning retaining walls can be subdivided, in terms of function and slope geology, into two types, as shown in Figure 3.15, while the standard dimensions for wall design are given in Table 3.8.

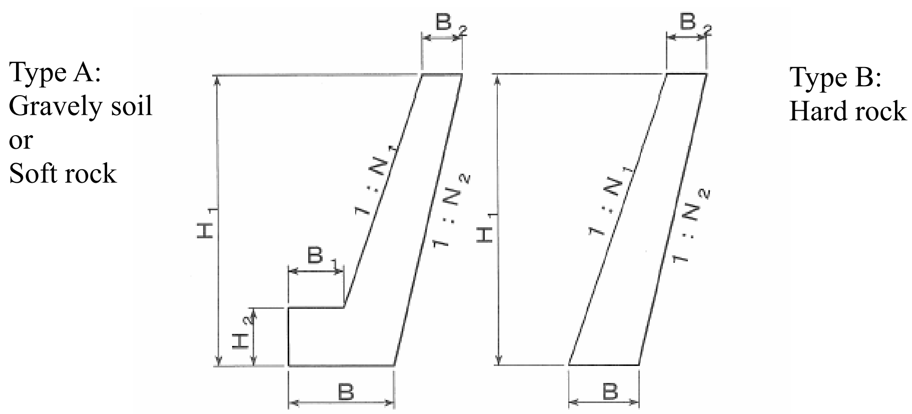


Figure 3.15 Structural View of Leaning Retaining Walls

Table 3.8 Standard Dimensions of Leaning Retaining Walls

Type of Ground	Height (m)	Front slope	Back slope	Base width (cm)	Base thickness (cm)	Foundation front width (cm)	Top edge width (cm)
	H1	**N1**	**N2**	**B**	**H2**	**B1**	**B2**
(A) Gravely soil, soft rock	3.0	0.60	0.40	1.62	0.80	1.00	0.50
	5.0	0.60	0.40	1.75	1.00	0.90	0.45
(B) Hard rock	3.0	0.40	0.30	0.75	0	0	0.45
	5.0	0.40	0.30	0.95	0	0	0.45
	8.0	0.40	0.30	1.25	0	0	0.45

Source: Modification from Reference No. 5 DESIGN GUIDE －EARTHWORKS, Published by Japan Highway Public Corporation, May 1998.

As shown in Figure 3.15, Type A is generally used as protection from small rock falls and design calculations against earth pressure is not conducted. The height of the wall shall be determined on the basis of the bearing ground, as shown in Table 3.9.

Table 3.9 Determination of Wall Height by Bearing Ground

Height H (m)	Bearing Ground	
Less than 10	Rock	
	Clayey soil C(t/m2)	Sandy Soil (N value)
Less than 7	C ≧ 7	N ≧ 30
Less than 5	C ≧ 6	N ≧ 25
Less than 3	C ≧ 4	N ≧ 20

Source: Modification from Reference No. 5 DESIGN GUIDE －EARTHWORKS, Published by Japan Highway Public Corporation, May 1998.

Moreover, the bedding depth for the wall is 1.0 m in principle, but may be reduced to 0.5 m where there is a bearing layer of hard rock.

(d) Gravity type retaining walls

For gravity type retaining walls, design considerations involve the above-mentioned analyses of the four states, namely, sliding, overturning, bearing capacity and overall stability. In determining the dimensions of the wall, it is desirable that the width, B, of the bottom slab is about 0.5 to 0.7 times the height of the retaining wall and that the thickness of the top edge is between 15 cm and 40 cm.

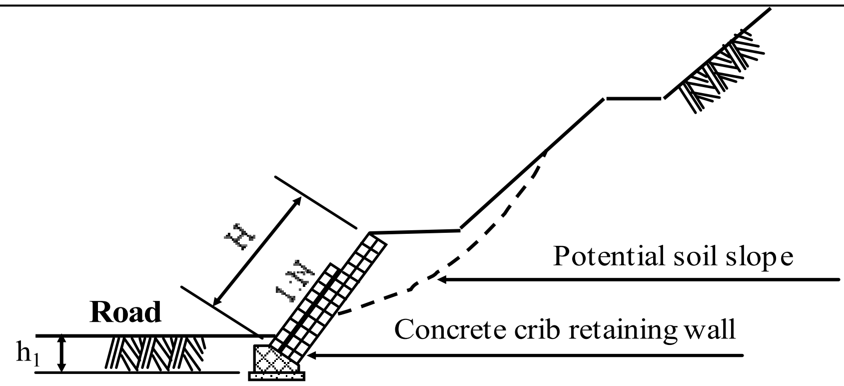
(e) Concrete crib retaining walls

Crib retaining walls, which are usually fabricated from pre-cast reinforced concrete elements, are flexible due to the segmental nature of the elements and are somewhat resistant to differential settlement and deformation.

Especially when the ground deforms considerably and there is a large amount of spring water in the potential soil slope collapse areas, crib retaining walls are applicable.

Stability is calculated for the whole structure as well as for several horizontal sections. Slope stability calculations should include the potential failure surface above the toe of the wall. Earth pressure calculations for the walls are similar to those for the gravity type retaining walls (Figure 3.16).

Moreover, the space inside the cribs should be filled with cobbles.



Note: 1) Height of Wall: H = 3.0 to 10.0 m,
2) Front Slope: 1V: 0.3H to 1V: 0.5H
3) Depth of Embedment h1=0.5m to 1.0m

Figure 3.16 Detail of Concrete Crib Retaining Wall Source: Modification from Reference No. 5 DESIGN GUIDE －EARTHWORKS, Published by Japan Highway Public Corporation, May 1998.

3.6.3 Pitching Works

Pitching works include concrete pitching, stone pitching and block pitching. They are commonly used on slopes gentler than 1V:1.0H. When the slope gradient is greater than 1V:1.0H, concrete retaining walls, stone masonry retaining walls or block masonry retaining walls may be adopted.

(1) Purposes

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

(2) Design Considerations

Stone pitching and block pitching are used for non-cohesive sediments, mudstone and collapsible clayey soils with a slope gradient less than 1V:1.0H. On the other hand, concrete pitching is employed for jointed rock slopes with a possibility of weathering and stripping. For large and/or steep rock slopes, it is desirable to reinforce the concrete with reinforcing bars or wire mesh. Adequate methods are selected by referring to Table 3.10.

Table 3.10 Selection of Pitching Works

Type	Pitching thickness (cm)	Gradient (V:H)	Height (m)	Geological conditions
Stone	25 to 35	1:1.0 to 1:1.5	Less than 5.0	Sediments, talus, cone mudstone and collapsible clayey soils.
	Less than 5	1:1.5 to 1:1.8	–	
Block	35	1:1.0 to 1:1.5	Less than 3.0	
	Less than 12	1:1.5 to 1:1.8	–	
Concrete	More than 20	less than 1:0.5	–	Bedrock with numerous joints and with a possibility of weathering and stripping.
Reinforced Concrete	More than 20	Over 1:0.5	–	

Note: The table is only preliminary. Further detailed analysis is to be carried out by the engineer.

Source: Modification from
Reference No. 1 Highway Earthwork Series, MANUAL FOR SLOPE PROTECTION, Published by Japan Road Association, March 1999.
Reference No. 5 DESIGN GUIDE —EARTHWORKS, Published by Japan Highway Public Corporation, May 1998.

Moreover, drain holes of about 5 cm diameter shall be provided every 2 to 4 m^2, regardless of the presence of spring water or seepage water.

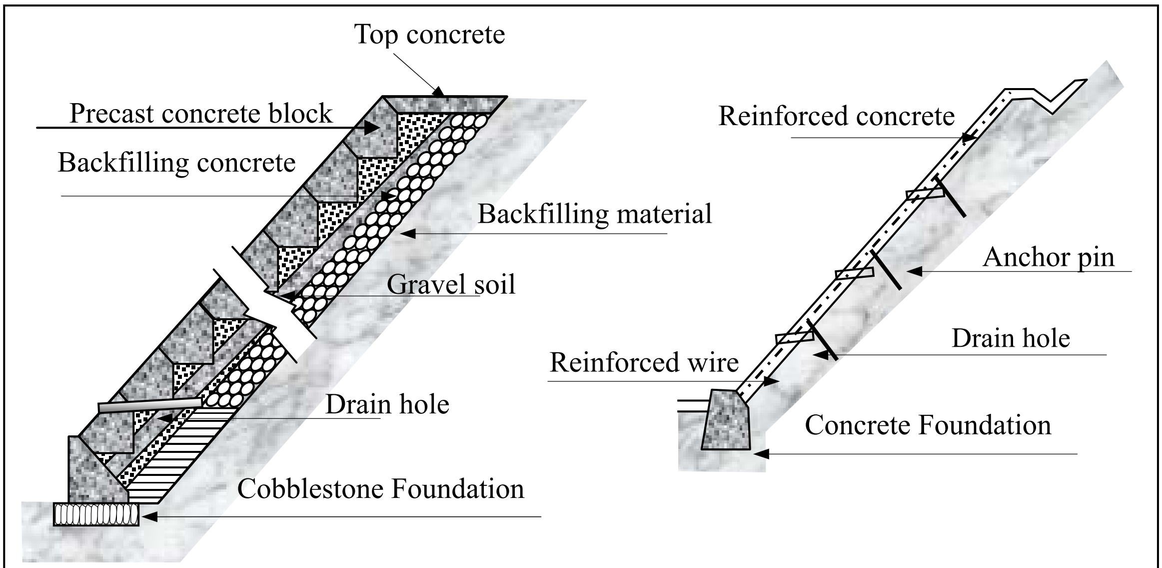


Figure 3.17 Examples of Pitching Works

3.6.4 Crib Works

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

(1) Purposes

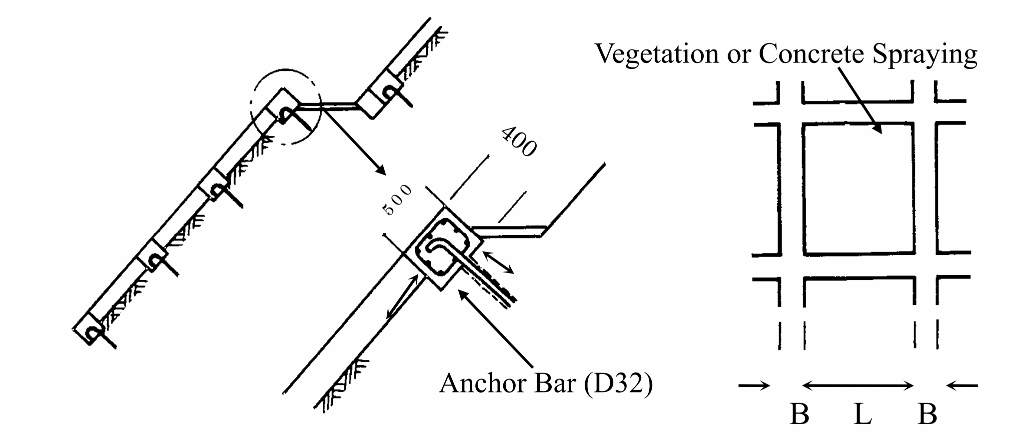
Crib works are chiefly applied to (a) prevent surface weathering, scouring and erosion, and in some cases, (b) control both rock fall and small-scale slope failure.

(2) Design Considerations

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

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

The crib (or frame) usually ranges in size from 200 × 200 millimeters to 600 × 600 millimeters at intervals of 2 to 5 meters. The spaces inside the cribs are filled and protected by stone pitching, mortar spraying, or vegetation, depending on the slope conditions (gradient, spring water, etc). Each intersection of the crib is anchored with stakes or anchor bars. Table 3.11 shows the applications of crib works. Figure 3.18 presents details of cast-in-place concrete crib work.



Note: B=200 to 600 mm, L=B×(5 to 10)

Figure 3.18 Details of Cast-in-place Concrete Crib Work

Table 3.11 Application of Crib Works

Type of crib works	Gradient (V:H)	Vertical height (m)	Condition of slope
Concrete block crib	Less than 1:0.8	Less than 5 m	Flat slope with spring water and large slope of gradient below 1:0.8
Shotcrete crib	Over 1:0.8	Less than 10 m	Slope of gradient above 1:0.8 and weathered or jointed rocks where spring water is present or where the soil is lacking in long-term stability
Cast-in-place concrete	Over 1:0.8	Less than 10 m	

Note: This table is only preliminary. Further detailed analysis is to be carried out by the engineer.

Source: Modification from
Reference No. 1 Highway Earthwork Series, MANUAL FOR SLOPE PROTECTION, Published by Japan Road Association, March 1999.

3.6.5 Rock Bolts with Concrete Crib Works

Where other works cannot meet the degree of safety required for a road slope, rock bolts with concrete crib work are used. The method is generally planned to cope with a small, shallow surface collapse of about 3 to 5 m in thickness.

Rock bolts with concrete crib work is similar to ground anchors in terms of function and design considerations. Purposes and design considerations are given in Section 5.5.6.

(1) Purposes

Rock bolts in association with concrete crib work are applied to stabilize a shallow surface collapse by exerting a force - the increased resisting power against shear force by the tension force of the rock bolts. The rock bolts with concrete crib work keeps the overall slope together, consequently preventing local collapse.

(2) Design considerations

Design considerations for rock bolts with concrete crib work include 1) Stability analysis and calculation of required preventive force; 2) Design of the rock bolts; 3) Design of the concrete crib; and 4) Design of the bearing plates.

(a) Stability analysis and calculation of required preventive force

Stability analysis is conducted using the Swedish slice method (refer to Section 5.3). Parameters for the stability analysis are generally estimated on the basis of visual soil observations, as given in Table 3.12.

In a unit width, the prevention force (Pr) required for stabilizing the potential local collapse is calculated using the following equation

$$P_R = PFs \times \Sigma T - (\Sigma N \times \tan\phi + C \times \Sigma L) \quad \cdots\cdots (3.4)$$

Where,

P_R (kN/m)= Required preventive force

PFs= Proposed safety of factor

N (kN/m)= Normal force attributable to gravity of the slice, N=W・cosα

T (kN/m)= Tangential force attributable to gravity of the slice, T=W・sinα

U (kN/m)= Pore water pressure acting on the base of the slice

L (m) = Length of sliding (or collapse) surface acting on the slice

C (kN/m^2)= Cohesion of sliding (or collapse) surface

ϕ degree= Internal friction angle of sliding (or collapse) surface

Table 3.12 Recommended Internal Friction Angle and Cohesion

Material	State	Unit Weight (kN/m^3)	Internal friction angle (Degrees)	Cohesion (kN/m^2)	Group symbol[1)]
Gravel	Dense and well graded	20	40	-	GW, GP
	Not dense, poorly graded	18	35	-	
Gravely sand	Dense	21	40	-	GW, GP
	Not dense	19	35	-	
Sand	Dense or well graded	20	35	-	SW, SP
	Not dense or poorly graded	18	30	-	
Sandy soil	Dense	19	30	-	SM, SC
	Not dense	17	25	-	
Clayey soil	Firm	18	25	Less than 50	ML, CL
	Slightly soft	17	20	Less than 30	
	Soft	16	15	Less than 15	
Clay and silt	Firm	17	20	Less than 50	CH, MH, ML
	Slightly soft	16	15	Less than 30	
	Soft	14	10	Less than 15	

Note: 1) Group symbols of the Unified Soil Classification System. 2) 1 tf/m^3 = 10 kN/m^3, 1 tf/m^2 = 10 kN/m^2

Source: Modification from Reference No. 5 DESIGN GUIDE －EARTHWORKS, Published by Japan Highway Public Corporation, May 1998.

(b)Design of rock bolts

The design tensile force (Td) for one rock bolt is calculated using the following equation:

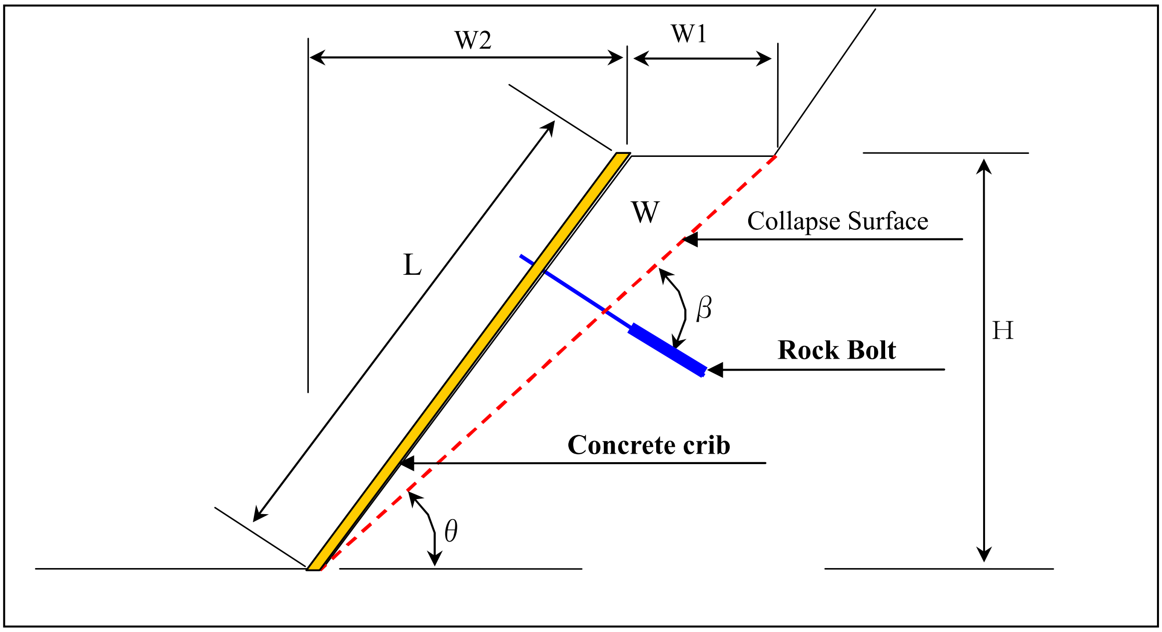


Figure 3.19 Model of Soil Slope Collapse and Arrangement of Rock Bolts

$$Td = \frac{P_R}{\sin(\alpha+\beta)\cdot\tan\phi+\cos(\alpha+\beta)\times\lambda}\cdot\frac{B}{N_1} \quad \cdots\cdots (3.5)$$

Where,

P_R (kN/m^2)= Required preventive force

α (degrees)= Inclination of the target slope

β (degrees)= Angle of slope of collapse surface

ϕ (degrees)= Internal frictional angle of collapse surface

B (m)= Interval between rock bolts in horizontal direction

N1= Number of steps for rock bolt installation (nos) (=L/w)

The tensile stress (σ_s) required against the tensile force of the rock bolt is calculated using the following formula:

$$\sigma s = \frac{Td}{As} < \sigma sa \quad \cdots\cdots (3.6)$$

Where,

As (cm^2)= Section area of steel material.

Table 3.13 Allowable Tensile Stress (σ_{sa}) of Rock Bolt Material (Unit: N/mm^2)

Type of steel	SR235	SR295	SD295AB	SD345	SD390
In normal case	140	160	180	200	210
In case of corrosion	120	140	160	180	190

Shear force (Ts) acting on one rock bolt shall be calculated using the following formula:

$$Ts = \frac{P_R \times B}{N_1} \quad \cdots\cdots (3.7)$$

The shear stress ($\sigma\tau a$) required against the tensile force of the rock bolt is calculated using the following formula:

$$\sigma\tau a = \frac{Ts}{As} < \tau_{sa} = 80 N/mm^2 \quad \cdots\cdots (3.8)$$

For the design tensile force (Td) of a rock bolt to meet the allowable tensile force, the length of contact between the ground and grout is compared with that between the steel material and the grout. Whichever is greater is used as the fixed length (L_a).

The length (L_{a1}) of contact between the steel material and the grout is calculated as follows:

$$La1 = \frac{Td}{\pi \times d \times \tau_{ca}} \quad \cdots\cdots (3.9)$$

Where,

d (mm)= Diameter of rock bolt
τ_{ca} (N/mm^2)= Allowable bond stress between the grout and the steel

Table 3.14 Allowable Bond Stress between the Grout and Steel Material

Type of steel	Design standard strength (N/mm^2)			
	18	24	30	More than 40
Different shape	1.4	1.6	1.8	2.0

Source: Modification from Reference No. 1 Highway Earthwork Series, MANUAL FOR SLOPE PROTECTION, Published by Japan Road Association, March 1999.

The length (L_{a2}) of contact between the ground and the grout is calculated as follows:

$$La2 = \frac{Td \times f}{\pi \times D \times \tau} \quad \cdots\cdots (3.10)$$

Where,

D (mm)= Diameter of Drilling Borehole

τ (N/mm^2)= Friction resistance of ground

f= Safety factor for rock bolts (generally f = 2.0)

Table 3.15 Friction Resistance of Ground with Rock Bolt

Ground Type			Friction resistance (N/mm^2)
Rock	Hard Rock		1.2
	Soft Rock		0.8
	Weathered Rock		0.5
	Semi-Consolidated Soil		0.5
Sand and Gravel Layer	N-Value	10	0.08
		20	0.14
		30	0.20
		40	0.28
		50	0.36
Sand Layer	N-value	10	0.08
		20	0.14
		30	0.18
		40	0.23
		50	0.24
Cohesive Soil			0.8*C (C: Cohesion)

Note: 1 tf/m^2 = 0.01 N/mm^2.

Source: Modification from
Reference No. 1 Highway Earthwork Series, MANUAL FOR SLOPE PROTECTION, Published by Japan Road Association, March 1999.

(c) Design of concrete crib work

Since concrete crib work offers little resisting force against the driving force of the soil slope collapse, each intersection of the crib is anchored with a rock bolt, as shown in Figure 3.20. The model of the design load is schematically shown in Figure 3.21.

Since the concrete crib is hard in comparison with the ground soil, the design load acting on the concrete crib is considered to be uniformly distributed. Accordingly, the design load (q) for one rock bolt is calculated as follows:

$$q = \frac{Td \times b}{(B + W - b) \times h} \quad \cdots\cdots (3.11)$$

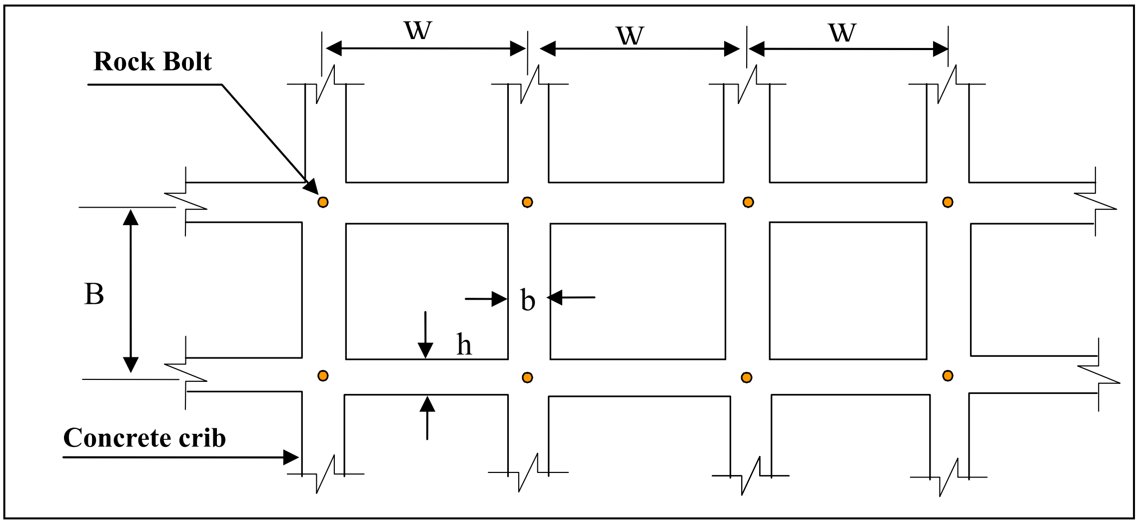


Figure 3.20 Arrangement of Rock Bolts

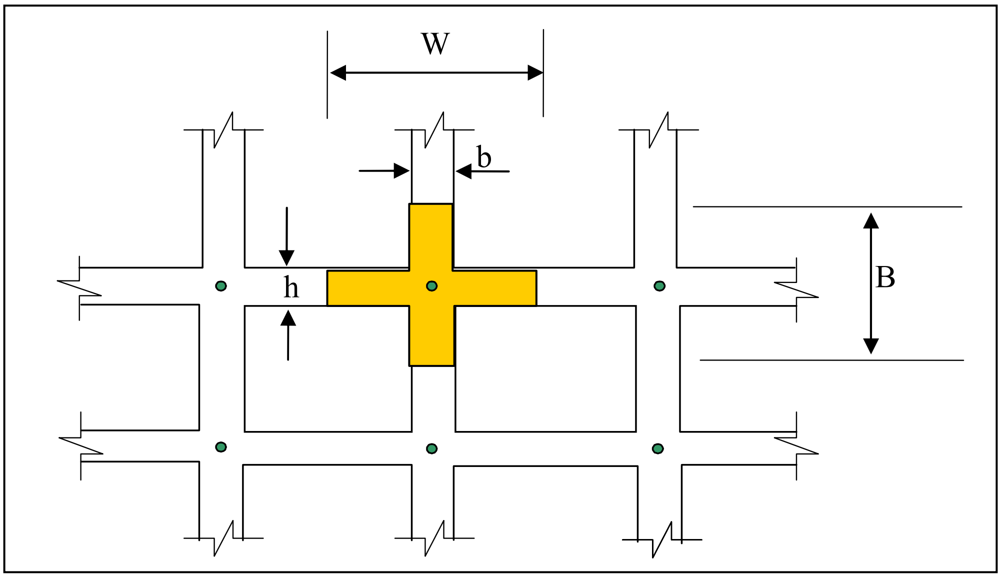


Figure 3.21 Model of Design Load

The maximum moment (Mmax) acting on the concrete crib is calculated using the following formula:

$$M\ \max = \frac{q \times B \times W}{9} \quad \cdots\cdots (3.12)$$

The maximum shear force (Smax) acting on the concrete crib (or frame) is calculated using the following formula:

$$S\max = \frac{q \times B \times 3}{5} \quad \cdots\cdots (3.13)$$

The required size (As) for the steel material is calculated using the following formula:

$$As = \frac{M\max \times 8}{\sigma_{sa} \times 7 \times d} \quad \cdots\cdots (3.14)$$

The sectional area (As) and effective height (d) of steel material is given in Table3.16.

Table 3.16 Type and Size of Steel Material Used for Different Concrete Cribs

No.	Size of Concrete Crib	Nominal Diameter	Weight (kgf/m)	Sectional Area (cm^2) (As)	Number to be Used for the Crib	Effective Height (cm) (d)	Diameter (cm)
1	150*150	D10	0.56	0.7133	2	7.5	0.953
2	200*200	D10	0.56	0.7133	2	15.5	0.953
3	200*200	D10	0.56	0.7133	2	15.5	0.953
4	300*300	D13	0.995	1.267	2	23.5	1.27
5	300*300	D16	1.56	1.986	2	23.5	1.59
6	300*300 with stir-lap	D16	1.56	1.986	2	23.5	1.59
7	400*400 with stir-lap	D16	1.56	1.986	4	31.5	1.59
8	400*400 with stir-lap	D16	1.56	1.986	4	31.5	1.59
9	500*500 with stir-lap	D19	2.25	2.865	4	41.0	1.91
10	600*600 with stir-lap	D22	3.04	3.871	4	51.0	2.22

Note: No. 2 = 1500*1200, No. 3= 1200*1200.

Source: Modification from
Reference No. 1 Highway Earthwork Series, MANUAL FOR SLOPE PROTECTION, Published by Japan Road Association, March 1999.

The ratio (p) of the steel material in the concrete crib is calculated using the following formula:

$$p = \frac{As'}{b \times d} \quad \cdots\cdots (3.15)$$

Calculation of the ratio (k) of the distance between the compressive surface and neutral axis to the effective height is calculated using the following formula:

$$k = \sqrt{2 \times p \times n + (p \times n)^2} - p \times n \quad \cdots\cdots (3.16)$$

The ratio (j) is calculated using the following formula:

$$j = 1 - k/3 \quad \cdots\cdots (3.17)$$

The tensile stress (σ_s) of the steel material is calculated using the following formula:

$$\sigma s = \frac{M\max}{A_s' \times j \times d} < \sigma_{sa} \quad \cdots\cdots (3.18)$$

The compressive stress (σ_c) of the concrete crib is calculated using the following formula:

$$\sigma c = \frac{2M\max}{k \times j \times B \times d^2} < \sigma_{ca} \quad \cdots\cdots (3.19)$$

The shear stress (τ) of the concrete crib is calculated using the following formula:

$$\tau = \frac{S\max}{b \times j \times d} < \tau_a \quad \cdots\cdots (3.20)$$

The adhesive stress (τ_b) between the concrete crib and the steel material is calculated using the following formula:

$$\tau_b = \frac{S\max}{U \times j \times d} < \tau_{ba} \quad \cdots\cdots (3.21)$$

Table 3.17 Allowable Stress for Concrete (Mortar) Crib

1. Design standard strength (N/mm^2),	15
2. Allowable compressive stress (N/mm^2) σ_{ca}	5
3. Allowable shear stress (N/mm^2) τ_a	0.33
4. Allowable adhesive stress (N/mm^2) τ_{ba}	1.3

Source: Modification from
Reference No. 10 GUIDELINE FOR DESIGN AND EXECUTION OF CRIB WORK, Published by Japan Slope Protection Association, March 1991.

(d) Design of Bearing Plates

The size (B) of the bearing plate is dependent on the allowable compressive stress, and is calculated using the following formula:

$$B \geq \sqrt{\frac{Td}{\sigma_{ca}}} + a \quad \cdots\cdots (3.22)$$

$$\sigma_{ca} \geq 0.3 \times \sigma_{ck} \quad \cdots\cdots (3.23)$$

Where,

B= the minimum width required (mm)

Td= Design tensile force for one rock bolt (kN/nos)

σ_{ca}= Allowable compressive stress (N/mm^2)

σ_{ck}= Design standard strength (N/mm^2)

a= hole area (mm2)