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THE PUBLIC WORKS
DEPARTMENT (JKR)
MALAYSIA

THE STUDY ON SLOPE DISASTER MANAGEMENT FOR FEDERAL ROADS IN MALAYSIA

GUIDE IV

GUIDE TO COUNTERMEASURE SELECTION AND COST ESTIMATION

MARCH 2002

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OYO CORPORATION

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CHAPTER 1 BASIC CONCEPT OF COUNTRERMEASURE WORKS AGAINST SLOPE FAILURE

1.1 General

This Guide presents a standard countermeasure and cost estimation method for SIMS (Slope Information Management System) that has been newly prepared by JICA Study from November 2000 to January 2001.

This Guide is consisted of the following Chapters:

Chapter 1: BASIC CONCEPT OF COUNTERMEASURE WORKS AGAINST SLOPE FAILURE

Chapter 2: SELECTION OF COUNTERMEASURE

Chapter 3: COUNTERMEASURE AGAINST COLLAPSE

Chapter 4: COUNTERMEASURE FOR ROCK FALL

Chapter 5: COUNTERMEASURE AGAINST ROCK MASS FAILURE

Chapter 6: COUNTERMEASURE AGAINST LANDSLIDE

Chapter 7: COUNTERMEASURE AGAINST DEBRIS FLOW

Chapter 8: COUNTERMEASURE AGAINST EMBANKMENT FAILURE

Chapter 9: APPROXIMATERY COST ESTIMATION OF COUNTERMEASURE

Chapter 10: EXAMPLE OF COUNTERMEASURE DESIGN

The purposes of this manual are:
1) To evaluate effect of existing countermeasure
2) To plan and design countermeasure for suffered slope
3) To estimate cost of countermeasure

1.2 Basic concept

Much of the major road network in Malaysia is distributed in hilly and mountainous terrain with steep slopes and highly weathered rocks that are prone to slope failure. Slope failures are, therefore, frequently encountered in road construction and maintenance in Malaysia.
This chapter briefly describes regional characteristics and occurrence mechanisms of slope failure, and gives a general description and classification of slope failures involving roads based on experiences and knowledge of road disaster mitigation in Japan.
Suitable countermeasures against slope failure should be based on a sound understanding of the characteristics of road slope failure. In undertaking investigations of, or planning to prevent, road slope failures, extreme care should be paid to the following points.

1) Field investigations should start with a comprehensive evaluation of general conditions (topography, geology, vegetation, etc). Investigators should not be

unduly absorbed in detail from the beginning, because initial impressions of such detail may often mislead them from understanding the true condition of the site.

2) Where an existing road is threatened by large-scale collapse, rock fall, landslide or debris flow that would be too costly or difficult to prevent, safe traffic movement must be maintained by relocating the road or applying traffic control. If a new road needs to be constructed, its alignment should be determined with the least risk of slope instability at the planning stage.

3) Large-scale fills or slope cutting in landslide-prone areas sometimes causes unforeseen disasters. Field reconnaissance and other necessary investigations, therefore, are essential for planning of safe roads. The cost of countermeasures after a slope failure is often several times the cost of taking proper preventative measures before any failures can occur. In slope protection engineering and stabilization, experience is a highly important factor, and the standard gradient of fill embankments and cut slopes is determined on an empirical basis. Design of slopes must be made not by simply applying the standard gradient, but must also be based on the judgment of experienced engineers who are well acquainted with the geological, topographic, meteorological and other natural conditions of the area.

4) Roads are often constructed initially as simple structures at low cost and then gradually upgraded and enhanced with varied functions through maintenance. The situation, however, changes in due course and the roads have to be constructed as complete a structure as possible to cope with possible disasters and reduce the cost of maintenance.

5) Water is an essential factor in controlling slope stability. Drainage is the most important factor for the safety of both natural and artificial slopes. Treatment of surface water and spring water and drainage of groundwater to achieve the largest possible drawdown of its level are important methods for stabilizing slopes.

6) Unexpected accidents, such as local slope failure or rock fall, may sometimes occur in the course of slope cutting work. In such cases, the design and the work plan have to be reviewed by well-experienced expert engineers. The original design should not be persisted with.

7) The safety of a road from natural disasters should be maintained and enhanced for constant smooth traffic flow. Periodical field inspection along the route is highly important

8) If any slope or slope-protection work shows signs of deformation such as swelling or sinking, stabilization works should be started immediately to prevent a large disaster from developing.

9) To preserve knowledge and experience, it is recommended to compile, and keep for an appropriate time, the data used for design, records of field inspection, histories of damage and repair works, records of additional stabilization work, and so on. These records can be very useful for future design, maintenance and general development of methods of preventing and treating road disasters.

1.3 Classification of Road Slope Failure

Slope failures occurring along federal roads in Malaysia, are classified into the following six types based on their occurrence mechanism and the types of countermeasures that need to be applied.

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

2) Rock Fall (RF) — the term ROCK FALL is reserved for abrupt free-fall movement of materials away from steep slopes, ranging in size from individual rock blocks to small-size failures with volumes of less than 2 m^3. Rock falls of greater size, exceeding 1,000 m3, are referred to as rock mass failure (see below).

3) Rock Mass Failure (RM) — the term ROCK MASS FAILURE includes toppling failures and rock slides, as distinct from rock falls, is characterized by failure masses of larger than 2 m^3. Its occurrence is closely related to geologic structure.

4) Landslide (LS) — the term LANDSLIDE is used to describe slow, long-term deformations of slopes underlain by soils or strongly weathered rocks and are usually characterized by recognizable sliding surfaces.

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

6) Embankment Failure (EB) — the term EMBANKMENT FAILURE is used to mean small-scale failure occurring in embankment slopes.

Table 1.3.1 Classification of Road Slope Failure

SLOPE FAILURE
COLLAPSE(CL)
ROCK FALL(RF)
ROCK MASS FAILURE(RM)
LANDSLIDE(LS)
DEBLIS FLOW(DF)
EMBANKMENT FAILURE(EB)

CHAPTER 2 SELECTION OF COUNTERMEASURE

2.1 General

Countermeasures for slope failure involving roads are classified into seven groups, in consideration of size, purpose, application, and design method, and are given in Table 2.1.1. A suitable combination of these methods should be implemented after consideration of the mechanism and dimension of slope failures, the importance of the objects to be protected, and the cost-effectiveness. Generally, countermeasures involve some or all of the following objectives:

1. Preventing erosion and weathering of the slope surface by the use of vegetation, shotcrete and surface drainage;
2. Reducing pore-water pressures in the slope by surface and subsurface drainage;
3. Reducing shear (or destabilising) force by removing the unstable materials from the upper part of the unstable slope;
4. Increasing shear strength (or stabilising force) by adding weight to the toe of an unstable slope or by increasing shear strength along the failure surface;
5. Supporting the unstable area of slope by the construction of retaining walls and similar structures;
6. Reducing or preventing the damages from slope failures by catch works, etc;
7. Avoiding the unstable area by relocating a route or by the construction of bridge and similar structures.

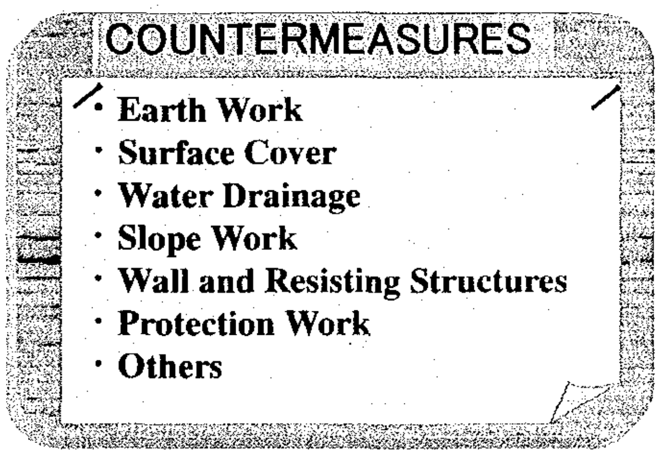


Figure 2.1.1 Classifications of Countermeasures

2.2 Selection of countermeasures

Table 2.2.1 gives the classification of countermeasures for preventing slope failure.

Table 2.2.1 Applicability of Countermeasures against Slope Failures

CLASSIFICATION		TYPE OF WORK	TYPE OF SLOPE FAILURE					
			CL	RF	RM	LS	DF	EB
1. EARTHWORK	Earthwork	Removal	○	○	○	○	○	×
		Rock Cutting	○	○	○	○	○	×
		Rock Pre-Splitting	○	○	○	△	○	×
		Soil Cutting	○	×	×	○	○	×
		Embankment	○	×	×	○	△	○
2. VEGETATION	Vegetation	Re-Vegetation	○	△	×	○	○	○
		Hydroseeding	○	△	×	○	○	○
3. WATER DRAINAGE	Surface Drainage	Drain Ditch and Cascade	○	△	△	○	△	○
		Subsoil Drainage Hole	○	△	×	○	×	○
	Subsurface Drainage	Culverts	△	×	×	△	○	○
		Horizontal Drain Hole	○	×	○	○	△	○
		Drainage Well	×	×	×	○	×	×
		Drainage Tunnel	×	×	×	○	×	×
4. SLOPE WORK	Shotcrete Work	Shotcrete (mortar)	○	○	○	×	○	×
		Shotcrete (concrete)	○	○	○	×	○	×
	Crib Work	Cribwork (Precast)	△	△	×	△	×	○
	Pitching Work	Stone Pitching	○	○	△	×	×	○
5. ANCHORING	Anchoring	Soil Nail	○	△	×	△	△	○
		Rock Bolt	○	○	○	○	△	×
		Ground Anchor	○	○	○	○	△	×
6. WALL AND RESISTING STRUCTURES	Retaining Wall	Stone Pitching Wall	○	○	○	○	△	○
		Concrete Block Wall	○	○	○	○	△	○
		Retaining Wall(Supported Type)	○	○	○	△	△	○
		Crib Wall	○	○	○	○	△	○
		Gabion Wall	○	○	×	○	○	○
		Pile Wall	○	○	○	○	△	○
	Catch Work	Catch Fill	△	○	△	×	×	×
		Catch Gabion	△	○	△	×	○	×
		Catch Concrete Wall	△	○	△	×	△	×
7. PILING WORK	Piling Work	Steel Pipe Pile	△	×	×	○	×	×
		H Steel Pile	△	×	×	△	×	×
		Shaft Work for Resistance Slide	△	×	×	○	×	×
8. PROTECTION WORK	Protection Work	Rock Fall Catch Net	△	○	○	×	×	×
		Rock Fall Catch Fence	△	○	○	×	×	×
	Rock Shed	Rock Shed	△	○	○	×	○	×
		Debris Shed	△	△	△	×	○	×
	Sabo (Check) Dam	Slit Dam	×	×	×	△	○	×
		Check Dam (Sabo Dam)	×	×	×	○	○	×
9. OTHERS	Avoiding Problem Work	Diversion (Shifting)	△	△	○	○	○	△
		Route Relocation	△	△	○	○	○	△

○ : Applicable △ : Limited case × : Not applicable

CL : Collapse **RF** : Rock Fall **RM** : Rock Mass Failure **LS** : Land Slide **DF** : Debris Flow **EB** : Embankment Failure

CHAPTER 3 COUNTERMEASURE AGAINST COLLAPSE (CL)

3.1 General

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

3.2 Selection of countermeasures

3.2.1 Classification of countermeasures

Table 3.2.1 shows the classification of countermeasures for preventing collapse.

3.2.2 Criteria for selection of countermeasures

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

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

Figure 3.2.1 shows a flow chart for the selection of countermeasures to prevent collapse. The success of such collapse prevention measures is influenced greatly by topographical, geological and meteorological conditions. In principle, cutting work, drainage work and vegetation are the preferable choices. Structural methods such as crib work and anchor work are adopted only when soil and gradient conditions are unsuitable for vegetation and slope stability cannot be secured by cutting and/or drainage works alone.

Table 3.2.1 Classification of Countermeasures against Collapse

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

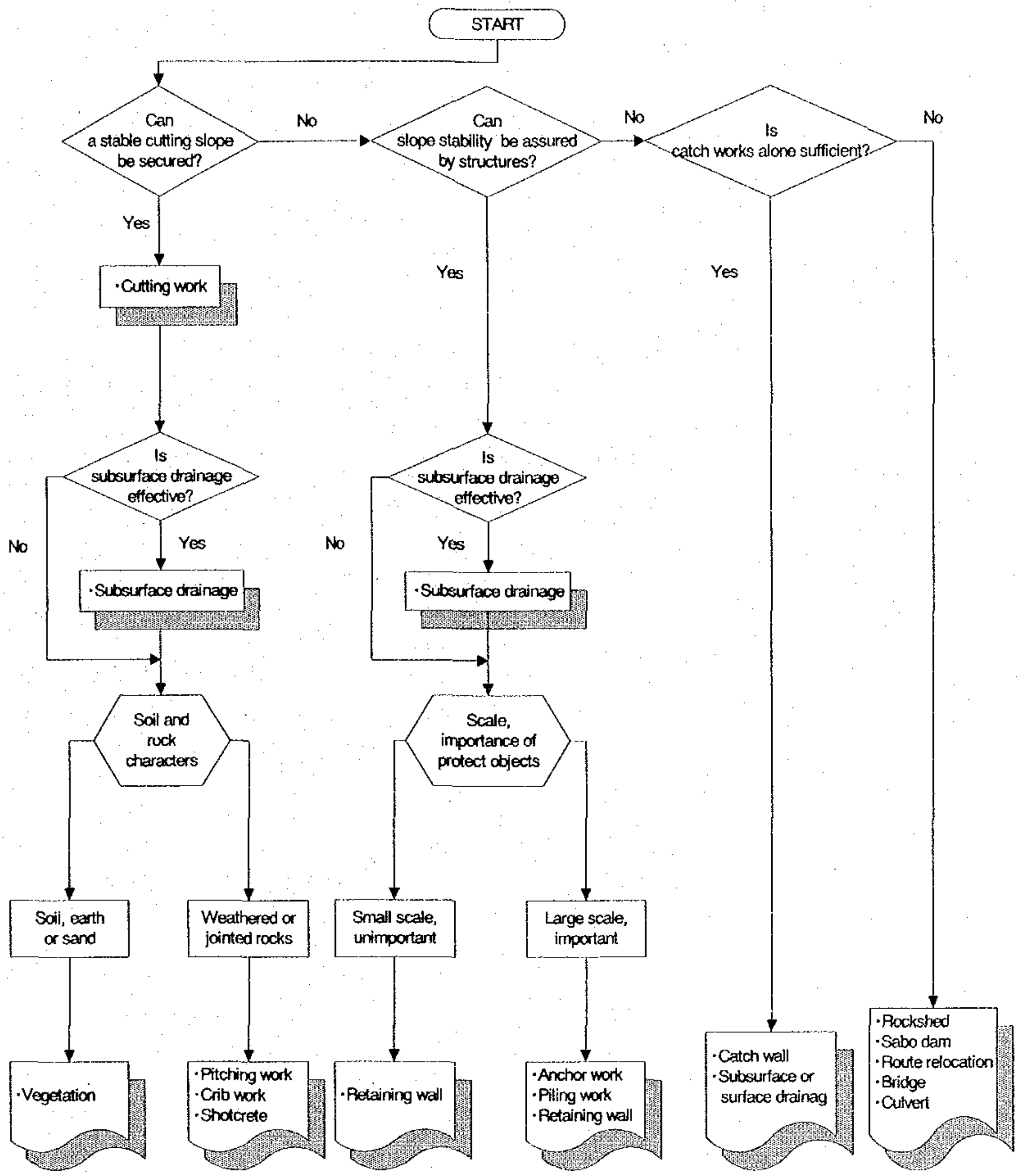


Figure 3.2.1 Flow chart for selection of countermeasures for collapse

3.3 Design Consideration

3.3.1 Earth work

1) Purpose

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

2) Design Considerations

The gradient and vertical height of the cutting slope should be determined on the basis of the geological conditions, etc. The gradient should be between 1V to 0.3H and 1V to1.5H depending on subsurface conditions and characteristics (Table 3.2.2). Berms 1 to 4 m wide should be created at intervals of 5 to 10 m in the vertical direction. Careful investigation of the stability of the back slope should be conducted prior to cutting. This suggestion is shown the only normal gradient, therefore applied gradient should be approved by the engineer.

Table 3.3.1 Geometric Suggestion of Cutting Slopes

Character of soil or bedrock		Height (m)	Gradient (i =V:H)
Hard rock			1:0.3 ~ 1:0.8
Soft rock			1:0.5 ~ 1:1.2
Sand	Those not dense, not solid and of bad grade distribution.		1:1.5 ~
Sandy soil	Those are dense and solid.	Less than 5 m	1:0.8 ~ 1:1.0
		5~10 m	1:1.0 ~ 1:1.2
	Those not dense, not solid.	Less than 5 m	1:1.2 ~ 1:1.5
		5~10 m	1:1.5 ~ 1:1.8
Sandy soil mixed with gravel or rock mass	Those 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
	Those not dense, not solid or of bad grade distribution.	Less than 10 m	1:1.0 ~ 1:1.2
		10~15 m	1:1.2 ~ 1:1.5
Residual soil		Less than 10 m	1:1.5 ~ 1:1.8
Cohesive soil mixed with rock mass or cobble stones		Less than 5 m	1:1.0 ~ 1:1.2
		5~10 m	1:1.2 ~ 1:1.5

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

Note2: Silt is placed under cohesive soil. Individual consideration is given to soils not be indicated in the table.

In designing a cut slope, the following geological conditions should be considered with the utmost care.

1. Colluvial deposit slope.
   Colluvium such as talus and debris flow deposits, being poorly consolidated, usually form a slope with a critical angle of stability. When excavated, the cut slope formed will become unstable. For this reason, a wide berm near the boundary between the bedrock and the upper colluvial deposit should be designed.

2. Erosive sandy soil
   Sandy soils, such as disintegrated granite and terrace gravel, are easily eroded by surface water to result in small shallow collapse.

3. Erodable soft rocks
   Cut slopes of soft rocks such as mudstone and tuffs become unstable after the completion of cutting because of the weak internal strength of the rock and stress release.

4. Fissured rock slope
   The stability of fissured rock slopes is governed by the degree of fissure development and their distribution.

To prevent erosion of the cutting natural slope, protection of the slope and the foot of slope should be considered. Slopes should be protected by a retaining wall or anchoring when it is unavoidable to form a cut slope with a gradient steeper than the standard gradient.

3.3.2 Vegetation

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

1) Purposes

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

2) Design Considerations

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

In selecting the type of vegetation to establish, careful attention should be paid to the rainfall, plant growth conditions, and the soil properties of the slope, as well as the timing of construction and the area of protection works. Table 3.3.2 gives general selection criteria for the various vegetation establishment methods.

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

Table 3.3.2 General selection criteria for vegetation

<table>
<tr><th colspan="2">Soil and rock properties</th><th>Methods</th></tr>
<tr><td colspan="2">Sand</td><td>Hydroseeding, seed mud spraying, vegetation mat</td></tr>
<tr><td rowspan="2">Sandy soil, gravel soil, sandy soil containing rocks and cobble stones</td><td>Loose</td><td>Sodding, hydroseeding, seed mud spraying, vegetation mat, vegetation net.</td></tr>
<tr><td>Dense</td><td>Hydroseeding, seed mud spraying, vegetation bag, vegetation hole, vegetation block, vegetation packet.</td></tr>
<tr><td rowspan="2">Clay, clayey soil, clay or clayey soil containing rocks and cobble stones</td><td>Soft</td><td>Sodding, hydroseeding, seed mud spraying, vegetation mat.</td></tr>
<tr><td>Stiff</td><td>Hydroseeding, seed mud spraying,, vegetation bag, vegetation hole, vegetation block, vegetation packet</td></tr>
<tr><td colspan="2">Soft rock</td><td>Hydroseeding, seed mud spraying, vegetation bag, vegetation hole.</td></tr>
</table>

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

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

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

Vegetation mat: 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 usually placed on 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 usually placed linearly along contour lines.

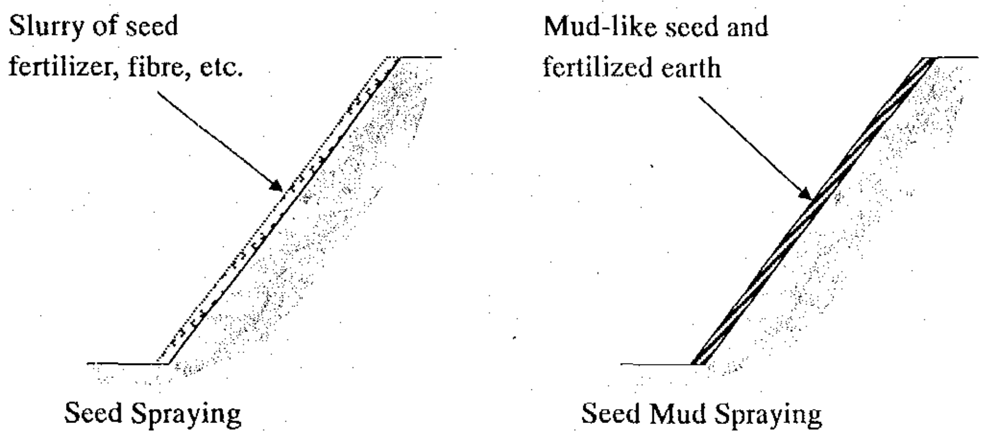


Figure 3.3.1 Typical vegetation works

3.3.3 Shotcrete work

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

1) Purposes

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

2) Design Considerations

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

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

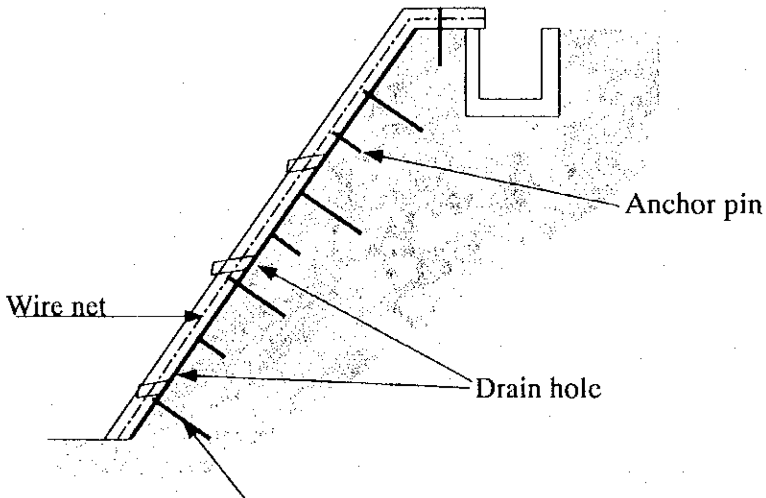


Figure 3.3.2 Typical example of mortar or concrete shotcrete works

3.3.4 Pitching work

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

1) Purposes

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

2) Design Considerations

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

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

Adequate methods should be selected by referring to Table 3.2.4.

Table 3.3.3 Selection of pitching work

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

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

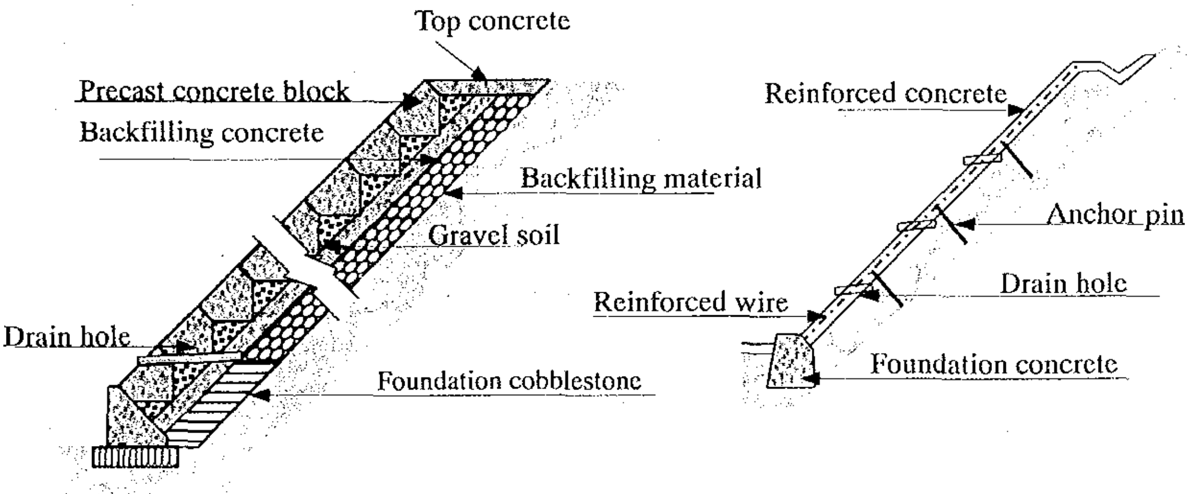


Figure 3.3.3 Examples of pitching works

3.3.5 Crib work

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

1) Purposes

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

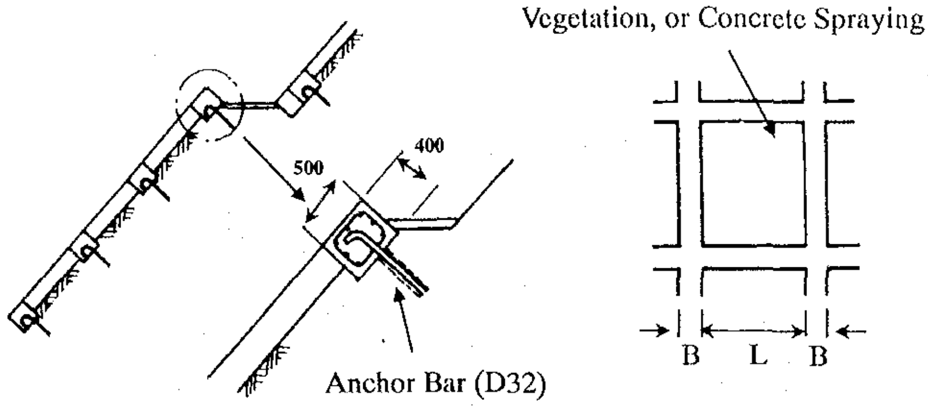
Concrete block crib work is used for slopes with gradients less than 1:1.0 (V:H) and when vegetation is suited to the slopes. Shotcrete crib and cast-in-place concrete crib works are used when the long-term stability of the slope is questionable, or when concrete block crib work is likely to collapse 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 millimetres to 800 × 800 millimetres at an interval of 2 to 5 metres. The spaces inside the cribs are filled and protected by stone pitching, mortar spraying, or vegetation, depending on the slope conditions (gradient, spring water, etc). Each intersection of the crib should be anchored with stakes or pre-stressed steel, depending on the conditions of the slope. Table 3.3.4 shows the applications of crib works. Figure 3.3.4 presents details of cast-in-place concrete crib work.

Table 3.3.4 Application of Crib Works

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

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



Note: B=300 to 600 mm, L=B×(5 to 10)

Figure 3.3.4 Details of Cast-in-place Concrete Crib Work

3.3.6 Soil nails

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

1) Purposes

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

2) Design considerations

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

In planning soil nailing, attention should be paid to soil properties. Soil nail is effective in firm dense low-plasticity soils and is not practical in loose sandy soils and soft clay. Commonly, one nail is used for each 1 to 6 m^2 of soil surface area combined with shotcrete facing (mortar or concrete). Standard nails vary in diameter between 12 mm and 32 mm, and are less than 5 m in length. Figure 3.3.5 shows a diagrammatic example of soil nail.

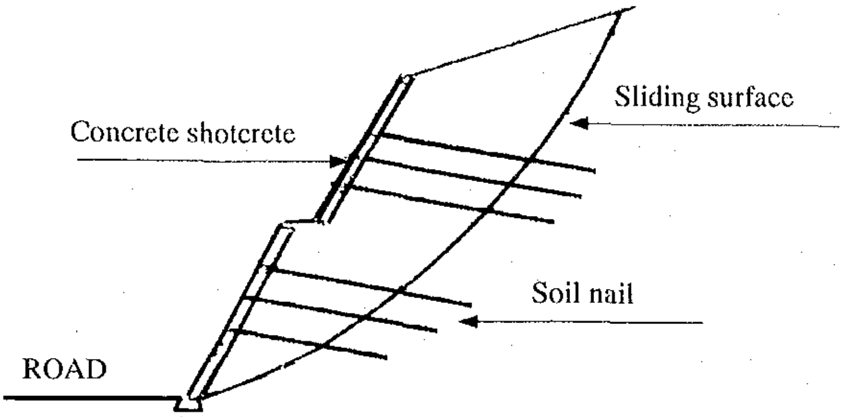


Figure 3.3.5 An example of soil nail

3.3.7 Retaining wall

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

1) Purposes

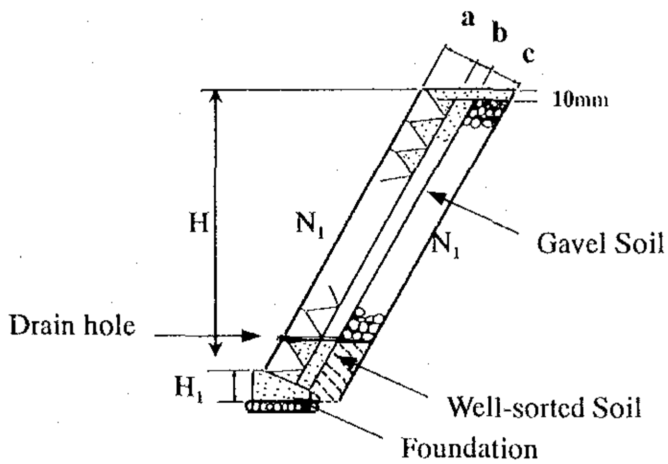
Retaining walls are used (a) to prevent small-scale shallow collapse and toe collapse of large-scale slope failures, and (b) as a foundation of other slope protection works such as crib works. Typically where the toe of slope has collapsed or the collapse is likely to enlarge upward along the slope,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

2) Design Considerations

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

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

Stone (or concrete block) masonry retaining walls must be wet masonry. Wall stability, especially the critical height, should be examined (refer to the depth from the wall top edge to the critical point that protrudes 1/3 outside of the force line centre). In general, the foundation must be embedded at least 30 centimetres. One drain hole (generally Ø5 mm) must be installed every 2 to 3 m^2, usually in a zigzag pattern, because of the poor drainage of the walls (Figure 3.3.6).



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

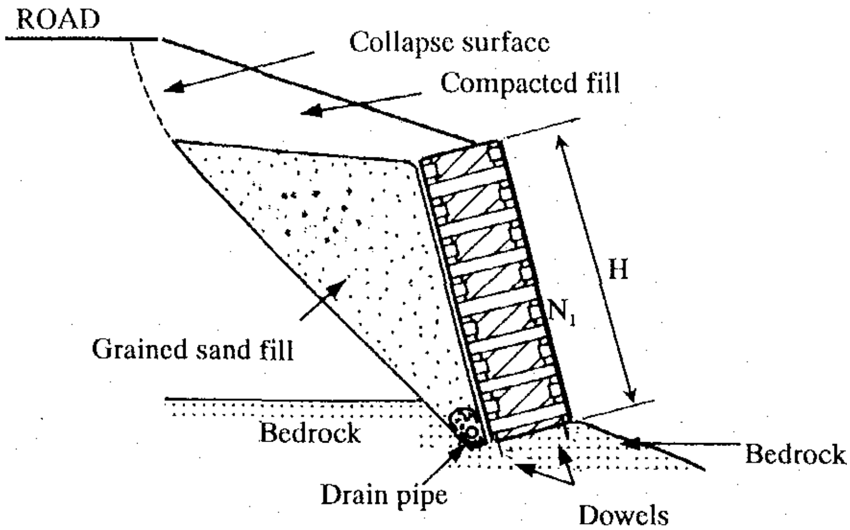
Figure 3.3.6 Detail of stone or concrete block retaining wall

Table 3.3.5 Standard Dimension of Stone or Concrete Block Retaining Wall

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

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

Crib retaining walls, usually being fabricated from precast reinforced concrete elements, are flexible due to the segmental nature of the elements, and are thus somewhat resistant to differential settlement and deformation. The stability is calculated for the whole structure as well as for several horizontal sections. Slope stability calculations should include the potential failure surface above the toe of the wall. Earth pressure calculations of the walls are similar to that of gravity type retaining wall (Figure 3.3.7).



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

Figure 3.3.7 Detail of crib retaining wall

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

Table 3.3.6 gives some recommended design constants.

Table 3.3.6 Recommended Design Constants

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

CHAPTER 4 COUNTERMEASURE FOR ROCK FALL (RF)

4.1 Selection of countermeasures

4.1.1 Classification of countermeasures

Countermeasures against rock fall can be classified into works to prevent rock fall and works to provide protection from rock fall. Rock fall prevention concentrates on the rock fall source, such as removal and crib work. Rock fall protection does not attempt to prevent rock fall, but aims at preventing the relevant objects from being damaged by rock fall. There are a variety of methods within the two major approaches shown in Table 4.1.1.

Table 4.1.1 Classification of Countermeasures against Rock Fall

CLASSIFICATION			TYPE OF WORK
ROCK FALL PREVENTION WORK	1. EARTH WORK	Earth Work	Removal
			Cutting
	2. VEGETATION	Vegetation	Hydroseeding
			Re-Vegetation
	3. WATER DRAINAGE	Surface Drainage	*Subsoil Drainage Hole*
			Drain Ditch and Cascade
	4. SLOPE WORK	Pitching Work	Stone Pitching
		Shotcrete Work	Shotcrete (mortar)
			Shotcrete (concrete)
		Crib Work	Cribwork
	5. ANCHORING	Anchoring	Rock Bolt
ROCK FALL PROTECTION WORK	6. WALL AND RESISTING STRUCTURES	Catch Work	Catch Fill
			Catch Gabion
			Catch Concrete Wall
	8. PROTECTION WORK	Protection Work	*Rock Fall Catch Net*
			Rock Fall Catch fenceFence
		Rock Shed	Rock Shed

4.1.2 Criteria for selection of countermeasures

To select adequate and effective measures for preventing damage from rock fall, one should consider topographical and geological conditions, vegetation, rock fall history, and the effects of the countermeasure by predicting the size and height of any potential rock fall. Figure 4.1.1 shows a procedure for selecting countermeasures against rock fall. The following criteria must be used for selection.

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

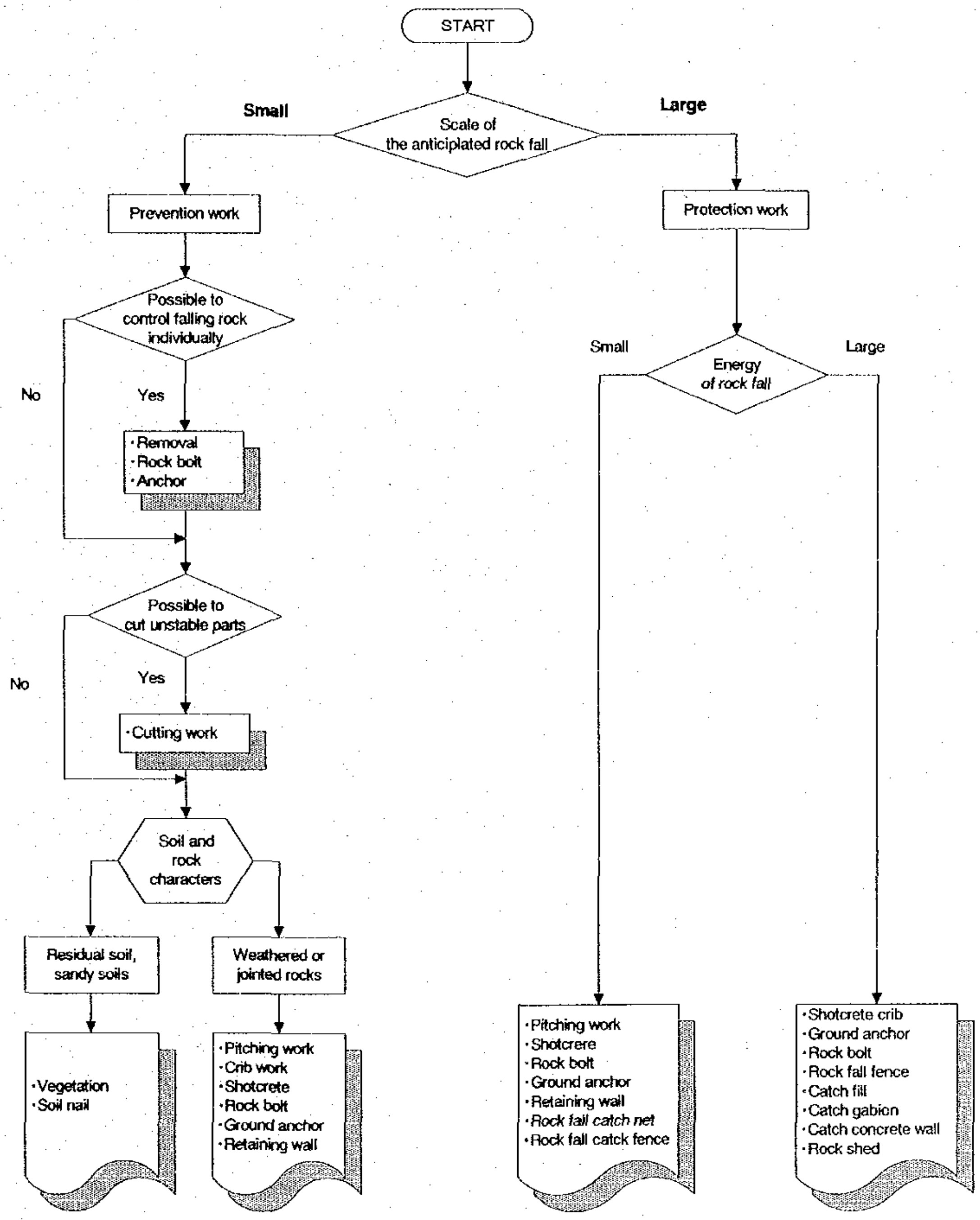


Figure 4.1.1 Flow chart for selection of countermeasures for rock fall

4.2 Design Consideration

4.2.1 Removal

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

4.2.2 Rock fall catch net

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

1) Purposes

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

2) Design considerations

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

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

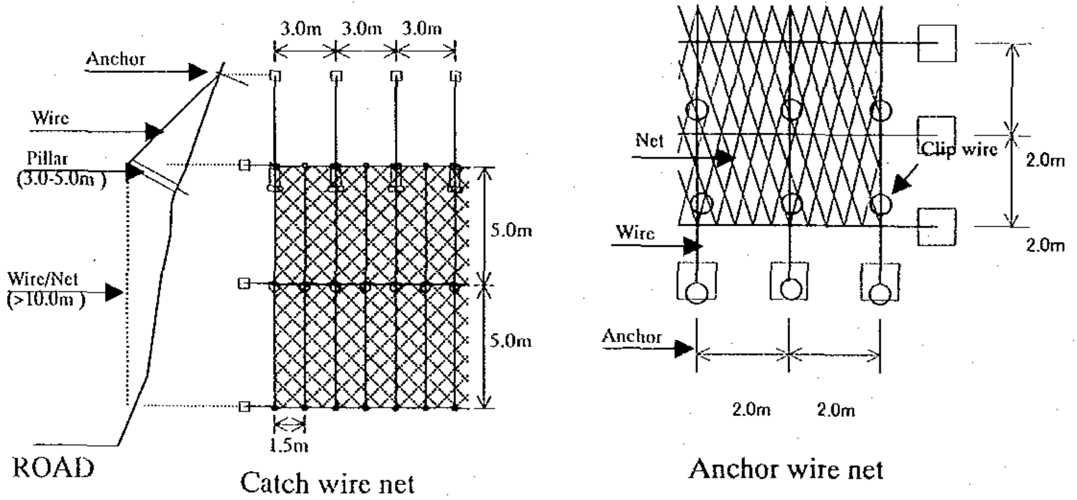


Figure 4.2.1 Example of rock fall catch net

4.2.3 Rock fall catch fence

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

1) Purposes

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

2) Design considerations

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

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

4.2.4 Catch fill and ditch

This method is commonly used and is cost-effective when scale of rock fall is likely to be large and difficult to control. However, there must be sufficient space between the unstable slope and the road to receive the full volume of potential rock fall. Figure 4.2.2 shows the conceptual arrangement of a catch fill and ditch.

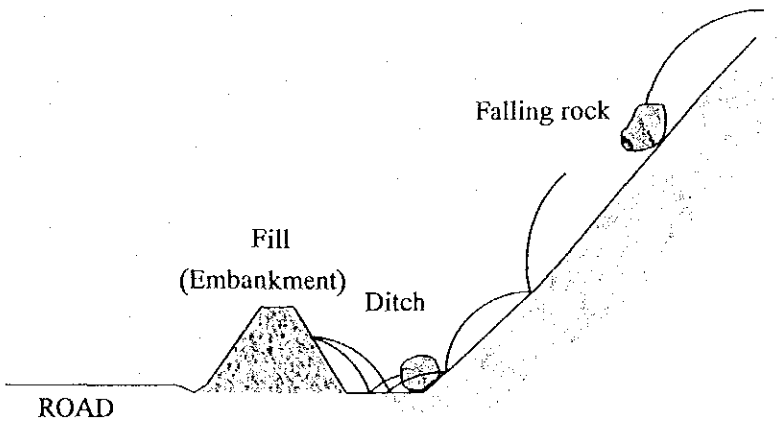


Figure 4.2.2 Diagrammatic layout of catch fill and ditch

1) Purposes

This method is used to reduce the effects of rock fall by absorbing and dispersing the impact force of falling rocks above the road or by diverting the direction of movement of any rock fall.

2) Design considerations

Apart from embankment stability analysis, design considerations are concerned with the shape and dimensions of the catch embankment and ditch in terms of their capacity for arresting and accommodating falling stones. Table 4.2.1 lists the recommended shapes and dimensions of this structure in relation to slope gradient.

Table 4.2.1 Recommended Shapes and Dimensions of Catch Ditch

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

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

CHAPTER 5 COUNTERMEASURE AGAINST ROCK MASS FAILURE(RM)

5.1 Selection of countermeasures

5.1.1 Classification of countermeasures

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

Table 5.1.1 gives the general countermeasures for rock mass failures and their classification. In the case of preventing small rock mass failures, countermeasures such as cutting, shotcrete, cast-in-place concrete crib, rock bolt and ground anchor may be the most cost-effective.

Table 5.1.1 Classification of Countermeasures against rock mass failure

CLASSIFICATION		TYPE OF WORK
1. EARTH WORK	Earth Work	Removal
		Rock Cutting
3. WATER DRAINAGE	Subsurface Drainage	Horizontal Drain Hole
4. SLOPE WORK	Shotcrete Work	Shotcrete (mortar)
		Shotcrete (concrete)
	Crib Work	Crib Work
5. ANCHORING	Anchoring	Rock Bolt
		Ground Anchor
6. WALL AND RESISTING STRUCTURES	Catch Work	Catch Fill
		Catch Concrete Wall
8. PROTECTION WORK	Protection Work	Rock Fall Catch Net
		Rock Fall Catch Fence
	Rock Shed	Rock Shed
9. OTHERS	Avoiding Problem Work	Tunnel, Bridge
		Route Relocation

5.1.2 Criteria for selection of countermeasures

Rock mass failures generally result from geological structures and mostly occur at a relatively large scale. In selecting and designing the countermeasures, the following points should be considered. Figure 5.1.1 shows a flowchart for selection of countermeasures for rock mass failure.

1. A comprehensive investigation should be conducted on the causes and scale of rock mass failure as well as the regional geological features. Where rock mass failure is closely related to large geological structures such as faults and folds, route relocation is the most cost-effective method because of the large scale involved. Where a rock mass failure threat is a result of geological composition such as limestone and metamorphic rock prone to weathering and jointing, framework and shotcrete work may, in some cases, be cost-effective.

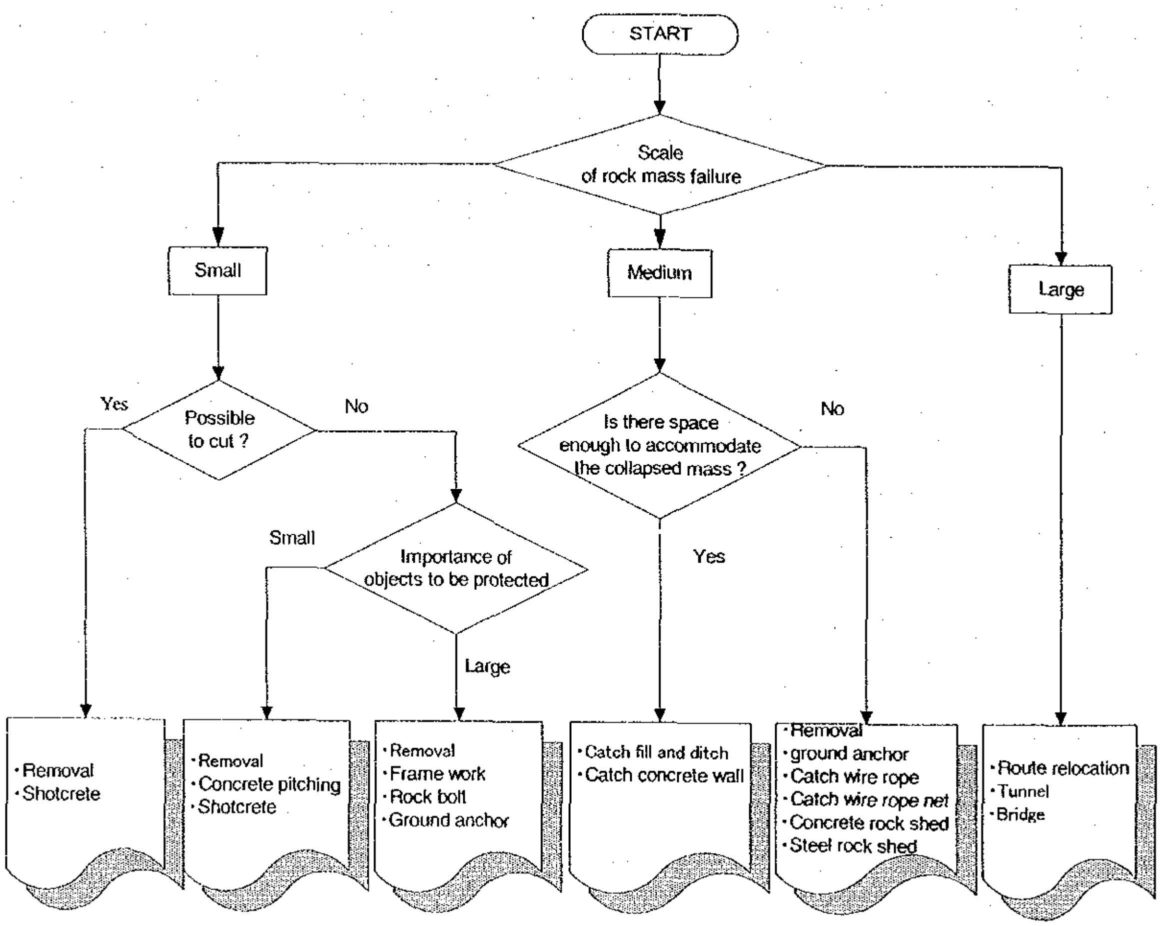


Figure 5.1.1 Flow chart for selection of countermeasures for rock mass failure

2. Suitable countermeasures should be selected after examination of the economics, effectiveness, maintenance requirements, environment and appearance. In most cases, maintenance is costly, so conservative countermeasures that will require little on-going maintenance should be selected. For example, engineering practice shows that to stabilise strongly jointed rock slopes, mortar shotcrete costs less than cast-in-place concrete crib, but is costly to maintain.
3. If removal work cannot be done by some conditions, protection works should be done to prevent occurrence of rock mass failure. Figure 5.2.4 shows the examples of countermeasures in these cases.

5.2 Design consideration

5.2.1 Cutting work

The purposes and design considerations for stabilising work are similar to those for collapse (Chapter 3). Cutting work is particularly effective to safeguard against rock mass failure and an example is shown in Figure 5.2.1.

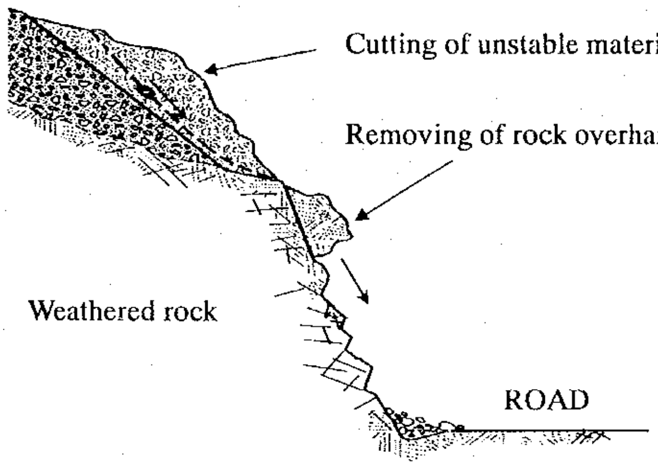


Figure 5.2.1 An example of cutting work to treat rock mass failure

5.2.2 Ground anchor and rock bolt

For purposes and design considerations, refer to Chapter 3.

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

Rock bolting is a shallow-fitting method, while ground anchoring is inserted deep into the slope. Therefore, rock bolts are applied to stabilize the slope face by exerting a force that compresses the joints and prevents loosening of the rock mass. Ground anchoring is applied to prevent a rockslide by tension force, generally in association with frame works. Figure 5.2.2 shows diagrammatically how unstable rock above a road can be stabilised by ground anchor and rock bolt.

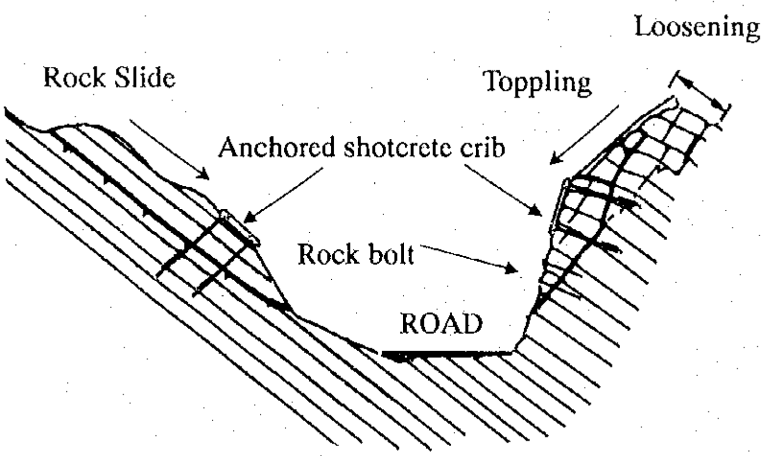


Figure 5.2.2 Stabilization of unstable rock slope above a road

5.2.3 Rock shed

Rock sheds are reinforced concrete or steel structures covering a road and can be subdivided into four types from a structural view; portal (gate) type, retaining wall type, arch type and pocket type (Figure 5.2.3).

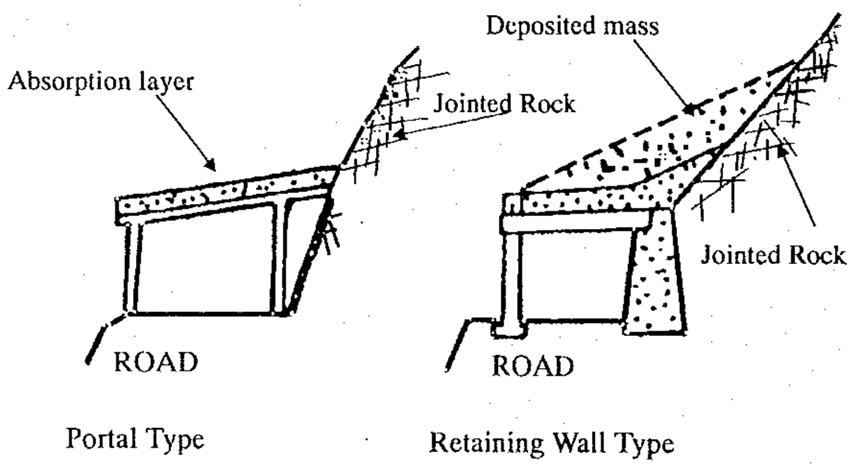


Figure 5.2.3 Types of rock sheds

1) Purposes

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

2) Design considerations

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

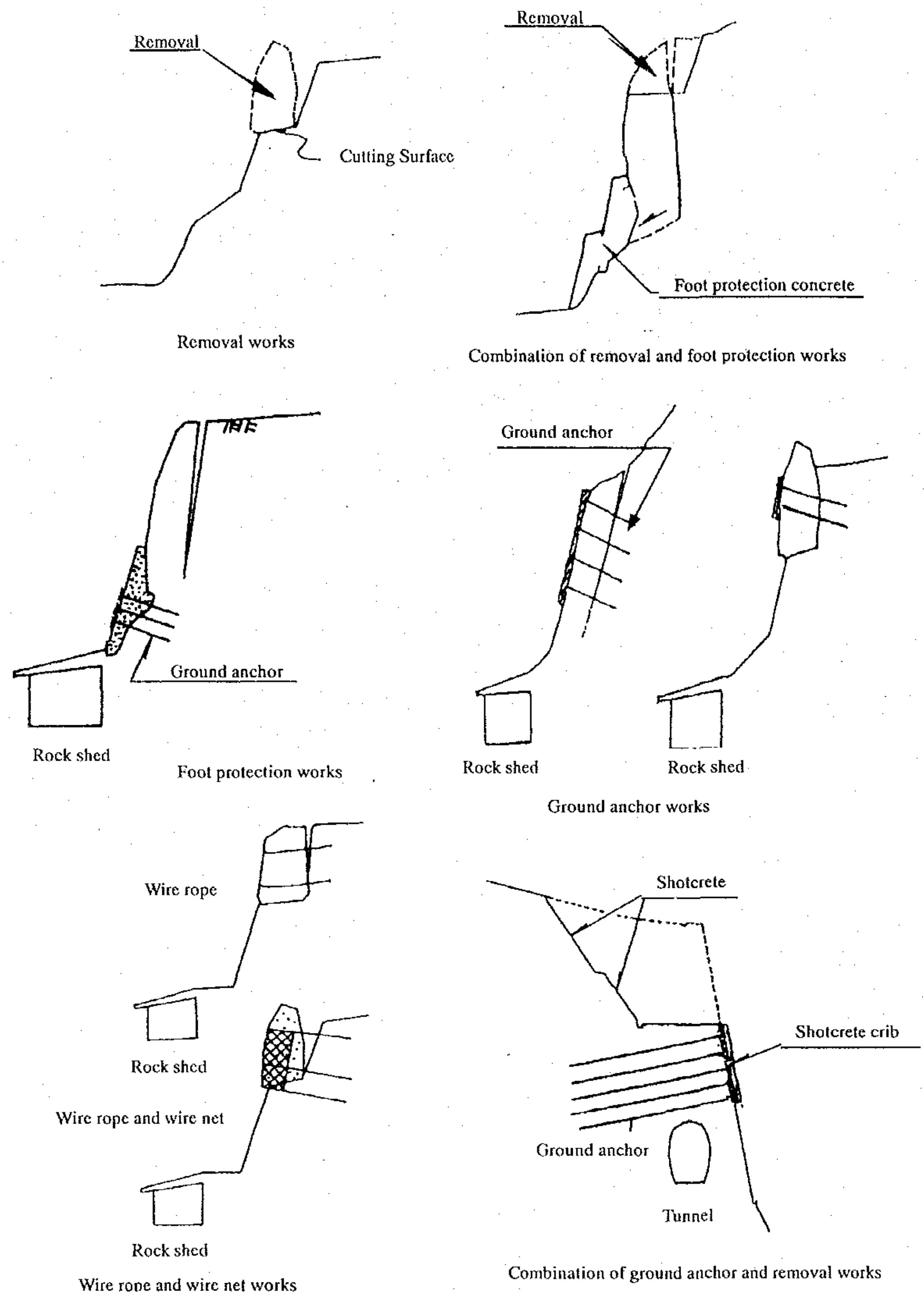


Figure 5.2.4 Examples of countermeasures against rock mass failure

CHAPTER 6 COUNTERMEASURES AGAINST LANDSLIDE (LS)

6.1 General

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

6.2 Selection of countermeasures

6.2.1 Classification of countermeasures

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

Table 6.2.1 Classification of Countermeasures against Landslides

CLASSIFICATION			TYPE OF WORK
CONTROLE WORK	1. EARTH WORK	Earth Work	Cutting
			Embankment
	2. VEGETATION	Vegetation	Hydroseeding
			Re-Vegetation
	3. WATER DRAINAGE	Surface Drainage	Drain Ditch and Cascade
			Subsoil Drainage Hole
		Subsurface Drainage	Horizontal Drain Hole
			Drainage Well
			Drainage Tunnel
RESTRAINT WORK	4.SLOPE WORK	Crib Work	Crib Work
	5. ANCHORING	Anchoring	Rock Bolt
			Ground Anchor
	6. WALL AND RESISTING STRUCTURES	Retaining Wall	Gabion Wall
			Retaining Wall
	7. PILING WORK	Piling Work	Steel Pipe Pile
			Shaft Work for Resistance Slide
9.OTHERS		Avoiding Problem Work	Diversion (shifting)
			Route Relocation
			Bridge, Tunnel

6.2.2 Criteria for selection of countermeasures

Figure 6.2.1 shows a flowchart for selection of countermeasures against landslides. Adequate works should be selected in consideration of the following points.

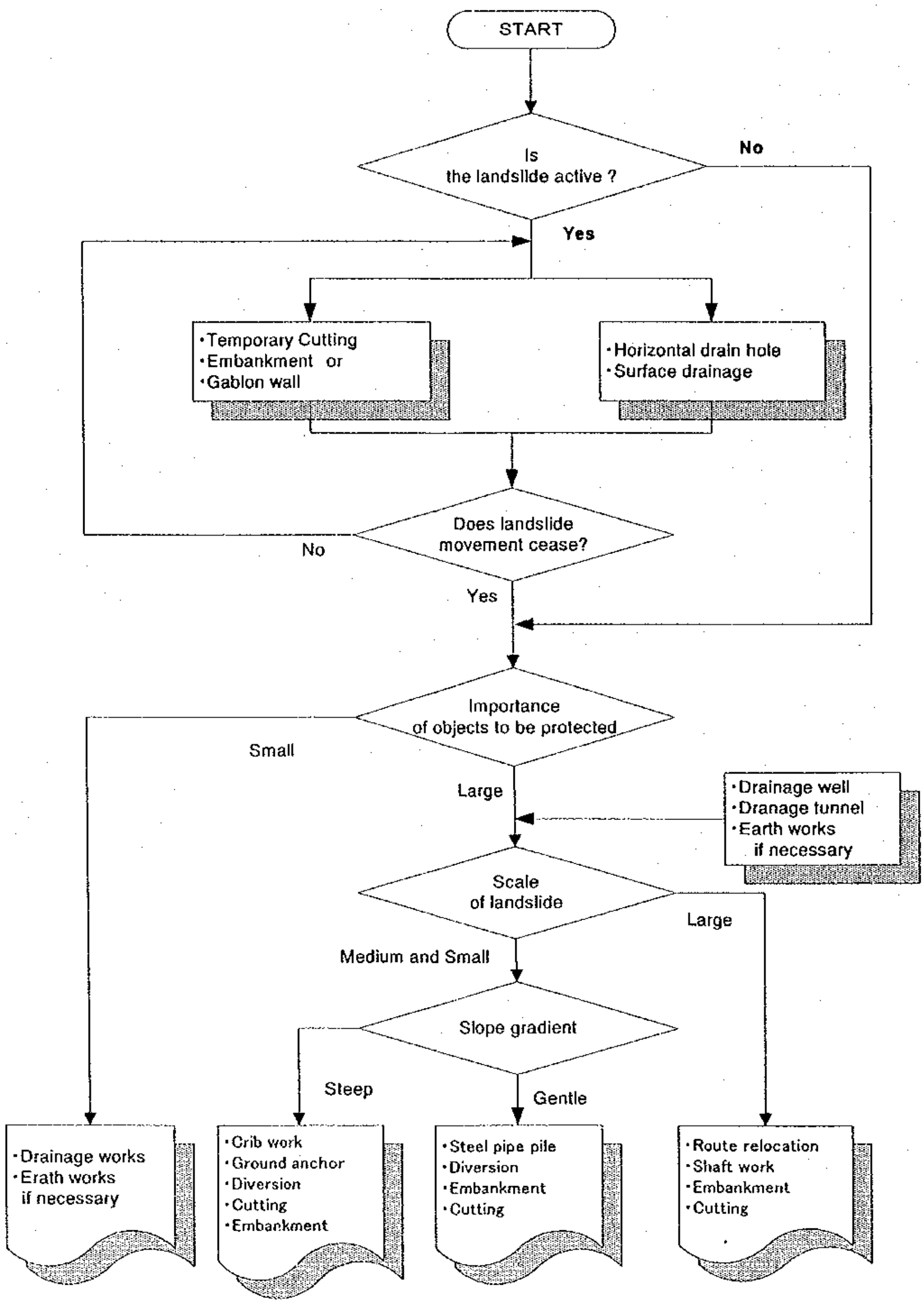


Figure 6.2.1 Flow chart for selection of countermeasures for landslide

The works selected should address the mechanism(s) of the landslide, the relationship between precipitation, groundwater and landslide movement, geological, topographical and soil properties, the scale and type of landslide and its likely movement velocity.
Control works should be regarded as the main method of landslide control, while restraint works should be adopted for the stabilization of small landslides to directly protect public facilities, houses, etc.
Where landslide movement is closely related to rainfall, surface drainage work should be immediately performed to minimise the infiltration of rainwater.
When a landslide continues to move, control works should be performed first; restraint works can then be done after reduction or arresting landslide movement by the control works.
An adequate combination of various works is cost-effective and should be selected.

6.3 Design considerations

6.3.1 Surface drainage

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

1) Purposes

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

2) Design Considerations

Drainage collection works are designed to collect surface flow by installing corrugated half pipes or lined U-ditches along the slopes, which are then connected to a drainage channel. The drainage channel works are designed to remove the collected water out of the landslide zone as quickly as possible, and are constructed from the same materials as the drainage collection works. The surface drainage control works are often combined with subsurface control works.
The drainage ditch beds should, in principle, be covered. Collecting boxes should be installed at the confluence with tributaries, curves and points of change in gradient (Figure 6.3.1).
Where conducted in the active area of a landslide, drainage ditches should have the required strength and be easy to repair. Bed consolidation should be planned every 20 to 30 m to prevent the drain ditch from sliding.
The shoulders and cut slope faces of the ditches must be protected with vegetation, boulder covers, and so on.

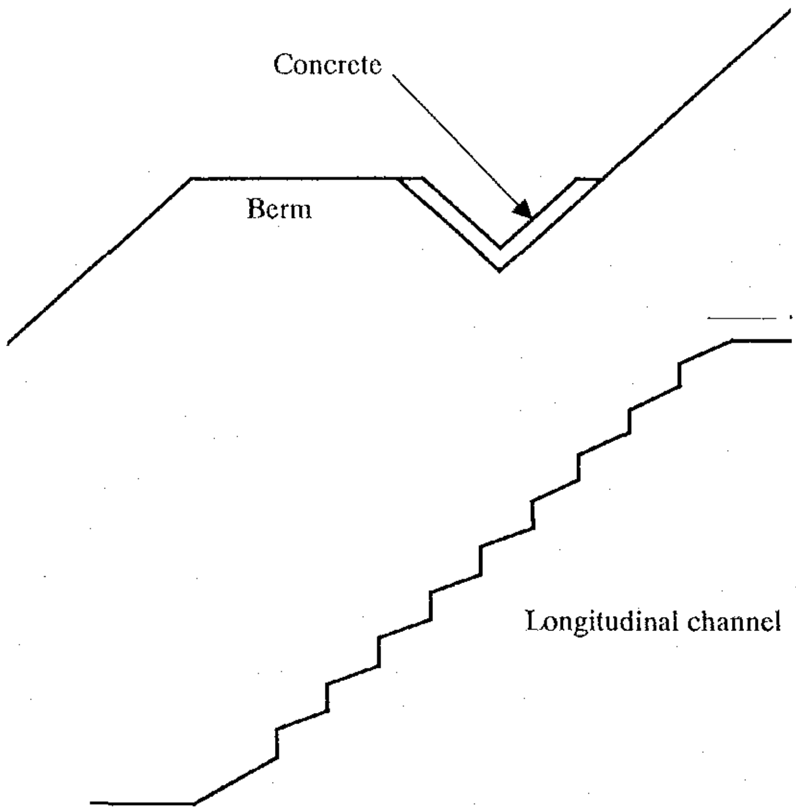


Figure 6.3.1 Standard drawings of drain

6.3.2 Horizontal drain hole

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

1) Purposes

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

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

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

2) Design Considerations

Horizontal drain holes are constructed for the drainage of shallow groundwater and deep groundwater. If topography prevents the groundwater from being drained on a gentle gradient, then drainage wells or tunnels with horizontal drain holes should achieve drainage. Horizontal drain holes, usually 20 to 50 meters in length, should be excavated at a gradient of 5 to 10 degrees with a diameter of 50 to 100 millimetres and should be designed to traverse aquifers.

A typical location of horizontal drain holes is shown in Figure 6.3.2.

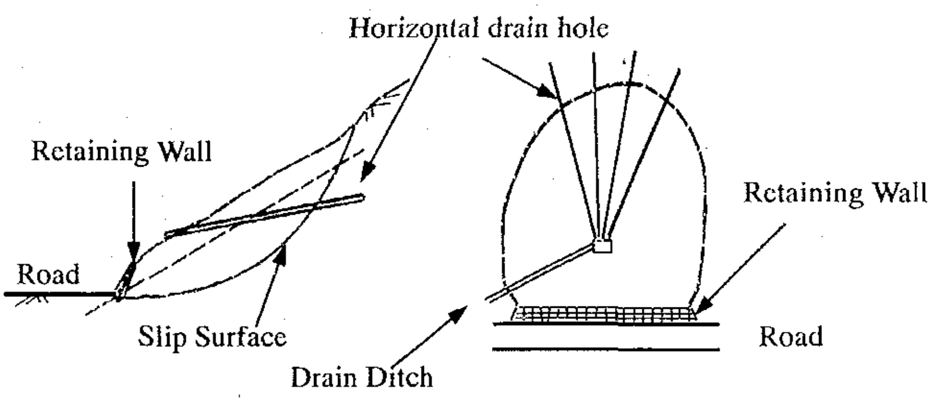


Figure 6.3.2 Typical location of horizontal drain holes

6.3.3 Drainage wells

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

1) Purposes

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

2) Design considerations

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

Collecting drains are similar to horizontal drain holes in terms of design considerations. The safety of drainage wells should be evaluated by checking the earth pressure of the surrounding area. The diameter of drainage holes should be based on catchment quality of groundwater. Figure 6.3.3 shows the details of a drainage well.

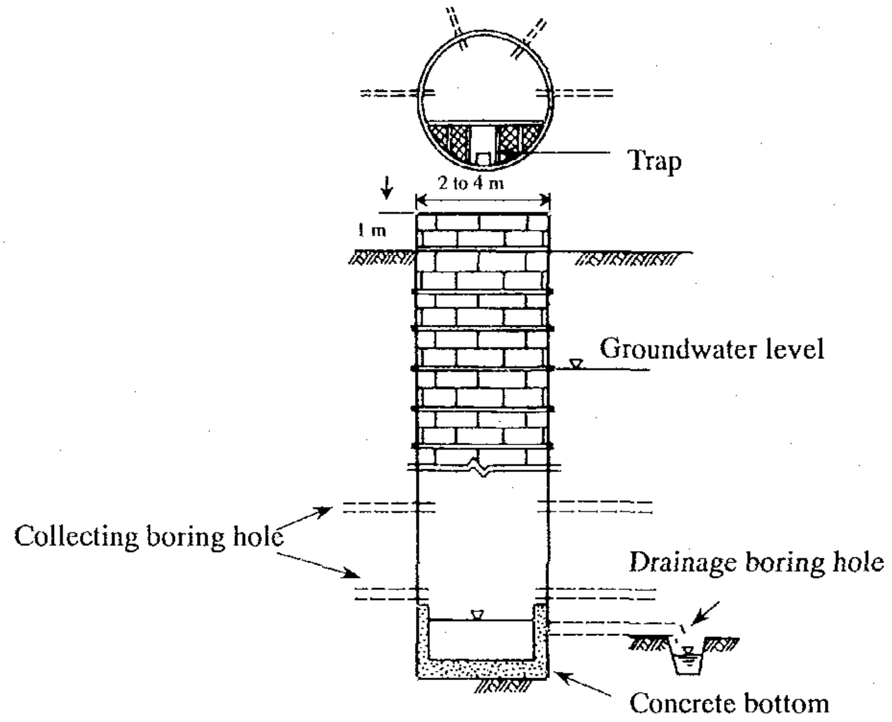


Figure 6.3.3 Details of drainage well

6.3.4 Ground anchor

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

1) Purposes

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

2) Design Considerations

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

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

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

Figure 6.3.4 shows a typical example of a stabilised landslide with ground anchors and Figure 6.3.5 shows details of an anchor structure.

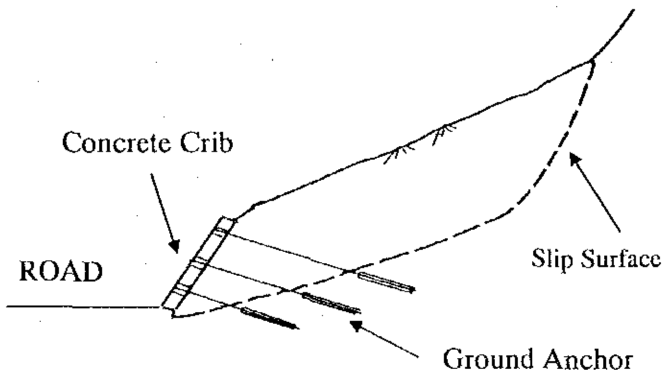


Figure 6.3.4 A landslide stabilized with ground anchors

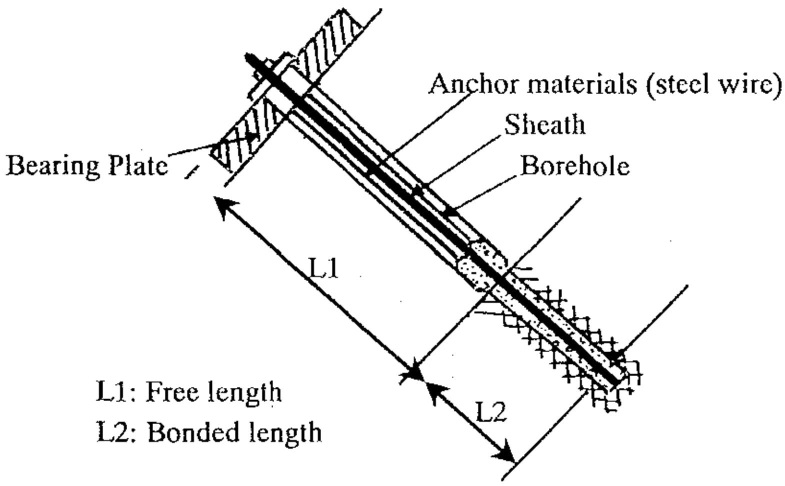


Figure 6.3.5 Outline of Anchor Structure

Figure 6.3.6 gives the design flowchart for anchors. The design process can be summarised as follows.

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

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

Td : Anchor power
Fsp : Design safety factor
c : Cohesion
l : Length of sliding surface
b : Width of slice
W : Weight of slice
u : Pore water pressure
α : Angle of slope of sliding surface
φ : Internal frictional angle of sliding surface (degree)
B: Interval between anchors in horizontal direction (m)
N: Number of anchor setting in vertical direction

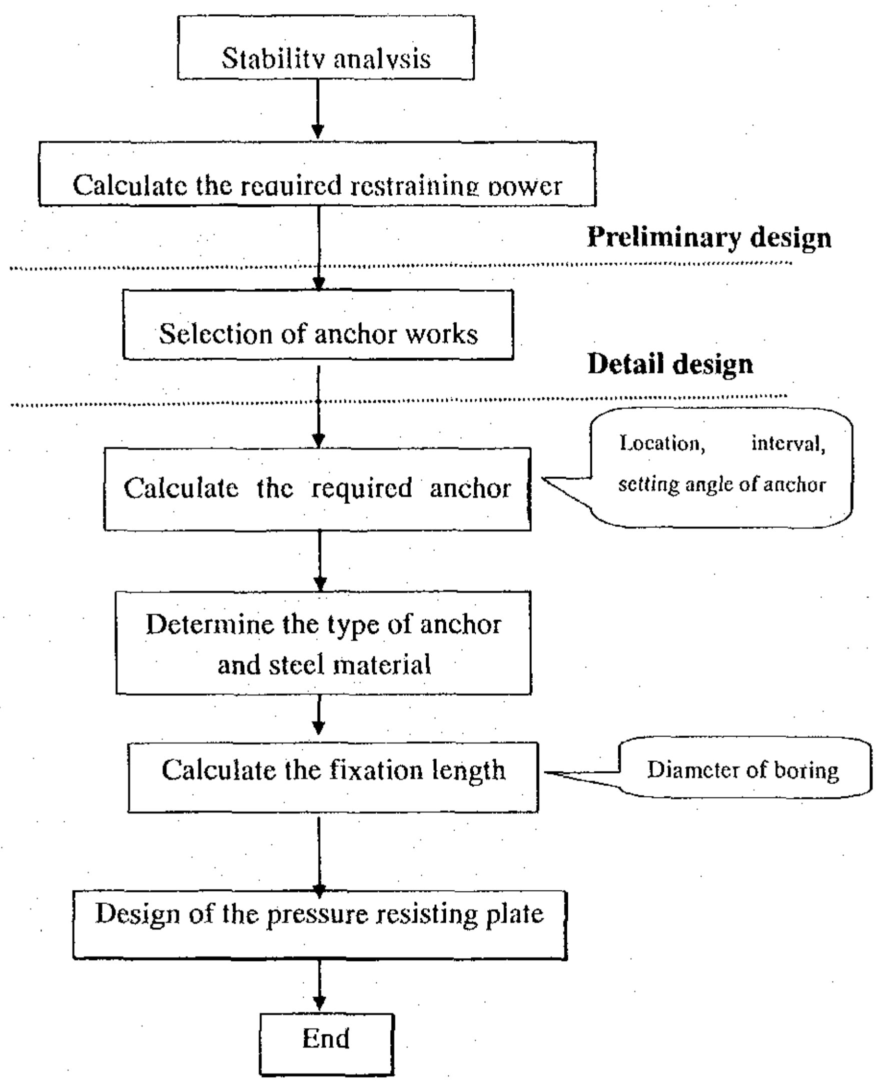


Figure 6.3.6 Design flowchart of anchor

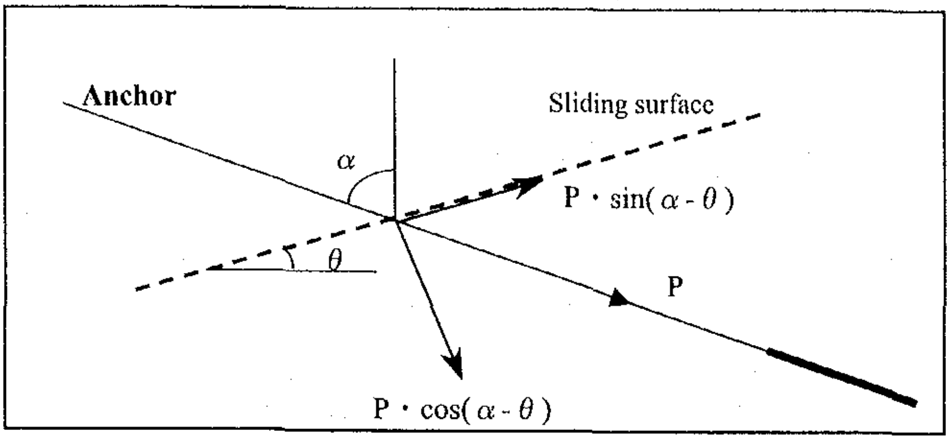


Figure 6.3.7 Functional description of an anchor

2. Determination of the type of anchor and steel material

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

3. Calculation of the fixed length of an anchor

For the design anchor power to meet the allowable anchor pullout force, the length of contact between the ground and grout must be compared with that between the tendon and grout. Whichever is longer should be used as the fixed length.

$$Tab = \pi D \cdot \tau ab \quad \cdots\cdots\cdots\cdots\cdots\cdots \quad (2.4.2)$$

Tab : allowable adhesive force (kN/m)

D : diameter of tendon (m)

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

$$Tag = \frac{1}{f} \cdot \pi D \cdot \tau ag \quad \cdots\cdots\cdots\cdots \quad (2.4.3)$$

Tag : skin friction force (kN/m)

f : safety factor

D : diameter of anchor (m)

τag : skin frictional resistance (kN/m^2)

$$ls = Td \,/\, \tau ab \quad (ls < lsa) \quad \cdots\cdots\cdots\cdots \quad (2.4.4)$$

ls : required length of tendon (m)

lsa : standard length of tendon

Td : design anchor power (kN/m)

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

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

CHAPTER 7 COUNTERMEASURE AGAINST DEBRIS FLOW (DF)

7.1 General

Debris flow countermeasure plans for hazardous streams should, in principle, be formulated to cope with debris flow rationally and effectively with respect to the occurrence frequency and scale of debris flow.

Debris flows generally involve a source area, transport zone, and a deposit area. Debris flow countermeasures are different for each of these zones and they should be considered separately.

For source areas, the range of possible countermeasures is basically the same as for landslides and collapse. Design considerations and purposes of these methods are given in Section 2.1 and Section 2.4. However, because of the wide area generally involved, vegetation and cutting works are both the most effective and the most costly.

The following mainly discusses methods for the transport zone and deposit areas.

7.2 Selection of countermeasures

7.2.1 Classification of countermeasures

Table 7.2.1 is a general classification of countermeasures for debris flow. The principal countermeasures are classified as follows according to their functions and the location of implementation.

a) Debris flow capturer structures
Sabo dams are the most typical example of this kind of structure, and include impermeable and permeable types. Their main functions are to (1) reduce the volume of sediment discharge, and (2) prevent the movement of sediments on streambeds.

b) Debris flow depositing works
Sabo dams and consolidation works are the main examples of this kind of works. They are used for reducing and depositing the debris flows.

c) Debris flow training works
Typical works are revetment, training levee and channel. These measures are used to direct debris flows to a safe place.

d) Debris flow prevention works.
Debris flow usually occurs at abundant unstable sediments on stream, so it is useful to prevent supply of stream sediment from mountain slopes. Prevention works should be done at mountain slopes by forest work, vegetation and some kind of structures to prevent collapse, landslides and other slope failures.

Table 7.2.1 Classification of Countermeasures against debris flows

CLASSIFICATION		TYPE OF WORK
1. EARTH WORK	Earth Work	Removal
		Cutting
		Embankment
2. VEGETATION	Vegetation	Hydroseeding
		Re-Vegetation
3. WATER DRAINAGE	Surface Drainage	Drainage Ditch (Channel)
	Water Way	Stone Pitching Water Way
		Concrete Pitching Water Way
4. SLOP WORK	Shotcrete Work	Shotcrete (mortar)
		Shotcrete (concrete)
	Crib Work	Crib Work
6. WALL AND RESISTING STRUCTURES	Retaining Wall	Gabion Wall
		Stone Pitching Wall
		Retaining Wall (Gravity Type)
		Retaining Wall (Supported Type)
	Catch Work	Catch Gabion
8. PROTECTION WORK	Rock Shed	Rock Shed
	Sabo (Check) Dam	Slit Dam
		Check Dam (Sabo Dam)
9. OTHERS	Avoiding Problem Work	Bridge (or Culvert)
		Route Relocation

7.2.2 Criteria for selection of countermeasures

Figure 7.2.1 shows a flowchart for selection of countermeasures for debris flow. In planning countermeasures on a stream prone to debris flow, various types of countermeasures should be reasonably combined in consideration of the likely occurrence frequency, volume (scale), flow characteristics, topography, and the objects to be protected.

For streams with a high frequency of debris flow occurrence, the following criteria should be used for selection and planning.

1. Calculate the proposed sediment discharge after consideration of the actual probable sediment discharge of debris flows.
2. Determine the type, location, and scale of countermeasures comprising a combination of works.

For hazardous streams with a low frequency of debris flow occurrence, the following procedures should be used for selection and planning.

1. Calculate the proposed sediment discharge on the basis of surveys of deposits within the streambed.

2. Plan and establish debris flow capture structures, debris flow depositing works and debris flow training works near the existing of debris flow.

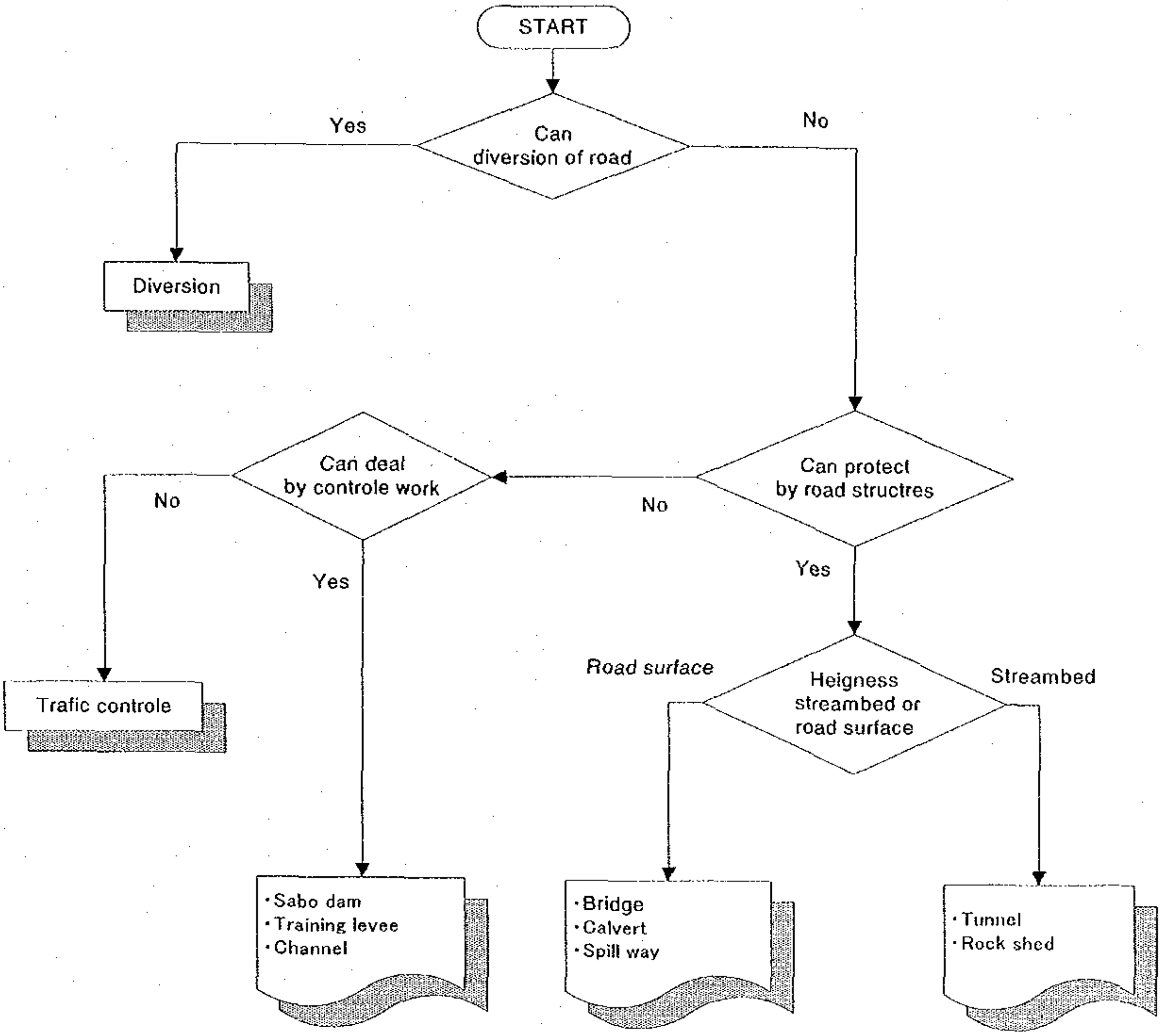


Figure 7.2.1 Flow chart for selection of countermeasures for debris flow

7.3 Design considerations

7.3.1 Sabo dam

Of the various countermeasures against debris flow, the most common approach is the construction of sabo dam(s). Sabo dams can take different functions depending on the location in which they are implemented. They can be constructed from masonry, concrete, reinforced concrete, steel crib, or timber.

1) Purposes

Sabo dams are implemented (a) to prevent erosion and toe failure of potentially unstable slopes; (b) to prevent and eliminate damage from debris flow itself; and (c) to improve the stability of a slope through sedimentation behind the dam.

2) Design Considerations

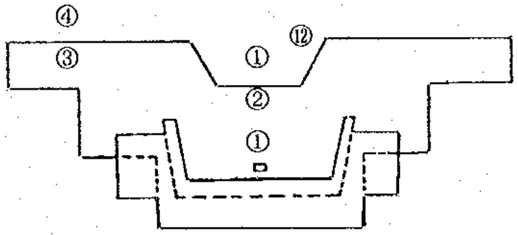
In designing a sabo dam, the location and scale (height and section) of the dam should be determined according to its purposes. In principle, the dam should be located on stable ground beyond the unstable area because sabo dams are easily destroyed by slope failure when constructed in an unstable area. A narrow location with a wider upstream section is desirable for improving cost-effectiveness.

The dam's foundations, especially where the height of the dam exceeds 15 meters, should be determined in consideration of the bearing capacity and permeability of the foundation rock. When the dam foundation conditions are poor, foundation treatment should be considered.

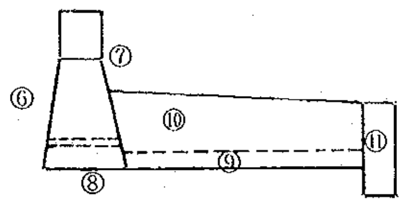
The height from the base of the dam to the crown of the overflow section (dam height) should be determined by considering the ground conditions, the proposed sediment discharge and the purpose of the dam.

Furthermore, stability against settlement of the foundation ground as well as the potential for the dam base to slide across the foundation ground should be considered.

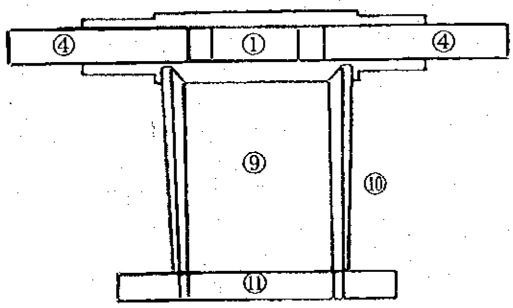
Figure 7.3.1 diagrammatically illustrates dam section nomenclature. Figure 7.3.2 gives an example of landslide stabilization with a sabo dam.



(a) Front view



(b) Side view



(c) Plan view

①	Spillway	⑦	Downstream slope
②	Spillway crown	⑧	Base of dam
③	Wing	⑨	Front apron
④	Wing crown	⑩	Side wall
⑤	Drain hole	⑪	Vertical wall
⑥	Upstream slope	⑫	Side of spillway

Figure 7.3.1 Diagrammatical dam section nomenclatures

(a) Cross section

(b) Plan

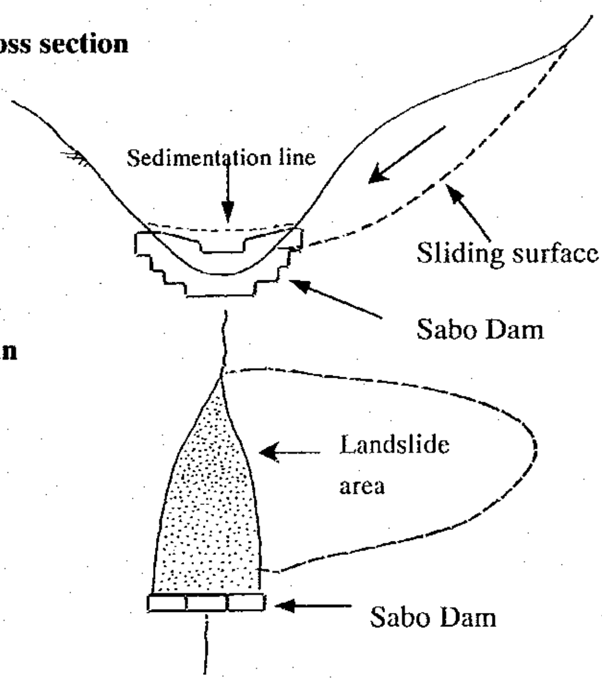


Figure 7.3.2 A typical example of landslide stabilised with a sabo dam

CHAPTER 8 COUNTERMEASURE AGAINST EMBANKMENT FAILURE (EB)

8.1 General

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

8.2 *Selection of countermeasures*

8.2.1 Classification of countermeasures

Table 8.2.1 shows the classification of countermeasures for embankment failures

Table 8.2.1 Classification of Countermeasures against embankment failures

CLASSIFICATION		TYPE OF WORK
1. EARTH WORK	Earth Work	Embankment
2. VEGETATION	Vegetation	Hydroseeding
		Re-Vegetation
3. WATER DRAINAGE	Surface Drainage	Drain Ditch and Cascade
	Subsurface Drainage	Horizontal Drain Hole
		Culverts
4. SLOPE WORK	Pitching Work	Stone Pitching
	Crib Work	Crib Work
5. ANCHORING	Anchoring	Soil Nail
		Ground Anchor
6. WALL AND RESISTING STRUCTURES	Retaining Wall	Gabion Wall
		Stone Pitching Wall
		Concrete Block Wall
		Retaining Wall (Gravity Type)
		Retaining Wall (Supported Type)
		Crib Wall
		Pile Wall

8.2.2 *Criteria for selection of countermeasures*

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

1. In principle, a standard embankment slope (gradient and height) should be designed, especially where sufficient land is available to meet the full width of the base of the embankment. If sufficient space is not available, a retaining structure such as a retaining wall should be considered.
2. The surface of an embankment should, in principle, be protected by closed turf. Selection of a type should take into account the susceptibility of embankment materials to weathering or erosion.
3. Separate drainage work to deal with surface water runoff and groundwater inside the embankment is essential, for both construction effectiveness and the long-term stability of the embankment.

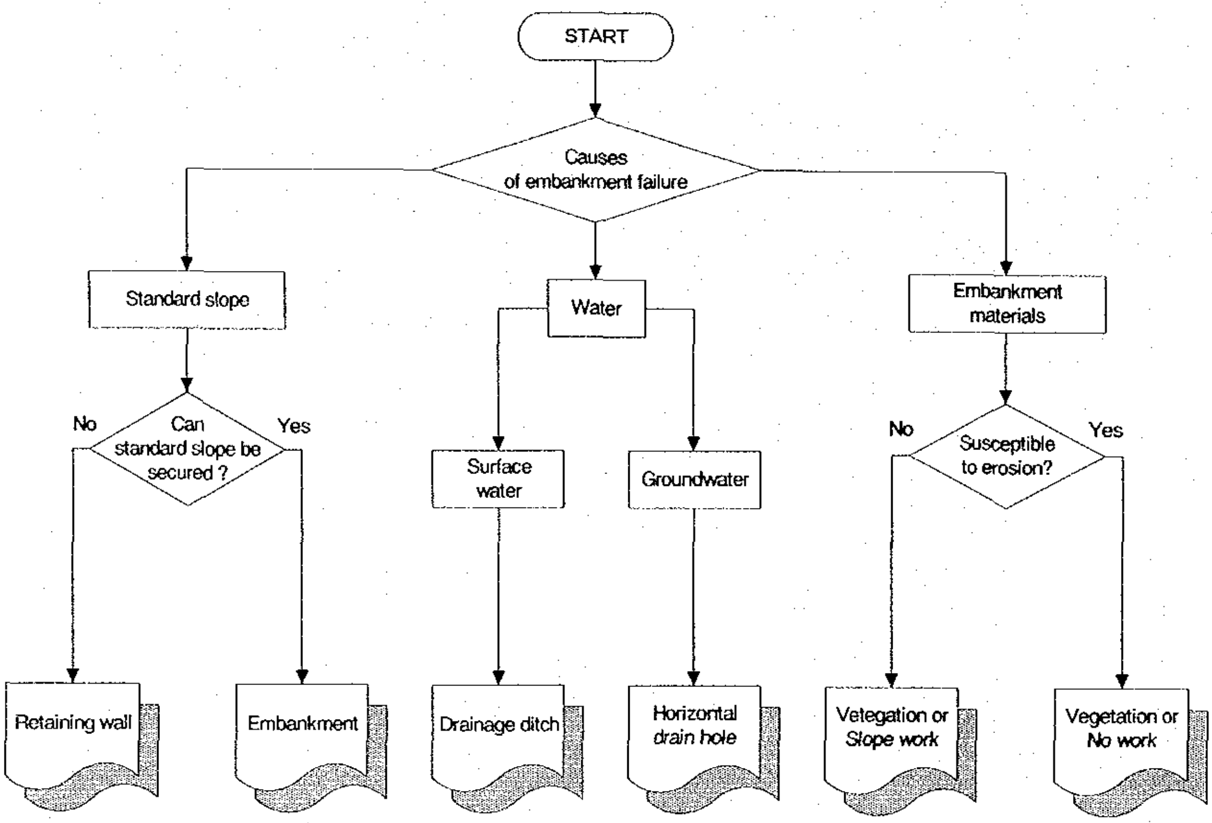


Figure 8.2.1 Flow chart foe selection of countermeasures for embankment failure

8.3 Design consideration

8.3.1 Embankment

1) Purpose

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

2) Design considerations

The main considerations for embankments chiefly concern stability analysis as well as the selection of slope gradient in proportion to embankment materials. In selecting embankment materials, their strength and deformation characteristics should be considered. Table 8.3.1 gives the recommended standard embankment slope for different embankment materials. These can only be applied where the foundation ground has sufficient bearing capacity.

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

Table 8.3.1 Recommended Standard Embankment Slopes

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

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

8.3.2 Other works

Design considerations for vegetation work and slope works involved in embankment design are given in Chapter 2 and chapter 5.