7.3 SURFACE DRAINAGE

Refer to APPENDIX 2; STANDARD DRAWING NO. 2; SURFACE DRAINAGE

Surface drainage facilities for slope protection are classified into:

- Top slope ditch
- Berm ditch
- Side ditch
- Vertical ditch

Each drainage facility is discussed below:

7.3.1 Top Slope Ditch

Top slope ditch are designed based on discharge but with some allowances considering terrain, slant and soil. They are provided along the entire length of the top of slope to avoid down-flow and seepage of surface water from the surrounding area. Ends of the ditch are connected with existing drainage system. The following types can be adopted:

- Gravel Ditch
- Soil Cement Ditch
- Stone Pitching Ditch
- Prefabricated Concrete U-Type Ditch

The following is a brief description of each type:

(1) Gravel Ditch

Gravel ditch may be used where the volume of catched water is small and the ground consists of impermeable soil. (See Figure 7-3).

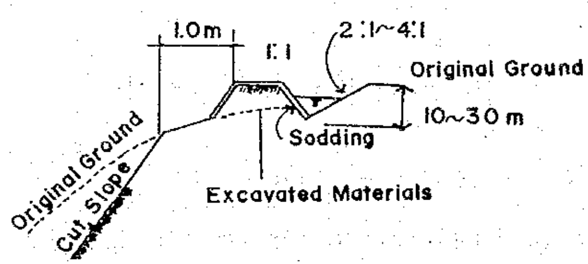


FIGURE 7-3 GRAVEL DITCH

(2) Soil Cement Ditch

Soil cement ditch can be adopted where the volume of water is a little large, and seepage is desirable to be prevented. The ratio of cement in dry weight may be 5 ∼ 10%, preferably 6%. Sandy soil would be a good material. However, if sandy soil is not available, lean mix concrete (cement volume 180 kg/m^3) may be used. See Figure 7-4.

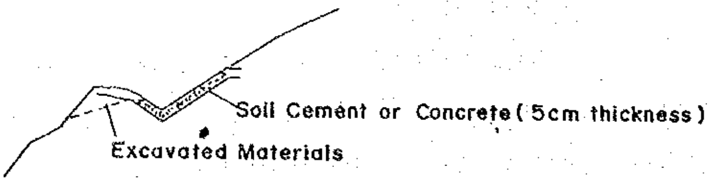


FIGURE 7-4 SOIL CEMENT DITCH

(3) Stone Pitching Ditch

Stone pitching ditch is preferred where the volume of water is big and the length of ditch is long. See Figure 7-5.

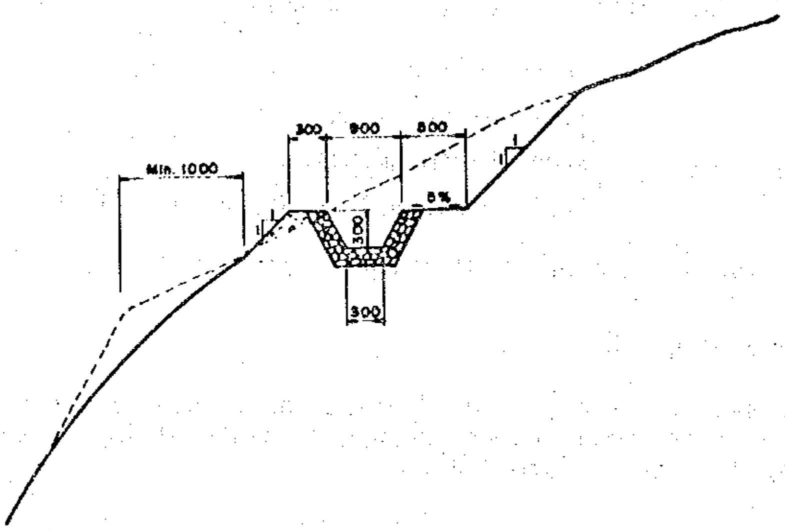
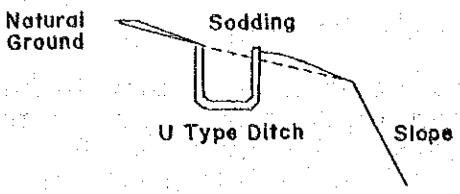


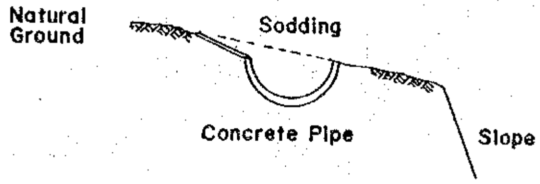
FIGURE 7-5 STONE PITCHING DITCH

(4) Prefabricated Concrete U-Type Ditch

Prefabricated reinforced concrete U-shaped type ditch or half circle-shaped centrifugal reinforced concrete pipe may be recommended where the volume of water is considerably big and the length of ditch is quite long. See Figure 7-6.



(a) PREFABRICATED CONCRETE U-TYPE DITCH



(b) HALF CIRCLE-TYPE CONCRETE PIPE

FIGURE 7-6 CONCRETE U-TYPE DITCH AND HALF CIRCLE-TYPE CONCRETE PIPE

7.3.2 Berm Ditch

Berm ditch are designed to discharge surface water on the slope above the berm for the protection of the slope below the berm. The types of berm ditch used are similar with those on top of slope.

- Gravel Ditch
- Soil Cement Ditch
- Stone Pitching Ditch
- Reinforced U-Type Ditch

Illustration of each type is described below:

(1) Gravel Ditch

Same as gravel ditch on top of slope.

(2) Soil Cement Ditch

Same as soil cement ditch. See Figure 7-7.

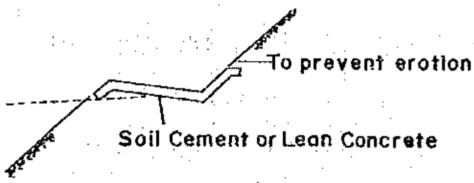


FIGURE 7-7 SOIL CEMENT DITCH

(3) Stone Pitching Ditch

Where the volume of water is considerably big and the length of berm ditch is long, stone pitching ditch as shown in Figure 7-8 is preferred.

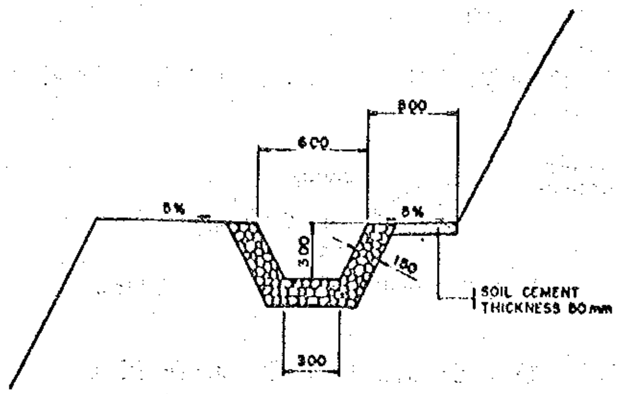


FIGURE 7-8 STONE PITCHING DITCH

(4) Reinforced U-Type Ditch

When the volume of water is quite big, reinforced concrete U-type ditch may be used. See Figure 7-9.

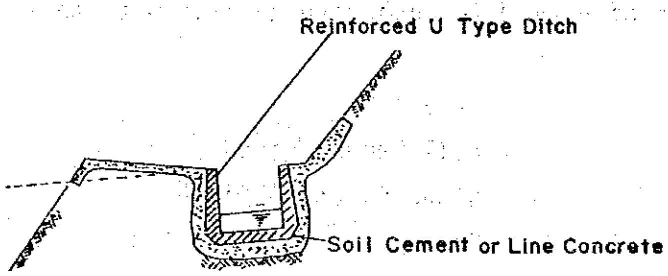


FIGURE 7-9 REINFORCED U-TYPE DITCH

7.3.3 Side Ditch

Side ditch are designed to cope with the maximum amount of run-off from the slope and adjacent areas.

The following types of ditch are generally used:

- Gravel Ditch
- Stone-Pitching Ditch
- Stone Masonry Ditch
- Cast-in-Place Concrete Ditch
- Precast Concrete Ditch

A description of each type is described below.

(1) Gravel Ditch

Gravel ditch may be used where the discharge is less and there is enough space available. See Figure 7-10.

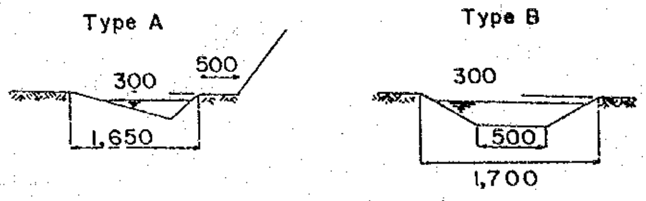


FIGURE 7-10 GRAVEL DITCH

(2) Stone-Pitching Ditch

The bottom of the ditch is protected with boulder stones. This type is adoptable when the velocity of water is a little faster. See Figure 7-11.

FIGURE 7-11 STONE PITCHING DITCH

(3) Stone Masonry Ditch

The ditch is covered with boulders at one or both sides, sometimes even the bottom. See Figure 7-12.

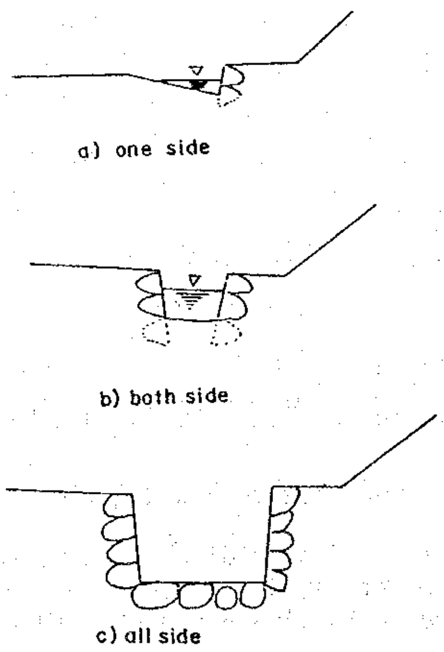


FIGURE 7-12 SEVERAL TYPES OF STONE MASONRY DITCH

The following stone masonry ditches may be recommended for mountainous and rolling areas, as shown in Figure 7-13.

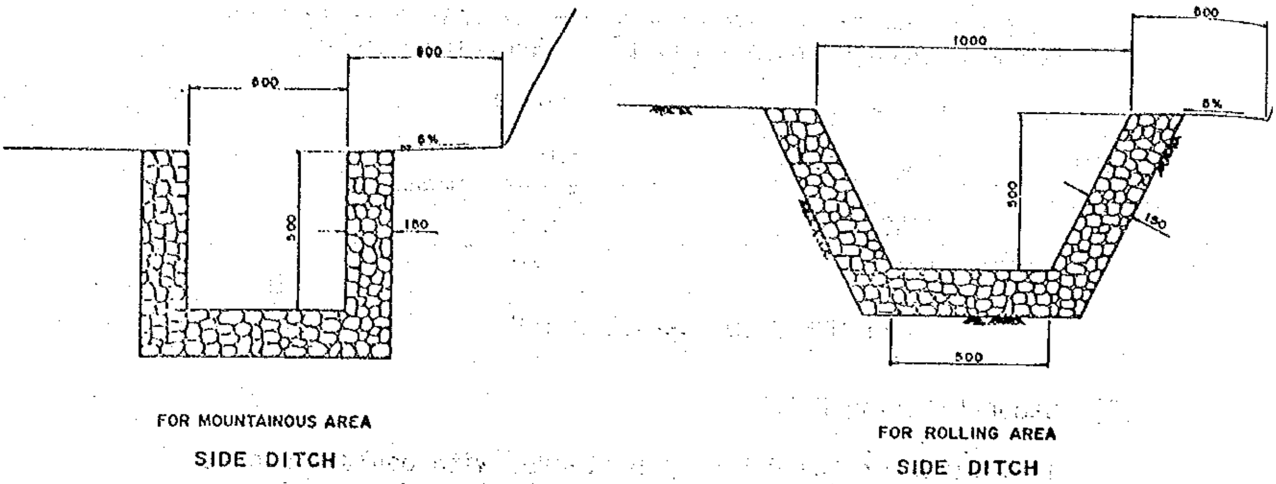


FIGURE 7-13 RECOMMENDED STONE MASONRY DITCH

7.3.4 Vertical Ditch

A vertical ditch is installed on the slope as waterway of run-off from ditches on top of the slope and at berms to the main drainage channel at the toe of the slope.

The following types of ditch are generally used:

Open Ditch

- Reinforced Concrete U-Shape Gutter
- Stone Pitching Canal
- Half Circle Hume Pipe

Closed Conduit

- Reinforced Concrete Pipe
- Cast-in-Place Concrete Ditch
- Vitrified Clay Pipe

A rough description of each type of ditch is discussed below.

(1) Reinforced Concrete U-Shaped Gutter

The advantage of open ditch such as reinforced concrete U-shape gutter, is it's easier to construct and maintain as compared with closed conduit type.

Typical U-shape gutter with socket and catch basin is shown in Figure 7-14.

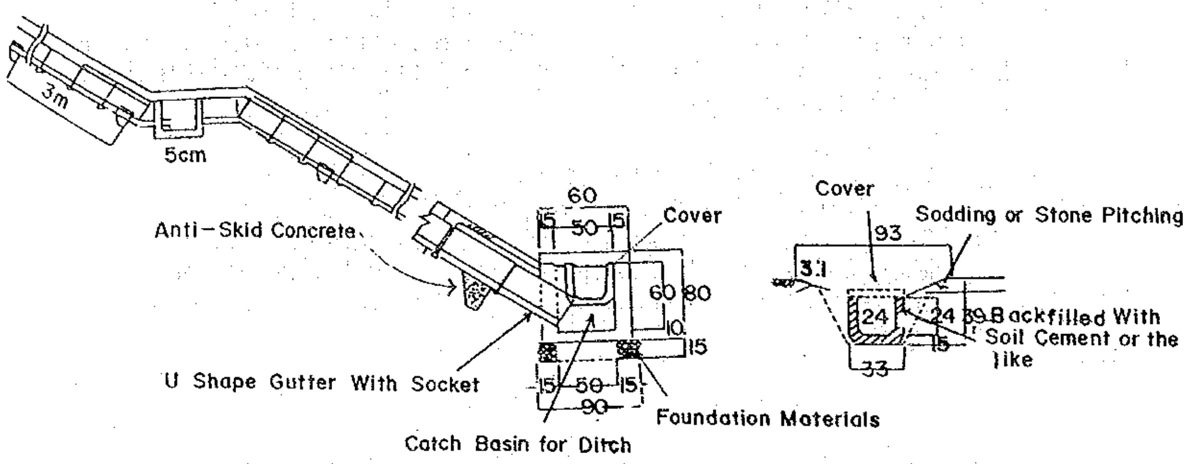


FIGURE 7-14 REINFORCED CONCRETE U-SHAPED GUTTER

Joint of Gutter

U-shape gutter with socket at the end is more preferable. The socket are well joined with mortar to prevent water from permeating to the back of the gutter from the gaps of joints.

Anti-skid concrete shall be provided at every 3 m. to prevent skid gutter.

Sodding or Stone Pitching

The speed of water running down through the vertical ditch is so fast that water may often splash out, thereby scouring both sides of the ditch. It is therefore, desirable to provide slopes at both sides of the ditch and to cover with sods on stone pitching.

Cover of Gutter

When the gradient is more than 1:1, the gutter is usually provided with cover with gutter gradient within 1.0 to 2.0 meters from the toe of slope.

Catch Basin

At places where the direction of water flow suddenly changes or when a vertical ditch meets other waterways, covered catch basins with simple sand pits are installed to reduce the energy of running water.

(2) Stone-Pitching Canal

Stone-pitching canal may be used as vertical open ditch when the water discharge is not so much and aesthetic consideration is not required. An example is shown in Figure 7-15.

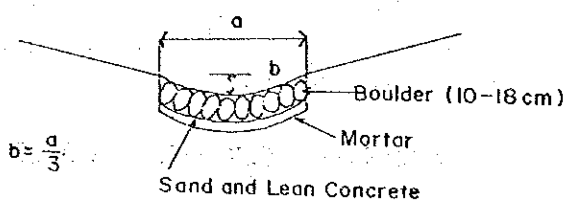


FIGURE 7-15 STONE-PITCHING CANAL

(3) Reinforced Concrete Pipe

Reinforced concrete pipe may also be used for vertical ditch as closed conduit. The maintenance, however, is not easy, thus it requires catch basins at proper intervals. A typical example is shown in Figure 7-16.

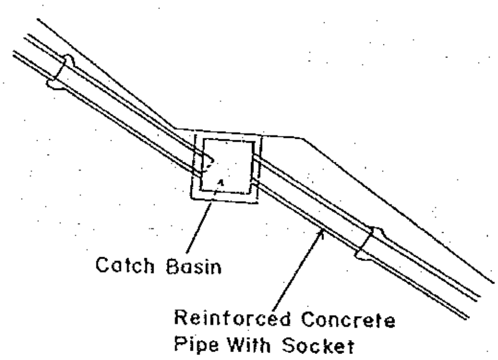


FIGURE 7-16 REINFORCED CONCRETE PIPE

(4) Cast-in-Place Concrete Ditch

Where the discharge is quite big and the velocity of water is fast, concrete ditch is recommended. Cast-in-place reinforced concrete ditch is often used, with or without cover. See typical example in Figure 7-17.

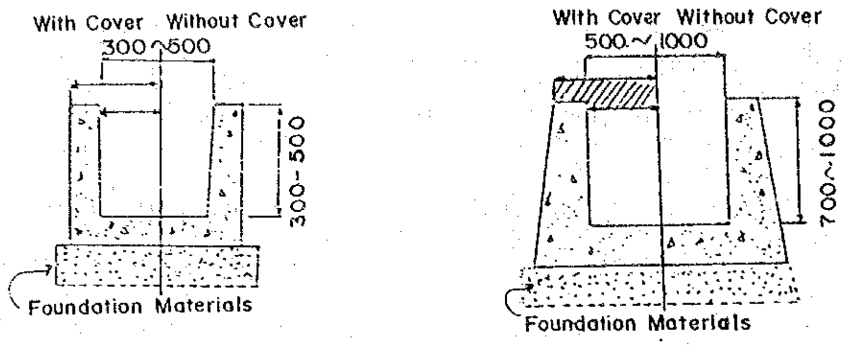


FIGURE 7-17 CAST-IN-PLACE CONCRETE DITCH

7.4 SUBSURFACE

Refer to APPENDIX 2; Standard Drawing No. 3; Subsurface Drainage.

Groundwater, spring water and seepage water near ground surface permeating into slope shall be drained in order to protect the stability of the slope. Subsurface drainage facilities are usually used in their case and are classified as follows:

<u>For groundwater in shallow stratum</u> (2 ~ 3 m. deep)

- Closed Conduit
- Closed Conduit with open ditch
- Gabion (Wire Cylinder)
- Horizontal Drain Hole

<u>For groundwater in deep stratum</u> (deeper than 3 m.)

- Horizontal Drain Hole
- Vertical Weep Hole
- Horizontal Drainage Layer

These subsurface facilities shall be systematically arranged with effective combination of conduit and channel as discussed in Section 7.4.3.

7.4.1 Drainage for groundwater in shallow stratum

(1) Closed Conduit and Closed Conduit with open ditch as collecting Conduit

Closed conduit and close conduit with open ditch are most suitable to collect and drain groundwater in shallow stratum (about 3 m. below ground surface). These are effective particularly to groundwater in soils with small coefficient of permeability.

These conduits are constructed in such a way that a fascine or gabion is installed in the ditch excavated to a predetermined depth as shown in Figure 7-18. Vinyl cloth or asphalt board is laid below them to prevent any leakage. Gravel is placed with filter around and above them to prevent clogging. Where the amount of collected water is large, perforated pipes are sometimes used. Catch basins or manholes are normally installed at every 20 to 30 m of conduit and are connected to surface water channel or draining conduit.

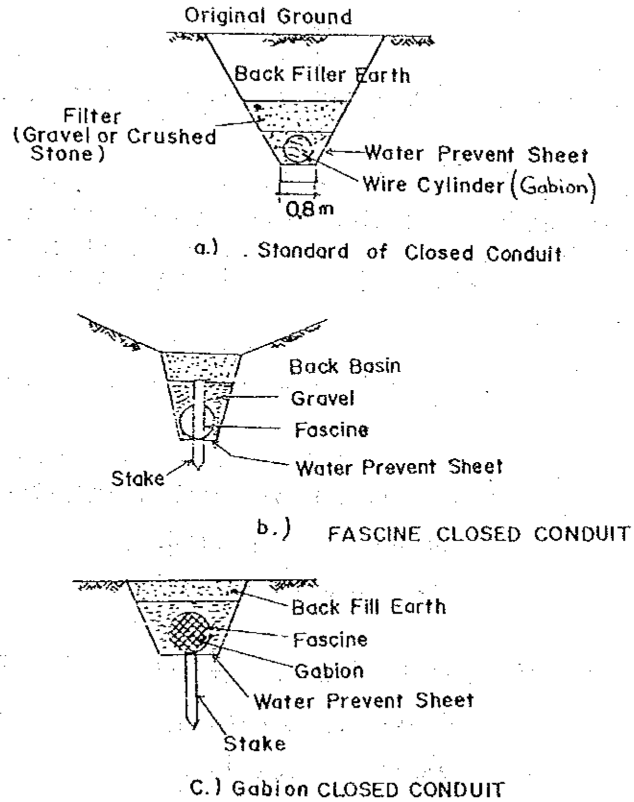


FIGURE 7-18 CLOSED CONDUIT

The flow of shallow groundwater which is similar to surface water is changed by terrain and is concentrated to valley or concaves. Closed conduit with open ditch is used in these cases to collect groundwater and surface water at the same time. A typical structure is shown in Figure 7-19.

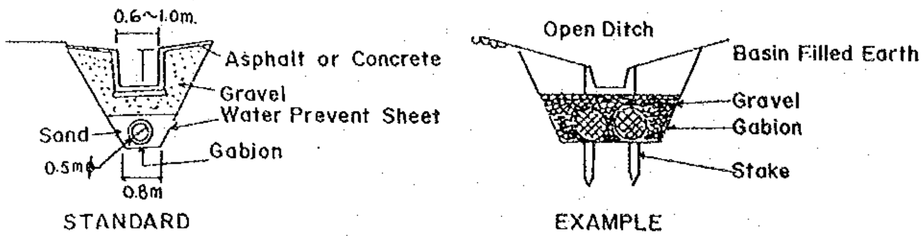


FIGURE 7-19 CLOSED CONDUIT WITH OPEN DITCH

(2) Gabion (Wire Cylinder)

For a slope with extensive spring water, gabion is laid near the toe of slope to function together with groundwater drainage facilities. Gabion is useful not only for drainage but also for preventing any failure at the toe of slope as shown in Figure 7-20 (a). For relatively small slopes, gabion is sometimes embedded instead of the groundwater drainage facilities, as shown in Figure 7-20 (b).

FIGURE 7-20 GABION

7.4.2 Drainage for Groundwater in Deep Stratum

(1) Horizontal Drain Hole

Horizontal drain hole may be used for groundwater in both shallow and deep strata.

Where spring water comes out to the face of slope, hole should be drilled and perforated pipes be inserted to the hole to drain water as shown in Figure 7-21. The length of this hole should not be less than two meters.

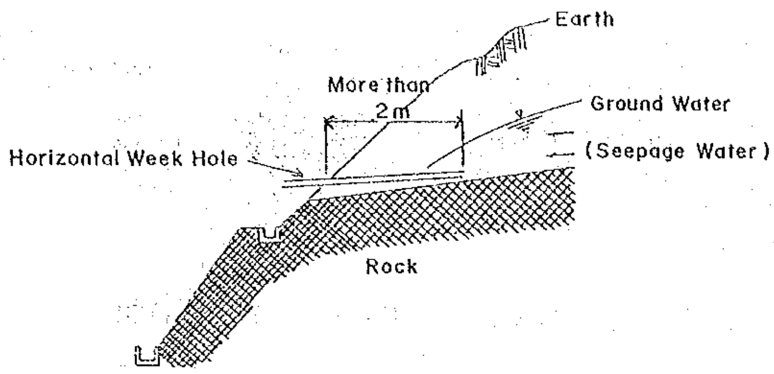


FIGURE 7-21 HORIZONTAL DRAIN HOLE

Where the stability of a long and large slope is likely to decrease due to seepage water, the drain hole shall be made into an acquifer to drain water. This is made by boring, the location of which shall be widely spread as shown in Figure 7-22, and a pipe with strainer should be inserted. The angle of drilling should be greater than 5° toward the acquifer. In this case, drilling work has to be carefully carried out because the fine-drained soil may flow out of the piping which may occur as a result of a runoff of water from the acquifer. The end of weep hole may sometimes scour due to discharge and, thus, should be protected by gabions or concrete wall.

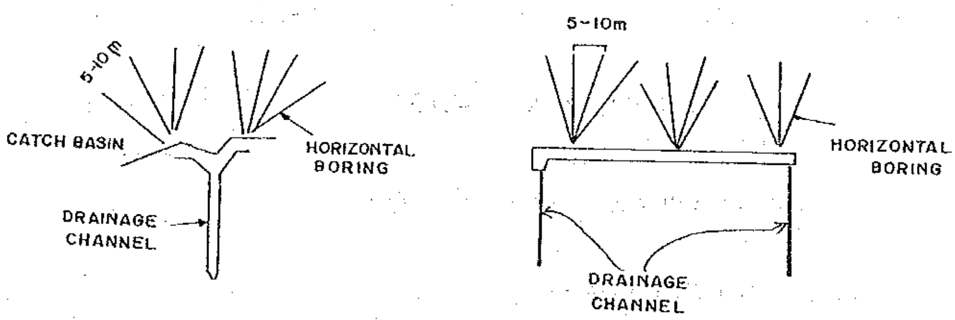


FIGURE 7-22 LOCATION OF BORING FOR HORIZONTAL DRAIN HOLE

(2) Vertical Weep Hole

Vertical weep holes with catchment well work made inside the slope or through the face of slope to remove the seepage water are normally used for this purpose.

(3) Horizontal Drainage Layer

In order to prevent the failures of embankment slopes, sand drainage layers may be arranged for every certain thickness of embankment. If a high embankment slope is constructed with earth which has large water content, pore water pressure inside the embankment may rise, resulting sometimes to the warping or failure of the face of the slope. To prevent this problem, sand drainage layers can be arranged as shown in Figure 7-23, to cause pore water pressure to decrease thus stabilizing the embankment slope.

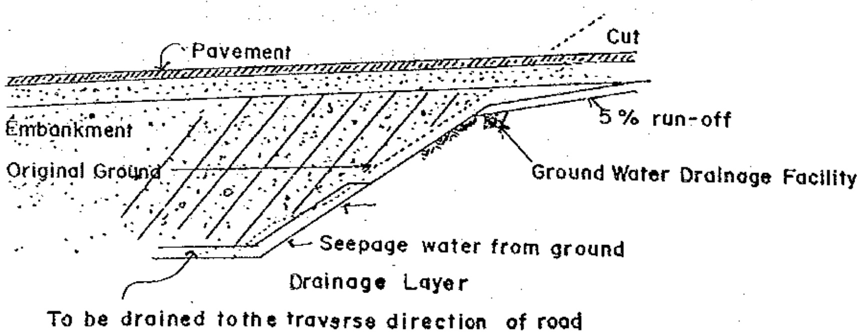


FIGURE 7-23 SAND DRAINAGE LAYER

Drainage layers may also be effective in preventing any failures when the seepage water from the ground adjacent to embankment slope will permeate into the slope.

A sand drainage layer is sometimes formed on the surface of the ground to prevent the infiltration of water from the ground to the embankment slope. The thickness of the drainage layer varies with the discharge of infiltration but is normally 20 to 30 cm. It is effective to embed perforated pipes in the drainage layer where high seepage water exists.

7.4.3 Subsurface Drainage System

To collect and drain groundwater permeating into the slope and seepage near the ground surface, groundwater drainage system should be designed as shown in Figure 7-24.

The groundwater drainage facilities are laid in the form of W-shape or Y-shape depending upon the condition of seepage in the slope. Catch basins or perforated pipes embedded in ditches are preferable at places where large seepage water exists or where several ditches meet each other.

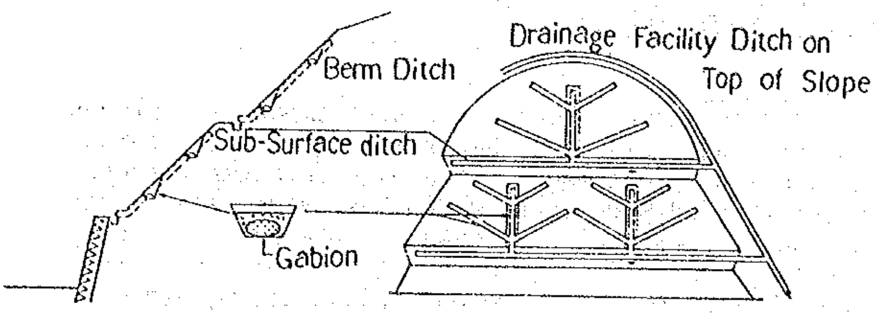


FIGURE 7-24 GROUND WATER DRAINAGE SYSTEM

Groundwater collected through closed conduit system should be immediately drained through surface drainage facilities, such as drain channel through draining conduit. Figure 7-25 shows a typical combination of conduit and channel drainage system.

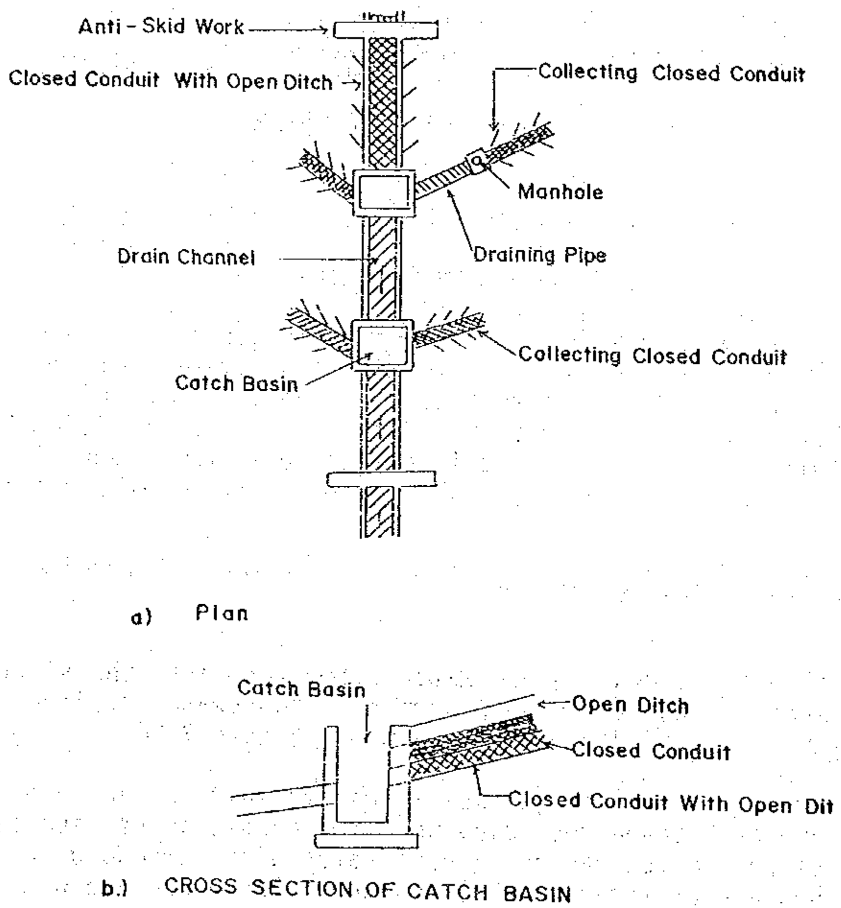


FIGURE 7-25 COMBINATION OF CONDUIT AND CHANNEL

CHAPTER 8 DESIGN OF PROTECTION WORKS

8.1 GENERAL

8.1.1 Summary of Countermeasures for Road Disasters

In general, the work on the countermeasures to protect, control or restrain road disasters are defined and classified in several ways in accordance with i) places where these works are applied, ii) purposes of works acting against disasters iii) materials to be used, and iv) shapes of works.

In the Study, the countermeasures are classified in the following eleven (11) types giving consideration to the convenience and the importance of the simplicity as an approach:

- Drainage Work
- Protection Work
- Earth Work
- Structural Work
- Fixing Work
- Catch Work
- Rock Work Shed
- Hillside Work
- Torrent Work
- Sabo Work
- Avoiding Problem Work

Table 8-1 summarizes these countermeasures in relation to the types of road disaster where they are aptly applicable, while detailed discussions on them are contained in the pertinent chapters hereof.

In this chapter, protection work which is one of the above types, is discussed.

8.1.2 Type of Protection Work

Protection work aims to eliminate or minimize erosion and/or weathering by constructing or implementing the countermeasure either directly on the surface of the slope or subsurface as the case may be. There are a number of protection works known to be effective countermeasures. They are classified into two (2) types, namely: i) vegetation and ii) protection works with structures, as shown in Table 8-2 showing among others the purpose and application.

TABLE 8.1 COUNTERMEASURES FOR EACH TYPE OF ROAD DISASTERS

Countermeasures \ Road Disaster			Cut Slope Failure	Embankment Slope Failure	Fall	Land-slide	Debris Flow	Remarks: Referential Chapters
Drainage Work	Surface Drainage		0	0	0	0		Chapter 7; Design of Drainages
	Subsurface Drainage		0	0		0		
Protection Work	Vegetation		0	0	0	0		Chapter 8; Design of Slope Protection Works
	Spraying		0		0			
	Pitching		0	0	0			
	Crib		0	0	0			
Earth Work	Removal		0		0			Chapter 10; Cut Slope Failures
	Recutting		0		0			
	Re-filling			0				Chapter 11
	Earth Removal					0		Chapter 13, Landslide
	Counterweight					0		
Structural Work	Retaining Wall	Stone	0	0				Chapter 9; Design of Retaining Wall
		Gravity	0	0		0		
		Supported	0	0				
		Gabion	0	0		0		
	Anchoring		0		0			Chapter 8
	Foot Protection			0				Chapter 11
	Piling					0		Chapter 13
Fixing Work	Supporting				0			Chapter 12; Countermeasure for Fall
	Anchoring				0			
Catch Work			0		0			Chapter 12; Countermeasure for Fall
Rock Shed					0			
Hillside Work							0	Chapter 16; Countermeasure for Debris Flow
Torrent Work							0	
Sabo Work							0	
Avoiding Problem Work	Route Relocation		0				0	Chapter 10; Countermeasure for Slope
	Bridge		0				0	

TABLE 8.2 TYPES OF PROTECTION WORKS

Classification			Type of Works	Purpose	Application: Cut Slope	Application: Embankment Slope
Protection Work	Vegetation Works		. Seed spraying . Seed-mud spraying . Sodding mat . Sodding	To prevent erosion due to rain water. For whole surfaces.	0 0 0 0	0 0 0 0
	Vegetation Works		. Vegetation simple terracing . Sod simple terracing	To prevent erosion of embankment. For partial vegetation	x x	0 0
	Vegetation Works		. Vegetation block . Vegetation sack . Vegetation digging	To prevent erosion of slope made of poor soil or hard soils	0 0 0	x x x
	Protection Works with Structure	Spraying	. Mortar spraying . Concrete spraying	To prevent weathering and erosion	0 0	x x
		Pitching	. Stone Pitching . Block Pitching	To prevent weathering and erosion	0 0	0 0
			. Concrete Pitching	1)	0	x
		Crib	. Concrete Block Crib	To prevent erosion when filled up with sediment or gravel	0	0
			. Cast-in-place Concrete Crib	1)	0	x
			. Sprayed Concrete Crib	1)	0	x
		Others	. Anchoring	1)	0	0
			. Wicker . Gabion	2)	0 0	0 0

Note: 1) To prevent collapse of surface layer of slope, prevent separation of bedrock and to retain slight earth pressure.

2) To control erosion of surface layer of slope and out-flow of surface layer due to spring water.

3) 0- Applicable; X- Not Applicable.

8.1.3 General Criteria in the Selection of Protection Works

Slope protection works should be carefully selected taking into consideration peculiarities of each protection work, considerations of slope, etc.

(1) Precedence in Selection of Slope Protection Works

Vegetation works should be given precedence over structural works in the selection of slope protection works.

Basically, vegetation work is to grow plants directly on the slope to firmly bind the materials at the surface of the slope. This type of countermeasure does not only serve to prevent erosion, but also to some extent as a landscaping method to improve the overall aesthetic features of the highways. Since in most cases the work is relatively inexpensive, it is frequently applied wherever vegetation is found possible.

For slopes with spring water, slope drainage work is used together with vegetation work to stabilize the slope and to prevent it from scouring.

Protection works with structures are adopted for special slopes, such as those not suitable for vegetation or those whose stability of slope can not be attained with vegetation alone, or those with chances of failure or rock fall. The structural slope protection works described in this chapter, except slope anchor work, are mainly utilized for the purpose of covering the slope and therefore are considered not resistant against earth pressure.

(2) Selection of Slope Protection Works by Type of Soil

Slope protection works should also be selected in accordance with the kind of soil. Works suitable to the following types of soil are discussed in this section, and summarized in Table 8-3.

- Alluvial Deposit, Strongly Weathered
- Materials and Clayey Soil
- Sandy Soil (easily erodable)
- Hard Soil
- Rock Fall-Prone Area
- Rock quickly weathered after cutting

TABLE 8-3 GENERAL CRITERIA ON SELECTION OF SLOPE PROTECTION WORKS BY TYPE OF SOIL

Condition of Soil		Condition of Slope		Slope Protection Work
Typical	Example			
Colluvial Deposit Strongly Weathered Clayey Soil (Easily Collapsed)	. Volcanic Mudflow . Loam . Cohesive Soil	Extensive Spring Water	Slope steeper than 1=1	Mat Gabion, Crib
			Slope gentler than 1=1	Gabion, Crib work filled gravel
		A little spring Water	Slope steeper than 1=1	Stone Masonry, Block Masonry
			Slope gentler than 1=1	Vegetation, if necessary, Crib work with filling gravel, Block Pitching
Sandy Soil (Easily errodable)	. Weathered Granite . Volcanic Ashes . Loose Sandstone . Sand of Diluvial Epoch	Cut	Extensive spring water	Gabion, Crib work with filled cobblestones, Wicker Work
			A little spring water	Vegetation, if necessary, Crib work with filled sediment, Wicker Work
		Embankment	Ordinary height	Vegetation
			Very high	Vegetation with Wicker Work on Concrete Block Crib work
Hard Soil	. Dense Sandy Soil . Hard Clayey Soil . Hard Clay . Soft Rock			Vegetation with Dressed Soil by growing of Digging
Rock Fall - Prone Area	. Sediment with Gravel . Weathered Soft Rock	Small Rock Fall	Ordinary Cases	Rock Fall Prevention Net, Fence, if possible, Seed Mud Spray
			Many fissures, No water fissures	Concrete Spraying
	. Soft and Hard	Big Rock Fall	Many joints distribution widely	Conctete Spraying
	. Soft and Hard	Cracks in Bedrock		Anchoring Work
		Unstable Pumice Stone		Rock Bolt, Removal of Rock
Rock quickly weathered after cutting	. Tertiary Mudstone . Shale . Tuff . Rhyolite . Igneous Rock	Gentle Slope, Few possibility of Failure after progress of weathering		If possible, Vegetation, Otherwise Crib work with filled Sediment or Cobblestone
		Steep Slope, considerable Possibility of Failure after progress of weathering		Concrete Spraying, Concrete Block Crib, Crib work with Block Pitching, Supported Retaining Wall

Type 1 : Alluvial Deposit, Strongly Weathered Materials, Clayey Soil

Slope composed of alluvial deposit, strongly weathered materials, volcanic mudlow, loam or other cohesive soil, has low degree of solidification in view of its high water content and therefore is easily collapsible.

a) Where there is extensive spring water

For slope steeper than 1.0:1.0 mat gabion or crib work capable of slightly resisting against earth pressure is suitable. Ditch must be provided in each berm. In case of a slope gentler 1.0:1.0 than gabion or crib work filled up with gravel is recommended since it is capable of preventing the surface sediment from run-off due to spring water. In addition to the above, berm drainage or groundwater drainage such as horizontal boring by driving pipes shall be installed.

b) <u>Where there is little spring water</u>

For slope steeper than 1.0:1.0, stone masonry or block masonry (where the foundation ground is stable), is frequently used, because of its resistance against earth pressure to a certain degree.

In case of slope gentler than 1.0:1.0, only vegetation is generally considered to be sufficient but, if necessary, other works such as crib work filled up with gravel or sediment and block pitching may be used to prevent the sediment from run-off due to surface water.

Type 2 : Sandy Soil (easily erodable sediment)

Slope composed of weathered granite (decomposed granite), shirasu (volcanic ashes), sandstone with a low degree of solidification, or sand of diluvial epock (pit-sand) is easily eroded by spring water or surface water, and surface layer of these slopes are often run-off by seepage water.

Particularly, great damage will result due to heavy rain during construction. In this case, it becomes necessary to install temporary drainage facilities using soil cement mixture or vinyl sheets on top of the slope or berms.

Protection works suited to cut and embankment slopes are described below.

a) <u>Cut Slope</u>

Where extensive spring water exists, gabion or crib-work filled up with cobblestones or wicker work is recommended depending upon the degree of spring water.

However, when applying these works, surface water is percolated and the rear portion is sometimes scoured. In this case, groundwater drainage facilities may be installed in the form of branches of tree and then be protected by concrete blocks.

Where little spring water exists, only vegetation work is generally employed, but as auxilliary method. Crib work filled up with sediment or wicker is suited.

When applying vegetation work alone, sodding work or sodding mat is more preferable because they can cover and protect the whole surface of the slope even just after construction. While, in case of seed-mud spraying, the slope should be protected with emulsion or net or straw until grasses grow densely.

Regardless of the amount of spring water, provision of drainage facilities at the top of slope and the berm is recommended.

b) Embankment Slope

Where sandy soil is used as filling material, the slope should be protected with overlay earth (soil suited to vegetation) about 30 to 50 cm. thick.

Where overlay earth is not used, sodding mat or work should be applied which are both capable of covering the whole slope.

In the case of seed-mud spraying, the slope should be protected with emulsion, nets or straws.

For high embankment slopes, the portion near the toe of the slope may sometimes scour and collapse forming mudflow due to seepage water. To prevent this, filter or groundwater drainage work together with vegetation work could be adopted. Concrete block crib (grib frame) or wicker can also be used.

Type 3 : Hard Soil

For slopes composed of dense soil, hard clayey soil (both exceeding the soil hardness of 27 mm), soft rock or hard clay (exceeding the soil hardness of 23 mm), soil dressing is required by grooving or digging at some portions of the slope to allow grasses to grow, and then vegetation should be applied on the dressed soil.

Type 4 : Rock Fall-Prone Area

Sediment with gravel or weathered soft rock may cause minor rock fall. Rock fall prevention net to retain supportless stones or rock fall prevention fence to stop rock falls to the road should therefore be employed, together with seed-mud spraying. For soft rock withmany fissures and no spring water, concrete spraying is recommended.

Where big rock falls are anticipated or where rocks have many joints distributed widely, concrete pitching becomes necessary to prevent separation or collapse of the rocks. Where there is any danger of big rocks to fall directly to the road, unstable rocks should first be removed. If complete removal is not possible, there would either be a need to fix the rocks or to provide rock fall prevention fence or shed for falling rock.

Anchoring work is applied where there are cracks in a bedrock of hard or soft rock slope to prevent the slope to collapse or separate.

Anchoring work is frequently used together with cast-in-place concrete crib work, concrete pitching or retaining wall.

Type 5 : Rock Quickly Weathered after Cutting

Tertiary mudstone, shale, tuff with a low degree of solidification rhyolite, igneous rock influenced by thermal metamorphism, etc. generally weathered very quickly after excavation and frequently cause surface failure.

Slopes of these types or rocks can be protected by the following methods:

a) Gentle slope which may not cause any failure even after weathering progresses.

   1) Sodding (for preventing flow of weathered surface layer)

   2) Crib work filled up with sediment or cobblestones, vegetation digging or vegetation sack (soil dressing by grooving) is suited when the sodding work is difficult to perform (such as bluish grey, green, or black rock)

b) Steep slope where minor failure may occur after weathering developed.

   Recommended are closed type protection works where surface water can not permeate into, such as concrete spraying, concrete block crib, crib work with block pitching and supported type retaining wall. Spring water must be completely disposed of. In general, mortar spraying may not be considered as a permanent structure.

8.2 VEGETATION

Vegetation aims to grow plants directly on a slope to firmly bind the materials at the surface of the slope. This type of countermeasure contributes not only to prevent erosion due to rain water and to ease temperature change on the ground surface but also to improve aesthetics on the roadway.

In this section, the survey necessary to execute vegetation, to determine the materials to be used and the selection of appropriate method of vegetation are discussed.

8.2.1 Survey for Vegetation

Since the success of vegetation works is governed by the growth of plants, survey prior to execution of the work should be conducted to obtain the following necessary informations.

(1) Physical condition of slope

The size of the area, the gradient and height of the slope should be surveyed to select the suitable type of work and to attain desirable workmanship.

(2) Condition of adjacent land

Prior to the actual spraying it should be ascertained that sprayed materials would not scatter and pollute crops, houses or structures.

(3) Soil condition

(Physical and chemical composition, water content, hardness unevenness, spring water, etc.)

Soil condition should be initially checked for the following characteristics; i) easily erodable as sandy soil, ii) planting is difficult because of solidified soil, clay or mudstone, iii) soil is very dry, iv) growth of plants is difficult because of strong acidic soil or other harmful component contents, v) presence of extensive spring water. The finishing requirements for the slopes vary with the types of works. For example, certain irregularity is rather desirable for seed spraying while a smooth surface is preferred for sodding mat. The desired finish of the face of a slope should first be determined before the execution of work.

(4) Weather condition

(air temperature, rainfall, sunniness, etc.)

Type of plants, optimum season, work method and curing method should be determined based on weather condition.

(5) Availability of Local Materials

The difficutly in securing local materials (such as earth and water) and their qualities, and the conditions of the access roads to bring machinery and materials should also be surveyed.

8.2.2 Materials for Vegetation

Materials used for vegetation are seed, fertilizer and curing materials.

(1) Seed

The following items should be studied in relation which the climate and other related conditions of the country:

- Kind of seed
- Suitable climate
- Suitable soil
- Seeding season
- Life of seed
- Life of grass
- Amount of seed to be planted
- Per cent of growing
- Per cent of mixture in harvested seed

(2) Fertilizer

In general, good fertilizer contains three elements thoroughly nitrogen mixed: nitrogen, phosporus and potassium.

A large amount of fertilizer is rather desirable as original fertilizer during execution of work,

On the other hand, excessive amount of fertilizer may impede the germination.

(3) Curing Materials

Curing materials aim to protect the seeds from being washed away by rain water or from getting dried, until germination is completed. They also aim to prevent erosion of the slope until vegetation covers the whole area.

Chemical Curing Agents

There are many kinds of chemical curing agents used with the seed spraying. Some would form films over the surface layer of the slope, while others would permeate into the layer to a certain depth and harden this layer. The most common agent of film type is asphalt emulsion (cationic) which also has the effects of erosion prevention. Polyvinyl acetate is also frequently used, and many synthetic resins as permeable and hardening type are available.

Fibers

Fibers were frequently used for seed spraying in recent years. Igneous fibers developed in U.S.A., as well as bark fibers and slag fibers are also available. In order to fully realize the effects of erosion prevention by fibers, the amount of fibers to be used should be greater than 150 g/m^2. If the amount of spraying is smaller than this, no effect of seed protection and erosion resistance can be obtained. It should be noted that fibers are easily affected by running water and scattered by wind after drying.

Covering Materials

Covering materials available for slopes are synthetic fiber nets, straw products, fiber mats and paper products. Mats and nets made of straw or fiber products have high erosion resistance. Smooth face of the slope done manually is desirable to attain full effects of the mats and nets.

8.2.3 Selection of Vegetation Works

Vegetation works should be carefully determined selecting the proper method of work based on the characteristics of each vegetation work, condition of the slope, soil condition, etc.

(1) Kind of Vegetation Works

Table 8.4 shows the kinds of vegetation works indicating the general characteristics and application methods.

(2) Vegetation Works for Cur Slope

Since roots of lawn grass can penetrate into sandy soil, clayey soil and clay (handness lower than 23 mm), sodding can be performed directly on this kind of soil. Seed spraying is advisable, if vegetation can be performed in suitable season. If the area is small, sodding or sodding mat is suited. If the hardness is greater than 23 mm but less than 27 mm, then seed spraying should be applied. If the hardness exceeds 27 mm, soil dressing by digging should be carried out to certain portions of the slope to allow the roots to penetrate and then sodding be applied.

In such cases, seed spraying with dressing soil is recommended. Vegetation sack or vegetation digging can also be applied as manual labor works.

Vegetation block or vegetation digging is suited in hard clayey soil and hard clay since grooving is possible, work vegetation sack is rather desirable for dense gravelly soil and sandy soil where grooves cannot be made easily.

If the soil of a slope is sand or sand mixed with gravel, the sand tends to flow out easily. Scouring due to spring water is expected and, even if the covering work is performed, the rear of the covering works may sometimes be excavated resulting in the occurrence of a sink hole. If this problem is anticipated, a concrete block framing should be formed, its inner spaces be filled up with good quality soil, and sodding works be carried out over the soil (vegetation works such as sodding, vegetation mats, seed spraying). If the moisture condition of the soil is good, soil dressing in the framing may be omitted and only vegetation mat or seed-mud spraying may be employed. However, if extensive spring water is present and vegetation is not suitable then stone pitching or the like should be adopted.

(3) Vegetation Works on Embankment Slope

Seed spraying is normally applied on embankment slopes. However, if the area is small, then vegetation simple terracing or sod simple terracing should be used.

TABLE 8-4 (1) KINDS OF VEGETATION WORKS

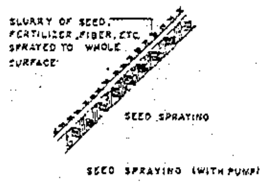
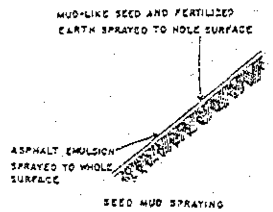
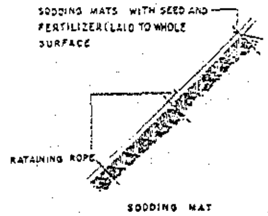
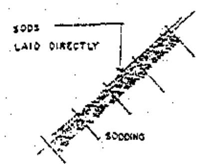
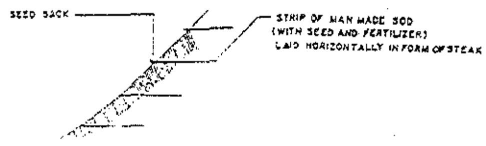
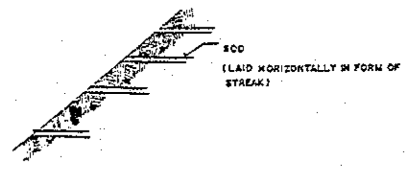
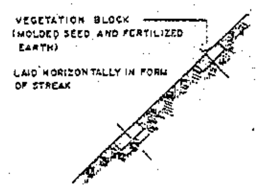
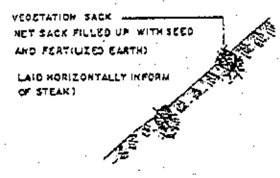
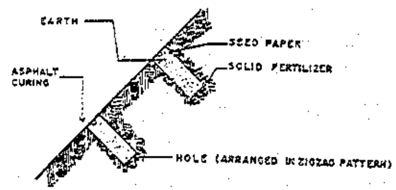
Name	Discription	Characteristics	Application	Illust ration
Seed Spraying	Uniformally mixed slurry (water, fibers, cohesive agent, fertilizer and seed are mixed and agitated) is made and sprayed with pump. Green colored igneous fiber is often used.	. Good efficiency in execution of work. . High erosion resistence. . Pump and tank with agitator are required.	. Preferable for gentle slope of embankment and cut in low land.	
Seed Mud Spraying	Mud-like mixture (seed, soil, fertilizer and water are mixed) is made and sprayed with gun and the asphalt emulsion is also sprayed for film curing.	. High erosion resistence . Spray gun and an compressor are required.	. Possible for steep slope of cut slope in high land. . Possible for surface with gravel and stone.	
Sodding Mat	Sodding mats (containing seed and fertilizer) are made manually and then cover slope. Mat materials are non-wooven cloth, rough cloth, paper, straw blind, straw mat and cut straw felt.	. Eary protection before completion of vegetation.	. Embankment slope with smooth and non-irregular surface.	
Sodding	. Well- known method. . Sod are directly laid on slope by hitting with tamping board to be tightly contacted with ground. . Field sods are normally used.	. Immediate effect of protection after placement of sods. . Effective for sandy soil.	. Slope with erodable soil (prefarably for embankment. . Possible for cut slope.	
Vegetation Simple Terracing	Strip clothes or papers (containing seed and fertilizer) are inserted horizontally into slope at the time of tamping of slope.	. Shorter time than sod single terrance until whole terrace face will be covered with vegetation.	. Embankment.	

TABLE 8-4 (2) KINDS OF VEGETATION WORKS
Cont'd.

Name	Description	Characteristics	Application	Illustration
Sod Simple Terracing	. Well-known metod. . Sods are inserted horizontally in form of streak into slope at the time of tamping of slope.	. Long time until whole surface will be covered with sod.	. Embankment.	
Vegetation Block	. Vegetation blocks (earth mixed with seed and fertilizer) are molded and then laid in form of streak into horizontal grooves on slope.	. Soil dressing effect. . Blocks may be molded either at site or in factory.	. Embankment.	
Vegetation Sack	. Net sacks (containing seed and fertilized earth) are laid in form of stream into horizontal grooves on slope.	. A little run-off of seed and fertilizer. . Sacks can be firmly borded to the ground because of their flexibility.	. Embankment. . Possible for steep slope.	
Vegetation Digging	Holes are made on slope and then seed and fertilized earth are filled into holes. Sometimes, peaty pots with cultivated lawn are embedded instead of seed .	. Thick soil dressing effect. . No run-off of fertilized earth.	. Cut slope. . Possible for hard soil such as hard clayey soil.	

In case vegetation work has to be completed in a short period or the slope is composed of erodable sandy soil which has been tamped, vegetation mat (covering the whole surface) or sodding (direct placement) is recommendable. These should be done in compliance with the progress of work for slope formation so that the surface of the slope will remain uncovered only for a short period.

8.3 MORTAR AND CONCRETE SPRAYING

Refer to APPENDIX NO. 2; STANDARD DRAWING NO. 4; CONCRETE SPRAYING

(1) Application

Mortar or concrete spraying is used for slope with the following conditions;

1) Easily weatherable rock through no spring water and no danger for the time being.

2) Weathered rock which may be stripped off.

3) Soils not suited for vegetation such as mudstone.

The standard thickness of spraying is 8 to 10 cm. and 10 to 20 cm. for mortar and concrete spraying, respectively. It should be noted however, that thinly sprayed mortar structure can not be recognized as permanent structure.

Where spring water is anticipated, proper drainage facilities such as horizontal drain hole or stone-filled drain should be provided prior to spraying works, since spring water can hardly be coped with after spraying.

(2) Typical Example

Typical examples of spraying are shown in Figure 8.1.

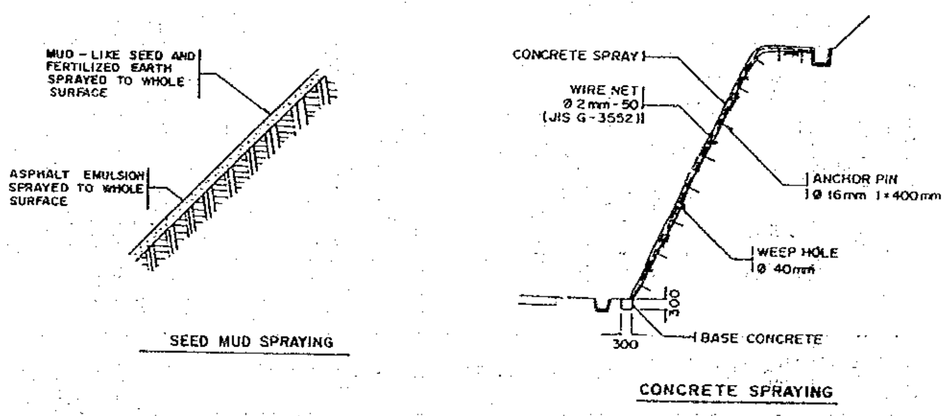


FIGURE 8-1 MORTAR AND CONCRETE SPRAYING

(3) Details

Thickness of Spraying

The thickness of spraying should be determined taking into consideration the kind of rock, slope condition and weather condition. A minimum thickness of 10 cm. is recommended in areas with bad weather condition.

Mortar spraying of 5 to 10 cm. in thickness is generally adopted for slopes of hard rock with gradient of 1.3:1.0, while concrete spraying of 10 to 15 cm. is used for soft rock with 0.5:1 gradient.

Mix Proportion for Mortar and Concrete Spraying

The standard mix proportion by weight of cement and aggregates should be 1:3 to 1:4 (C:S) for mortar spraying and 1:3:1 to 1:5:2 (S:S:G) for concrete spraying. Water cement ratio should be 45 to 50% for mortar spraying and about 40 to 45% for concrete spraying. Table 5-5 presents an example of a mixed proportion for mortar and concrete spraying.

TABLE 8-5 MIXED PROPORTION FOR MORTAR AND CONCRETE SPRAYING

	Weight Ration	W/C (%)	Cement (kg)	Sand (kg)	Gravel (kg)	Mix. Size (mm.)
Mortar Spring	1:4	45	430	1742	-	-
Concrete Spraying	1:6.5	45	310	1321	660	15

(4) Notices of Construction

Prior to spraying, supportless stones and dust on the face of the slope to be sprayed should be removed with pressured water or compressed air and then wire mesh should be placed and anchored over the surface of the slope. Diamond-shape wire mesh is used for irregular slope surface, and welded wire mesh for slightly irregular. The standard number of anchors is 1 to 2 per square meter.

As a rule, weep holes should be provided for spraying. At least one weep hole is needed per 2 to 4 square meters.

Spraying can be performed either by dry or wet method, but wet method is more common. In dry method, water and other materials are separately conveyed with compressed air through different hoses and then sprayed from the same nozzle. In wet method, however, all materials including water are mixed together in a mixer, conveyed to a nozzle with compressed air, and then sprayed from the nozzle.

Spraying is normally performed from the top to the bottom, since the mortar is likely to drip down and should be repeated until the spraying thickness is attained. The tip of the nozzle should be held normal to the face of the slope to be sprayed and should be moved slowly drawing a circular orbit while spraying uniformly. When stopping the spraying operation, it should be at a proper place such as, at a construction joint.

The distance from the tip of the nozzle to the face to be sprayed should be about 1 m. The thickness of a single spraying is determined from the cohesion of mortar and the rate of setting.

Setting time can be shortened by adding accelerating agent of either the powder of liquid type. The appropriate amount of the agent is about 3% of the weight of cement for the powder and about 2 to 4% for the liquid.

Losses of concrete which may be filled into concaved portions and rebound during spraying work should be taken into account. Rebound ratio (ratio between the amount lost due to rebound) is governed by the mixed proportion of materials supplied to the sprayer, properties of aggregates, amount of accelerating agent added to cement, gradient of face of the slope to be sprayed and skill of the operator of sprayer, but about 10 to 15% is used as rebound ratio. Re-use of aggregates dropped is not permitted.

Sprayed portion of concrete at the top of the slope should be completely embedded into the ground or firmly connected to a ditch to prevent seepage of surface water as shown in Figure 8-2.

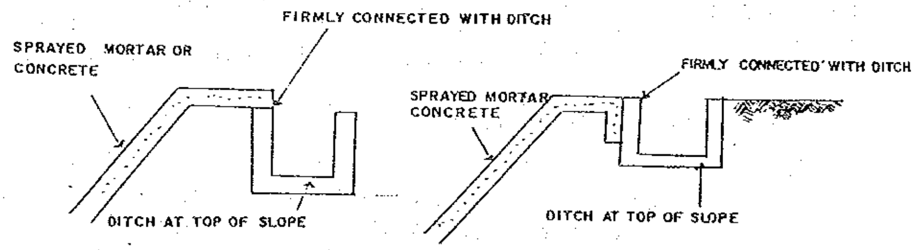


FIGURE 8-2 CONNECTION OF SPRAYED CONCRETE WITH DITCH

Longitudinal construction joint should be provided every 10 to 20m. for relatively flat surface, while this may not necessary for remarkably irregular surface. An example of construction joint is shown in Figure 8-3.

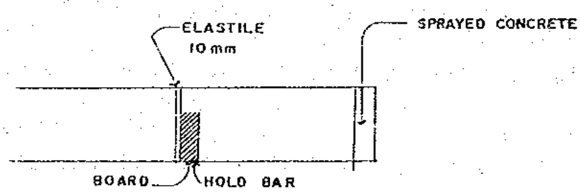


FIGURE 8-3 CONSTRUCTION JOINT OF CONCRETE SPRAYING

8.4 PITCHING

8.4.1 Stone Pitching and Block Pitching

Refer to APPENDIX 2; STANDARD DRAWING NO. 5; STONE AND BLOCK PITCHING

(1) Application

Stone pitching and block pitching aim to prevent the slope from weathering and erosion. These are usually employed for slopes with gradient gentler than 1:1 and composed of non-cohesive sediment, mud stone or easily collapsible clay.

In case the gradient of the slope is steeper than 1:1, stone masonry retaining wall and block masonry retaining wall should be adopted since these are expected to resist earth pressure.

(2) Typical Example

A typical examples of stone pitching and block pitching are shown in Figure 8-4.

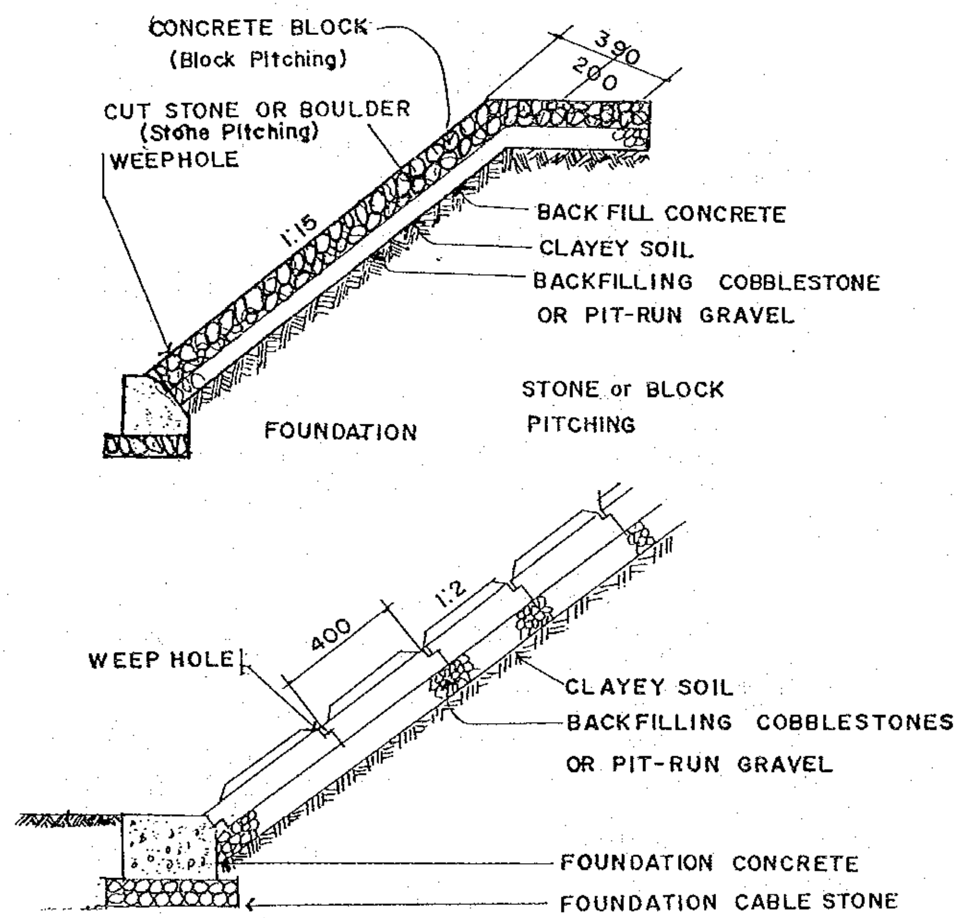


FIGURE 8-4 STONE PITCHING AND BLOCK PITCHING

(3) Details

Gradient of stone pitching using various sizes of stones should be gentler than 1.5:1.0 and height smaller than 5 m.

Flat concrete block pitching is used when the length of the slope is short and the gradient is gentle.

Dry pitching (without concrete backfilled between cut stones) is preferable for slopes where spring water is expected. Dry pitching for high slope however, has a possible danger of warping so that the maximum height should be less than 3 m. If high pitching can not be avoided, only a portion of pitching rear spring water can be provided with dry pitching.

(4) Notices in Construction

Where spring water or seepage water exists, backfilling with cobblestones or pit-run gravel should be performed to provide better drainage from the rear of the structure. Filter should be provided where the fine-grained portion of soil is likely to run off together with water. In this case, the thickness of backfilling should be about 20 cm.

Weep holes with diameter of about 5 mm should be provided at a standard rate of one weep hole per 2 to 4 m^2, but this rate should be increased where spring water is extensive. In case of a large amount of spring water, stone pitching should be performed after installing sufficient drainage facilities.

Stone or block should be fixed with ties or some supports and then backfilling should be done avoiding any gap or space behind the stone or block, especially near the top of the slope.

Foundation can be cobblestone, concrete, pile or ladder type footing. Construction joints for motor pitching, (wet pitching, with concrete backfilled between cut stones) shall be 10 to 20 m. to cope with different settlements.

8.4.2 Concrete Pitching

(1) Application

Concrete pitching is used for slope of bedrock with many joints or of loose talus cone layer, where concrete block crib work or concrete spraying may not be sufficient to protect the slope.

Plain concrete pitching (without reinforcing bar) is used for a slope with gradient gentler than 1.0:1.0. For a long and large slope with gradient about 0.5:1, reinforced concrete pitching is adopted.

(2) Typical Example

A typical example of concrete pitching is shown in Figure 8-5.

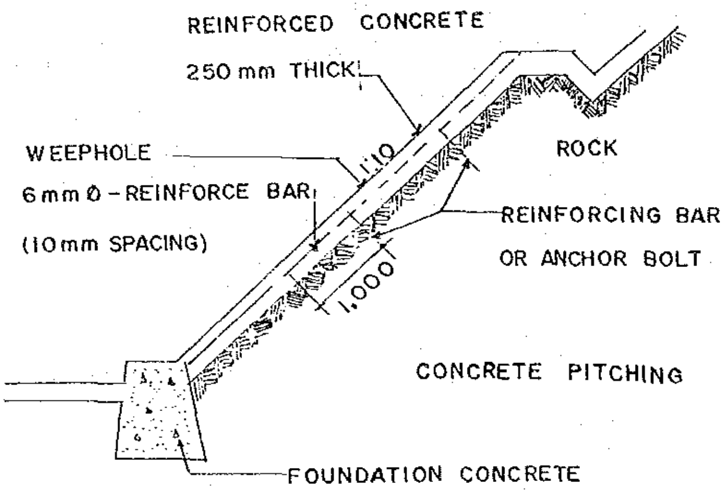


FIGURE 8-5 CONCRETE PITCHING

(3) Details

Plain concrete pitching requires a minimum thickness of about 20 cm. Non-slip anchor should be placed at a rate of one anchor per 1 to 2 m^2, and the standard depth of embedment is 1.5 to 2.0 times the thickness of concrete.

Reinforcing bar or wire mesh is used and non-slip legs or anchor bolts are installed in the same way for plan concrete pitching.

(4) Notices in Construction

During the execution of work, it is required i) to prevent the permeation of ground water into bedrock, ii) to place concrete on whole surface of the slope without any running portion, iii) to completely dispose of spring water by means of weep holes, and iv) to properly embed the upper end of concrete pitching in the ground.

If the face of the slope is improperly prepared prior to the placement of concrete, air gap may be created between the concrete and the ground, and grasses or trees may germinate through the joints, thereby resulting in the penetration of rain water into the air gap.

If a construction joint of concrete is made horizontally, the portion of concrete above the joint may occasionally begin to slip out and, thus, the construction joint must be made normal to the face of the slope or half-lap joint must be used as shown in Figure 8-6. Spacing of construction joints is about 20 m.

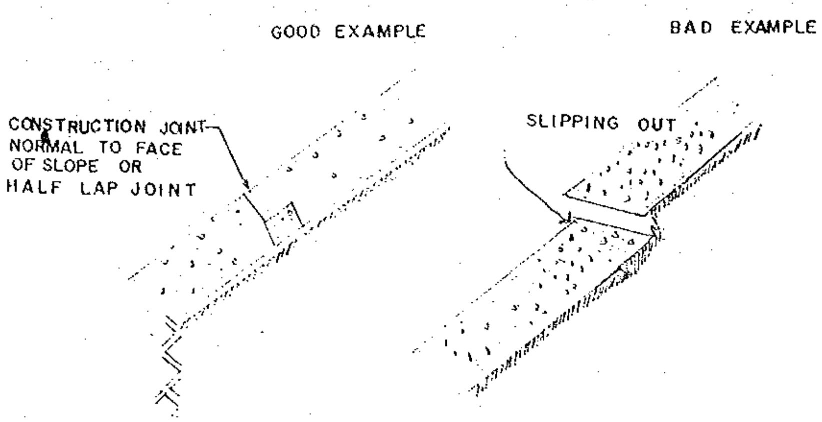


FIGURE 8-6 CONSTRUCTION JOINT OF CONCRETE PITCHING

8.5 CRIB

8.5.1 Concrete Block Crib

(1) Application

Concrete block crib is used for gentle slope with gradient of 0.8:1.00 less than with the following conditions.

1) Cut slope with spring water.
2) Embankment slope with large-scale or steeper than standard gradient, where vegetation can not be applied.
3) Slope which may collapse even protected with vegetation.

This type of slope protection can not be assured to resist earth pressure.

(2) Typical Example

A typical example of concrete block crib is shown in Figure 8-7.

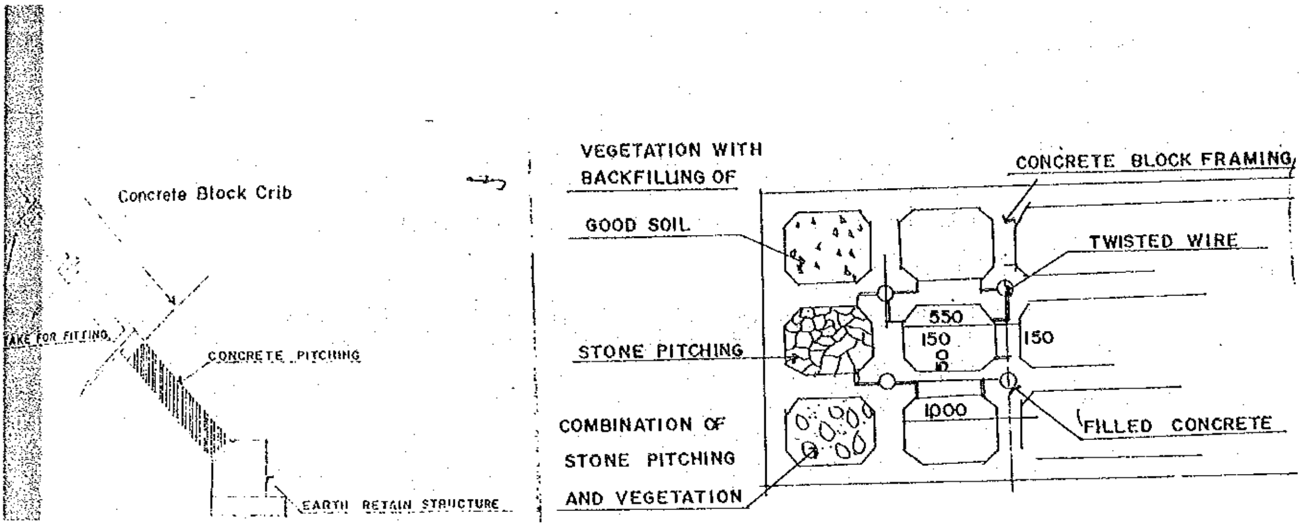


FIGURE 8-7 CONCRETE BLOCK CRIB

(3) Details

Spaces inside the frame should be filled up with good quality earth to protect the surface of the slope with vegetation except in the following cases which may require stone or concrete block pitching.

- Gradient of slope is steeper than 1.2:0.
- Considerable amount of spring water exists.
- Good quality soil is not available.
- Vegetation may flow out.

If aesthetic considerations are required, vegetation may be applied filling the space with seeds and fertilized earth between the cobblestone by using seed-mud spraying or by filling vegetation sacks.

(4) Notices in Construction

The face of the slope should be finished flat so that members of the crib are fixed to the slope, not to allow them to slip. Wire from each member should be tied with a stake or anchor bolt driven at each intersection of members and each whole is filled up with mortar for fixing. Stake or steep anchor bolt should be 50 to 100 cm. in length.

Special precautions should be taken to prevent the sediment to run-off from the rear of the framing due to improper handling of spring water, and the disengagement of filled materials in the framing due to insufficient compaction.

When constructing crib with dry cobblestone pitching inside the framing on a slope with non-cohesive sand or on a slope with spring water, it is recommended to install the framing after suppressing sediment run-off by installing stone-filled drains in the form of branches of trees or by laying water permeable mats.

Cobblestone to be filled should be laid on its butt end and be fully interlocked with other cobblestones. Use of weathered stone or stone with small grain size is not desirable.

When filling sediment, complete compaction is necessary to prevent the materials from slipping down with rainfall run-off.

8.5.2 Cast-in-Place Concrete Crib

Refer to STANDARD DRAWING NO. 6; CAST-IN-PLACE CONCRETE CRIB

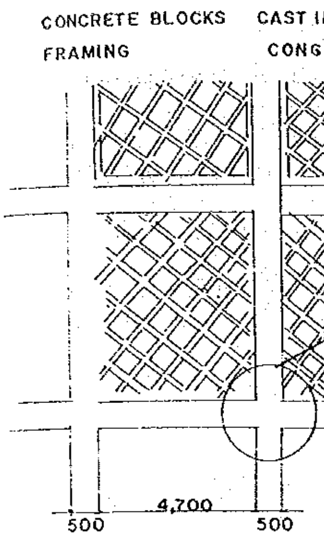
(1) Application

Cast-in-place concrete crib is used for slope with the following conditions.

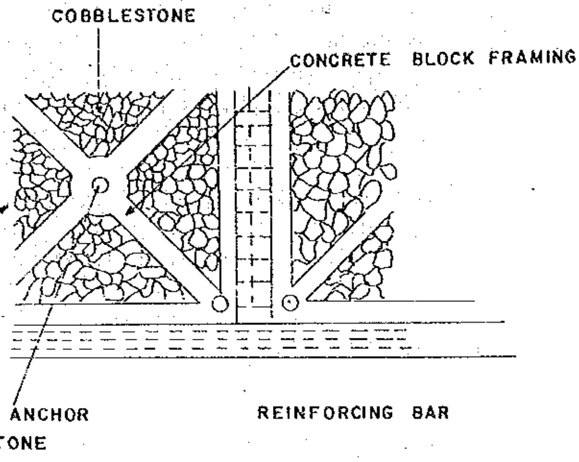
1) Future stability of the slope is questionable such as weathered rock with spring water and large-size slope with spring water.
2) There is a fear that concrete crib work may collapse.
3) Supportless stones and rocks can not be fixed by concrete spraying on bedrock with many joints and cracks.

(2) Typical Example

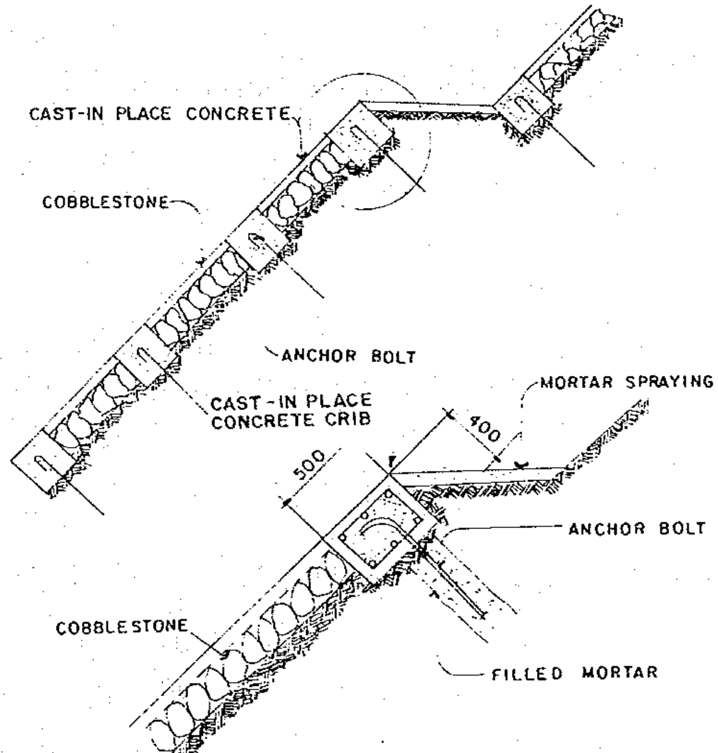
A typical example of Cast-in-Place Concrete Crib is shown in Figure 8-8.



(a) Plan



(b) Detail



(c) Section

FIGURE 8-8 CAST-IN-PLACE CONCRETE CRIB WORK

(3) Notices in Construction

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

Framing joints should be anchored with a stake or pre-stressed steel bar for fixing. Framing may be partly embedded in or just laid on the slope.

8.5.3 Sprayed Concrete Crib

Refer to APPENDIX 2; STANDARD DRAWING NO.9; SPRAYED CONCRETE CRIB.

(1) Application

Sprayed Concrete Crib is used under the same conditions as in Cast-in-Place Concrete Crib. However, the latter requires to correct the irregularity of slope surface and the form for concreting,while the former does not, except wire mesh as the form for concrete. The former is usually employed where the correction of irregularity is difficult or costly.

(2) Typical Example

The plan is the same as in Cast-in-Place Concrete Crib. In Figure 8-9, the side views are presented to show the difference between the two methods.

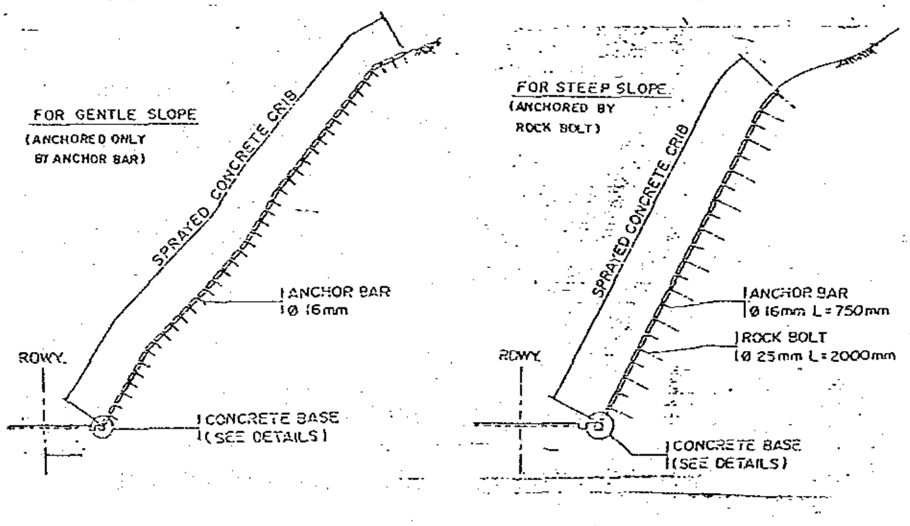


FIGURE 8-9 SPRAYED CONCRETE CRIB

(3) Detail

Framing made by wire mesh for concreting and reinforcing bar to make cribs are placed on the face of the slope in conformity with the irregularity of the face of the slope, and then concreting is done by concrete spraying.

In this method, works to place and remove forms for concrete are not necessary. This method is efficient for large and steep slope in mountainous area.

8.6 OTHER PROTECTION WORKS

8.6.1 Wicker

Refer to APPENDIX 2; STANDARD DRAWING NO. 8; WICKER

(1) Application

Wicker work is used for slopes which may be eroded before plants by vegetation work will have been fully grown to stabilize the slope.

(2) Typical Example

Several examples of wicker are shown in Figure 8-10.

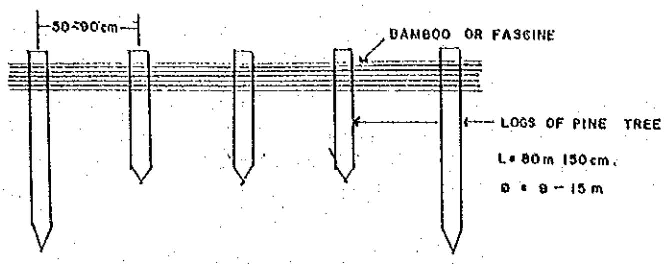
(3) Notices of Construction

Wooden stakes are driven into the face of the slope and then fascine, bamboo or net made of macromelecular material is woven between each stake to retain earth.

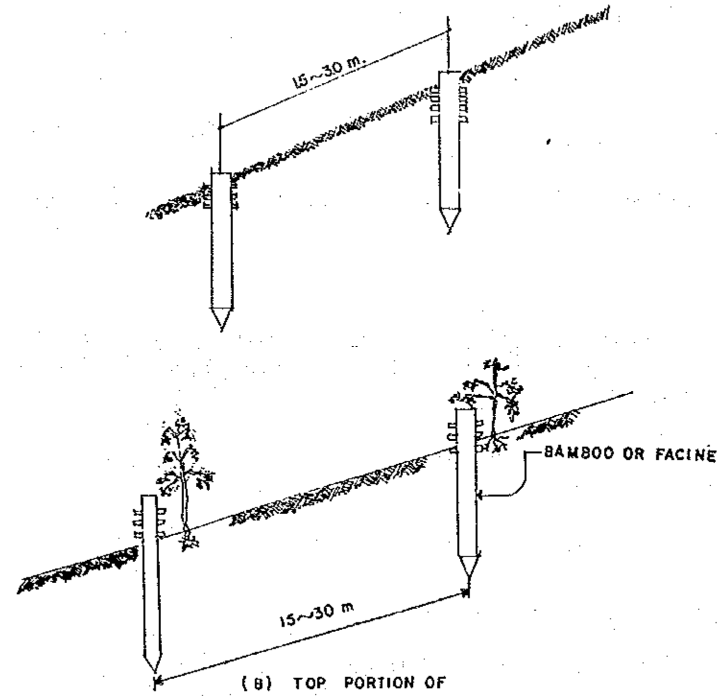
Wooden stake should be 80 to 150 cm. long with 9 to 15 cm. diameter. Wooden stakes are driven at 50 to 90 cm. span, and the spacing between wickers is normally 1.5 to 3.0 m. Stakes should be driven vertically or with a little inclined angle.

When applying wicker to embankment slope, the soil should be fully compacted and then bench cut is carried out starting from the bottom of the slope. After wickers are placed, the soil should be backfilled and fully compacted with hammer.

Planting of wood, such as willows, etc. is recommended on wet slopes or long and large slopes.

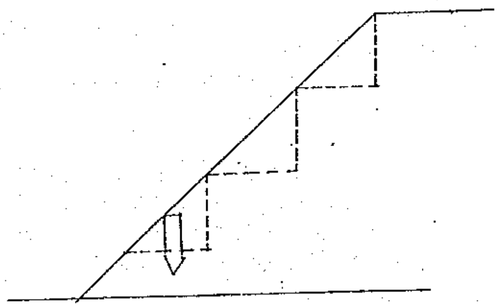


(a) Typical Example of Wicker



(B) TOP PORTION OF WICKER WORK ABOVE GROUND

CONSTRUCTION OF WICKER WORK



(c) PLACEMENT OF WICKER WORKS BY BENCH CUT

(b) Types of Work

FIGURE 8-10 WICKER

8.6.2 Gabion

Refer to APPENDIX 2; STANDARD DRAWING NO. 9; GABION

(1) Application

Gabion is used for slope where the sediment may run-off due to spring water or the collapsed portion is going to be restored.

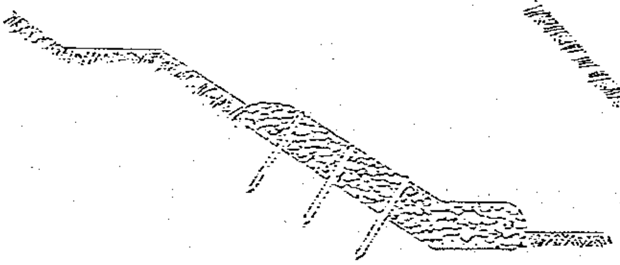
There are several types of gabions such as ordinary, mat, free and flat.

An ordinary gabion is mainly used for disposing of spring water in the surface layer of the slope and for draining surface water.

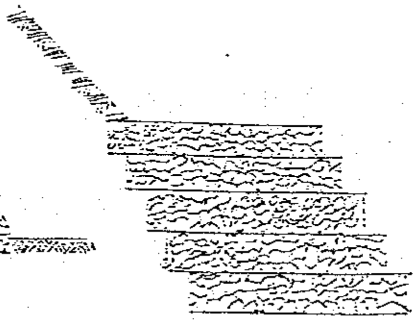
A mat gabion is used as restoration work for slope failure due to spring water or due to landslide. It is considered as more of sheathing work rather than slope protection work.

(2) Typical Example

The types of gabions are shown in Figure 8-11.



A) ORDINARY GABION



B.) MAT GABION

FIGURE 8-11 GABION

(3) Notices of Construction

In case of very extensive spring water, water collected by gabions must be quickly drained. If gabions are likely to be clogged due to the runoff of sediment from the slope, the surrounding area of the gabions should be protected by gravel.

8.6.3 ANCHORING

Refer to APPENDIX 1: DESIGN EXAMPLE NO. 3; DESIGN OF RETAINING WALL WITH ANCHORING and
APPENDIX 2: STANDARD DRAWING NO. 10; ANCHORING

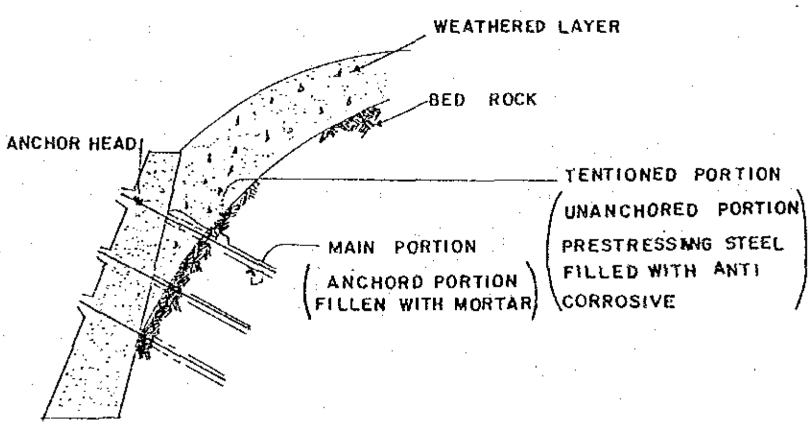
(1) Application

Anchoring is used on slopes of hard or soft rocks with joints or cracks and on the slopes where the chance of collapsing or falling down of rocks is high. It aims to prevent collapsing and detaching of bedrocks by directly tightening them up.

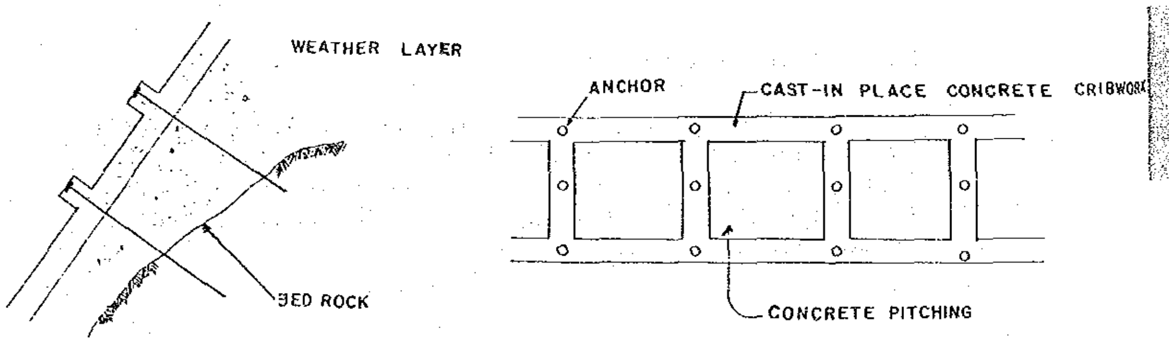
Anchoring, although used individually, is more frequently adopted with other slope protection works such as cast-in-place concrete crib, concrete pitching and retaining wall in order to increase the protection ability of these works.

(2) Typical Example

Two examples of anchoring are shown in Figure 8-12.



(A) SLOPE ANCHOR WORK USED WITH RETAINING WALL

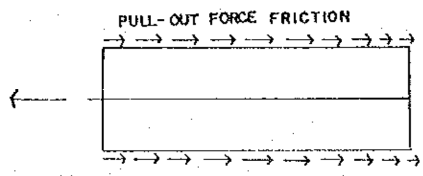


(b) Slope anchor used with cast-in-place concrete crib work

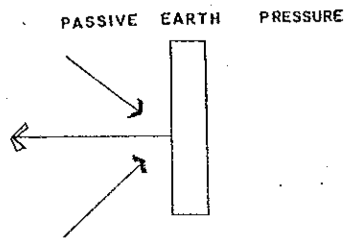
FIGURE 8-12 ANCHORING

(3) Details

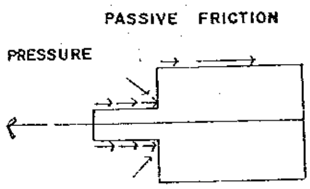
In accordance with anchoring method, slope anchors are classified into three types, as follows:



(a) Friction Type



(b) Bearing Type



(c) Combined Type

FIGURE 8-13 ANCHORING METHODS

(a) Friction Type Anchor

Pull-out force of anchor is expected to be transferred to the bedrock by frictional resistance between the bedrock and the periphery of the main portion of the anchor. This type is most commonly used.

(b) Bearing Type Anchor

A part of the main portion of the anchor is enlarged to resist against pull-out force by passive earth pressure.

(c) Combined Type

Combination of Types (a) and (b)

Structural detail of anchoring members is shown in Figure 8-14.

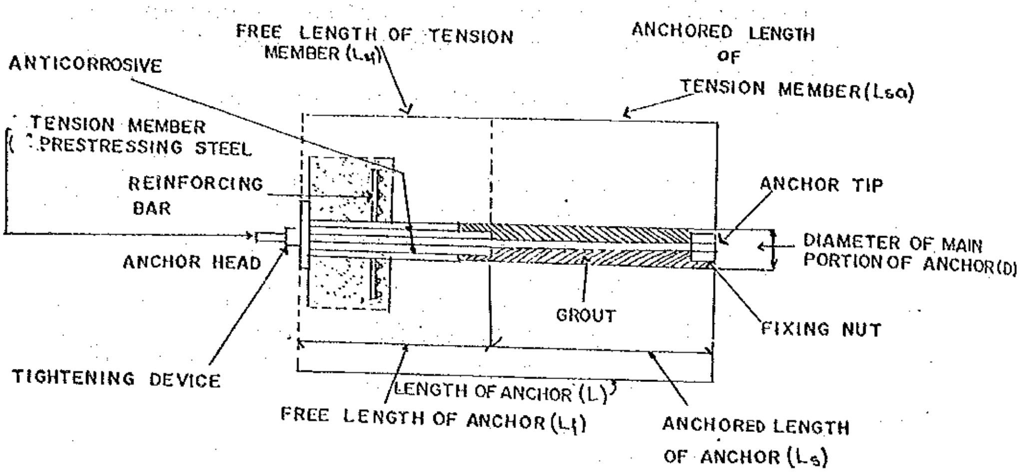


FIGURE 8-14 STRUCTURAL DETAIL OF ANCHORING MEMBER

Because of high tension acting against tension member of anchor, pre-stressed steels, such as pre-stressed steel rod, pre-stressed steel strand and pre-stressed steel wire are generally used as materials for pre-stressing member, in order to reduce relaxation of pre-stressed steel.

(4) Design of Anchoring

The strength of anchor is determined by the resistance of the anchor portion against the pull-out force and the elongation of pre-stressed steel. Failure of the anchor and the bedrock in case of rock with relatively large strength, while failure occurs at the ground in case of low strength soil such as sediment.

Ultimate Tensile Resistance Force and Length of Anchor

Ultimate tensile resistance force of the bonding portion between the anchor and the ground can be calculated from the following equation:

$$T = \pi D (L - L_f) \cdot \tau$$

Where:

T : Ultimate tensile resistance force of anchor (kg)

D : Diameter of main portion of anchor (cm)

L : Total length of anchor (cm)

L_f : Length of unanchored portion (cm)

τ : Pull-out shearing resistance between ground and main portion of anchor (kg/cm^2)

If factor of safety F_s is determined, the length of anchor can be determined from an equation:

$$L - \ell_f = \frac{F_s T}{\pi D \tau}$$

Shearing Resistance (τ)

Value of τ should be determined by the pull-out test. In the absence of test, may be approximately estimated based on volumes shown in Table 8.6

TABLE 8-6 SHEARING RESISTANCE (τ) OF ANCHOR

	Kind of Ground		(kg/cm^2)
Rock	Hard Rock Soft Rock Weathered Rock		15 ~ 25 10 ~ 15 6 ~ 10
Gravel	N - Value	10 20 30 40 50	1.0 ~ 2.0 1.7 ~ 2.5 2.5 ~ 3.5 3.5 ~ 4.5 4.5 ~ 7.0
Sand	N - Value	10 20 30 40 50	1.0 ~ 1.4 1.8 ~ 2.2 2.3 ~ 2.7 2.9 ~ 3.5 3.0 ~ 4.0
Clayey Soil			1.0 C

Factor of Safety

The following factor of safety may be recommended.

TABLE 8-7 FACTOR OF SAFETY (F_s) OF ANCHORING

		F_s
Temporary Structure		1.5
Permanent Structure	Permanent Load	2.0
	Ordinary Load	3.0

Bond Stress

Bond stress between pre-stressed steel and grouting material shall be checked in accordance with the method to analyze bond stress between reinforcing bar and concrete.

Pre-stressed Steel

Tensile stress of pre-stressed steel shall also be calculated, satisfying the following two cases:

(a) $\sigma_{ap} \leqq 0.6 \; \sigma_{up}$

(b) $\sigma_{ap} \leqq 0.75 \; \sigma_{yp}$

Where:

σ_{ap} ; Allowable tensile stress of Pre-stressing steel (kg/cm^2)

σ_{up} ; Maximum tensile stress of steel (kg/cm^2)

σ_{yp} ; Yield stress of steel (kg/cm^2)

(5) Notices in Construction

The main portion of the anchor shall be anchored to the bedrock not weathered and installed deeper than the anticipated slide plane. Anchors shall be arranged based on the results of actual ground survey because ground is so complicated.

When using anchor as semi-permanent structure, steel tension member shall be properly treated to prevent erosion. After anchoring, grout is poured into the portion of free length of tension member.

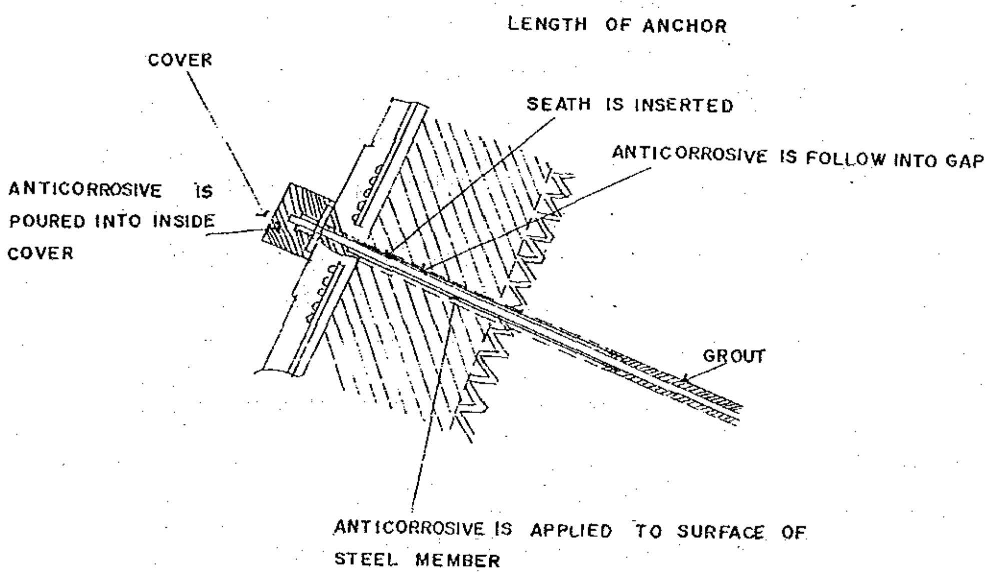


FIGURE 8-15 ANTICORROSIVE OF ANCHOR

After grout gains the designed strength, tension test shall be carried out for more than 5% of the total number of anchors or for more than three. Confirmation test shall also be conducted for all other remaining number of anchors. The maximum load for tension test is about 1.2 to 1.3 times the designed anchor force and for confirmation test about 1.0 ~ 1.2.

An example of mix proportion for grout is shown in Table 8-8.

TABLE 8-8 MIX PORTION FOR GROUT OF ANCHORING

	Cement	Water	Sand
Cement Mortar	1	0.5 0.03	0.5
Cement Milk	1	0.5 0.03	-

CHAPTER 9 DESIGN OF RETAINING WALLS

9.1 GENERAL

Retaining walls are structures to support and retain earth in order to prevent failure of sediment in the places where stability of slope can not be assured by normal ground conditions (earth alone) or by other slope protection works.

Retaining walls are classified into the following types in accordance with the shapes and characteristics.

- Stone Masonry Retaining Wall
- Gravity Type Retaining Wall
- Supported Type Retaining Wall
- Cantilever Beam Type Retaining Wall
- Counterfort Type Retaining Wall
- Buttress Type Retaining Wall
- Gabion Retaining Wall

Figure 9-1 show the (conceptional) shapes of each type of retaining wall.

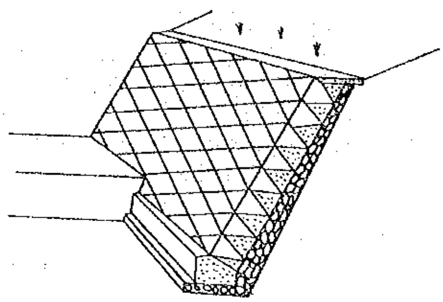
To select a most appropriate type of retaining wall, a comparative analysis is recommended among several alternative types. In the analysis, topography, geology and conditions for construction should be taken into consideration.

In Table 9-1, types of retaining walls generally adopted are presented in accordance with the height. The typical example and the general application of each type is discussed in this chapter.

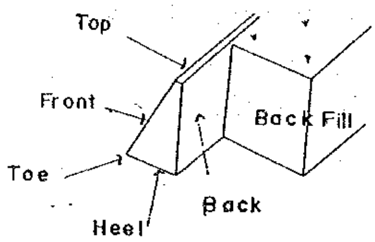
9.2 LOADS

Generally, loads acting to retaining wall are dead load, surcharge, earth pressure, buoyancy, impact, water pressure and earthquake. Loads to be considered in the design are a combination of dead load, surcharge and earth pressure.

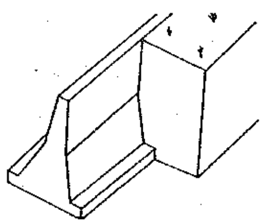
Design analysis for earthquake in ordinary retaining wall on embankment is not required considering the fact that the increase of load due to seismic force will be compensated by a safety factor which may be assessed slightly bigger than the normal case and by resistance forces against which are not taken into account in the design.



a) Stone Masonry Type

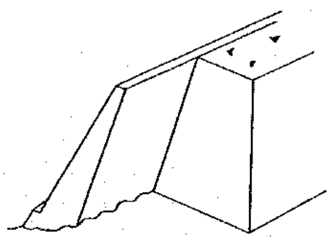


GRAVITY TYPE



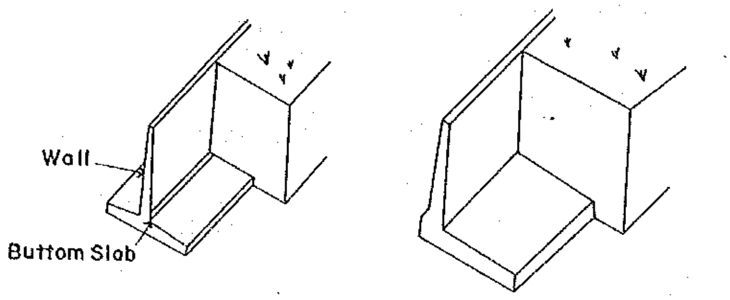
SEMI GRAVITY TYPE

(b) GRAVITY TYPE



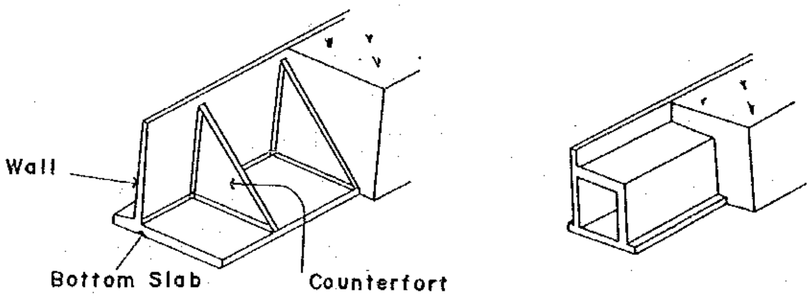
(C) SUPPORTED TYPE

FIGURE 9-1 (1) TYPES OF RETAINING WALL



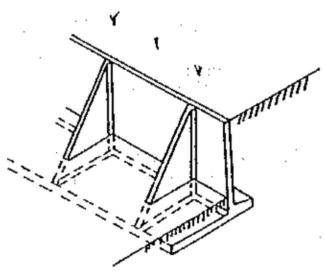
INVERTED T TYPE L TYPE

(d) CANTILEVER BEAM TYPE



WALL TYPE BOX TYPE

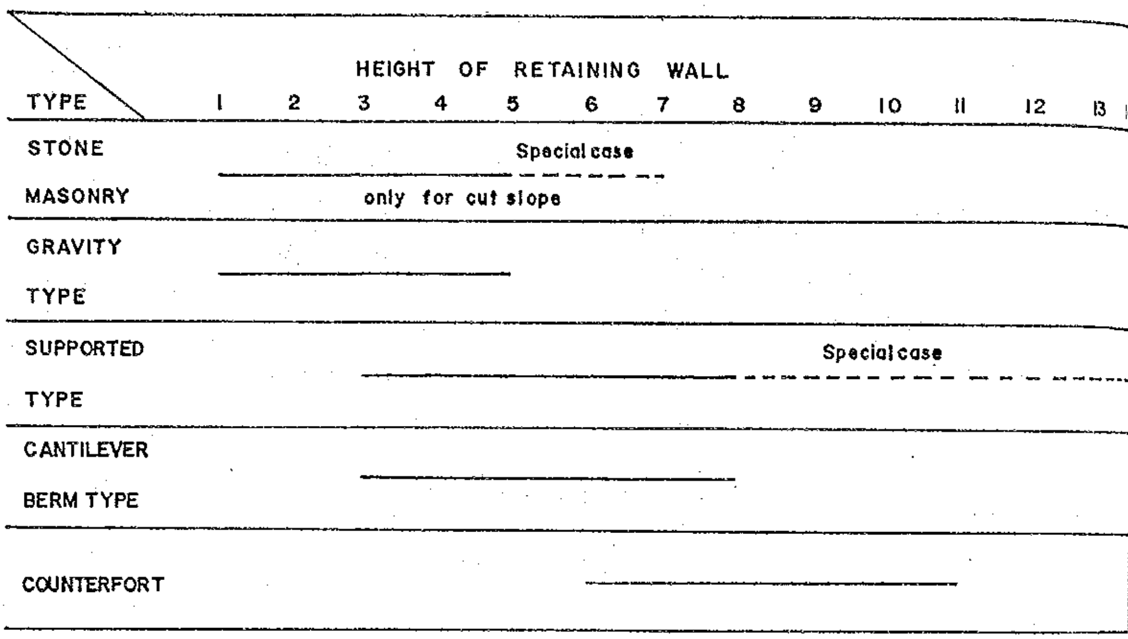
(e) COUNTERFORT TYPE



(f) BUTTRESS TYPE

FIGURE 9-1 (2) TYPES OF RETAINING WALL

TABLE 9-1 RECOMMENDED TYPES OF RETAINING WALL IN ACCORDANCE WITH HEIGHT



Note:

Gabion Retaining Wall is excluded in this table

However, retaining wall higher than 8.0 m or failure of which may cause serious damages should be designed taking into consideration effect of earthquake.

Earth pressure may be estimated by the formula shown in Table 9-2. Detailed explanation on each formula is described below.

TABLE 9-2 FORMULAE FOR ANALYSIS OF EARTH PRESSURE

	Normal Case	Earthquake
Embankment	1) Height less than 8 m. . Ordinary Retaining Wall - Figure 9-4 . Supported Type Figure 9-5	Analysis may not be required. If necessary, Mononobe - Okabe's Formula. (See Section 9.2.5)
	2) Height more than 8 m. . Uniform gradient of back slope - Coulomb Formula . Irregular gradient of back Slope - Trial Method with Wedge Shape	Mononobe - Okabe's Formula (See Section 9.2.5)
Cut	1) Stable Slope - Funicular Polygon Method	Funicular Polygon Method considering inertial force due to earthquake.
	2) Unstable Slope - Special Treatment (Method for embankment may be applied)	Special Treatment (Method for embankment may be applied

9.2.1 DEAD LOAD

The dead load acting on a retaining wall is made up of weight of the structure itself and the weight of the earth directly on top of the footing stab, as shown in Figure 9-2.

The unit weight of each materials to be used in design is indicated in Table 9-3.

TABLE 9-3 UNIT WEIGHT OF MATERIALS

Materials	Unit Weight (t/m^3)
Reinforced Concrete	2.5
Concrete	2.35
Gravel, Gravelly Soil, Sand	2.0
Sandy Soil	1.9
Sill, Cohesive Soil	1.8

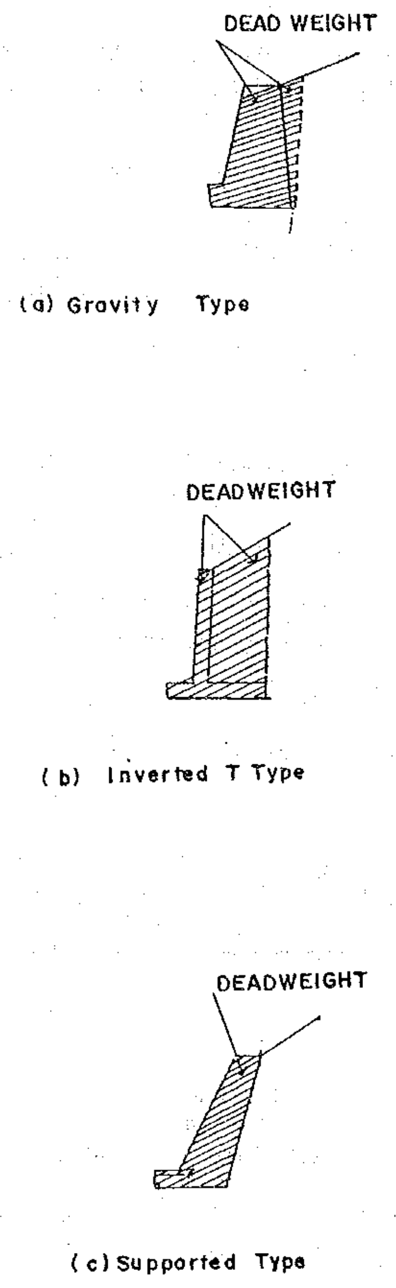


FIGURE 9-2 DEAD LOAD OF RETAINING WALL

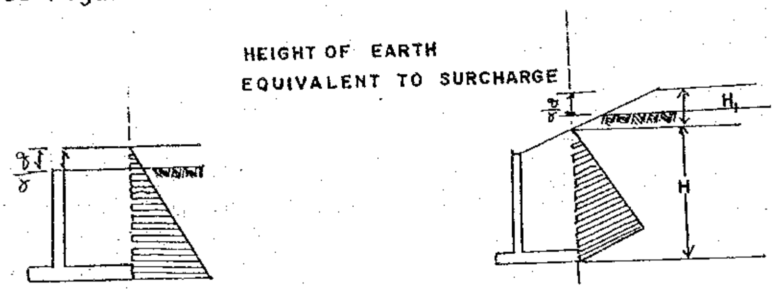
9.2.2 Surcharge

The live load acting on a retaining wall which is considered as surcharge is calculated by the equation.

$$q = 1.0\ t/m^2$$

where: Live load acting on retaining wall

In actual design the height of earth behind retaining wall can be assumed higher, equivalent to the amount of the live load. See Figure 9-3.



NOTE: $= 1.0\ t/m^2$ (Live Load)

$=$ Unit weight of soil (t/m^3)

FIGURE 9-3 SURCHARGE

9.2.3 Earth Pressure for Embankment Section

(1) Ordinary Retaining Wall less than 8.0 m high.

Earth pressure on ordinary retaining wall less than 8.0 m high can be calculated using the coefficient of earth pressure shown in Figure 9-4 and with the following equations:

$$P_h = \frac{1}{2} K_a \cdot H^2$$

$$P_v = \frac{1}{2} K_v \cdot H^2$$

Where:

P_h : Horizontal component of resultant of earth pressure (t/m)

P_v : Vertical component of resultant earth pressure (t/m)

K_h : Horizontal coefficient of earth pressure (t/m^3)

K_v : Vertical coefficient (t/m^3)

H : Height of wall for calculation of earth pressure (Refer to Figure 9-4).

(2) Supported Type Retaining Wall with a height less than 8 m.

Instead of Figure 9-4 for ordinary retaining wall. Figure 9-5 can be used for supported type retaining wall with height less than 8 m.

(3) Retaining Wall more than 8.0 m high

As a rule in the design of the retaining wall, soil survey and test should be carried out for materials to be used for backfilling and for foundation. Based on the result of test, earth pressure can be estimated adopting proper methods such as Coulomb's Formula for uniform gradient of back slope and Trial Method with Wedge Shape for irregular gradient of back slope, as discussed below.

(i) Coulomb's Formula

Resultant of active earth pressure acting per m. of the width of retaining wall is given by the following formula.

$$P_a = \frac{1}{2} K_a \cdot \cdot H^2$$

$$K_a = \frac{\cos^2(\phi - \alpha)}{\cos^2\alpha . \cos(\alpha + \delta) \quad 1 + \frac{\sin(\phi + \delta) . \sin(\phi \ldots}{\cos(\alpha + \delta) . \cos(\alpha \ldots}}$$

Where:

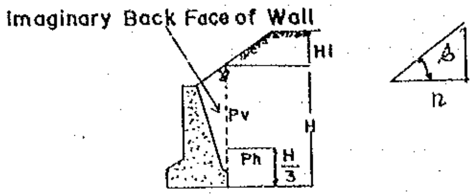
P_a : Resultant of Active Earth Pressure

K_a : Coefficient of Active Earth Pressure

γ : Unit of Soil of Backfilling

H : Height of Wall for Calculation of earth Pressure (Refer to Figure 9-4 and 9-5)

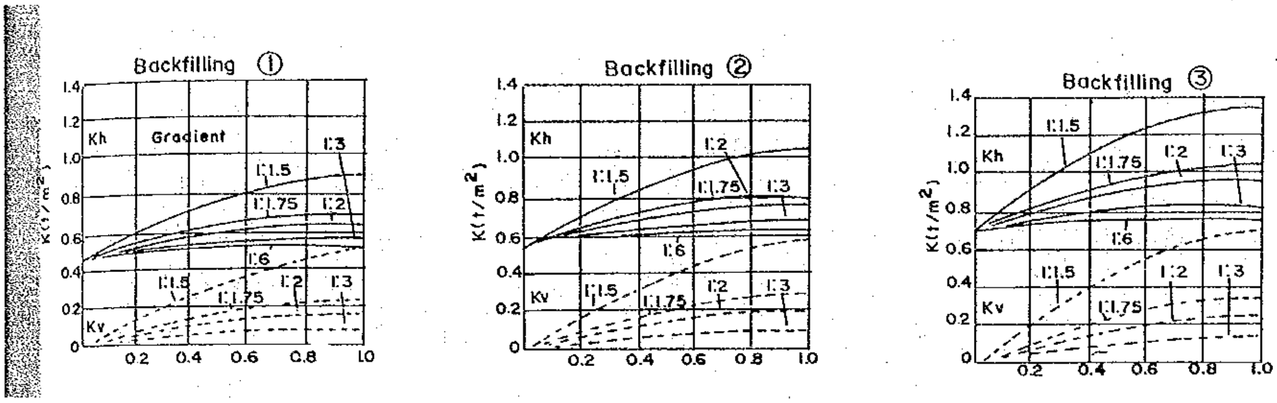
CASE 1



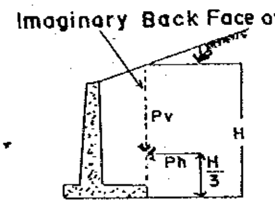
$Ph = \frac{1}{2} \cdot Kh \cdot H^2$

$Pv = \frac{1}{2} \cdot Kv \cdot H^2$

Gradient = 1 = n

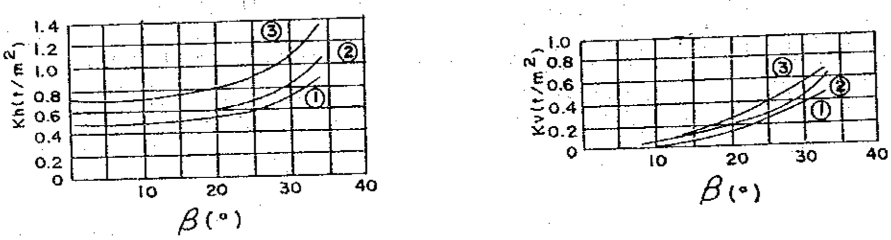


CASE 2



$Ph = \frac{1}{2} \cdot Kh \cdot H^2$

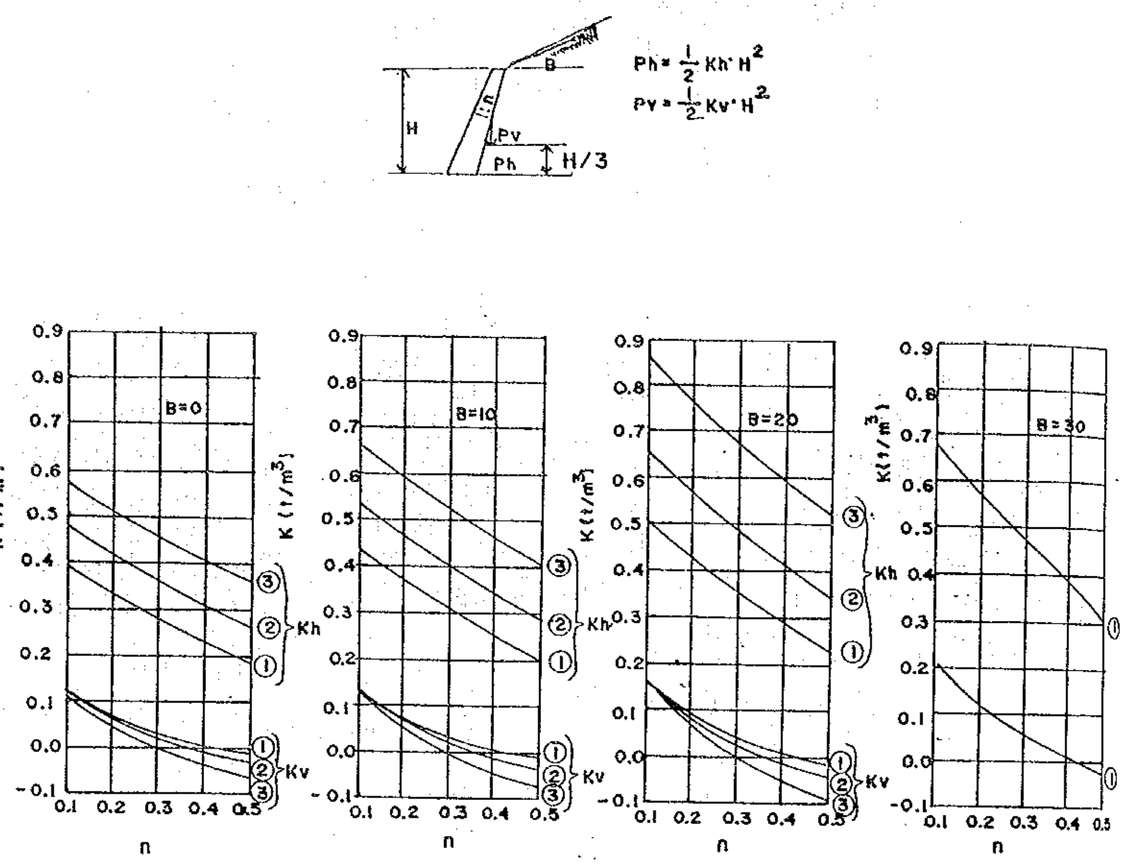
$Pv = \frac{1}{2} \cdot Kv \cdot H^2$



Note: Figures on curve show kind of soil used for back-filling as follows:

(1) Gravel, Gravelly Soil and Sand
(2) Sandy Soil
(3) Silt and Cohesive Soil ($W_L < 50\%$)

FIGURE 9-4 COEFFICIENT OF EARTH PRESSURE FOR DESIGN (Ordinary Retaining Wall with a Height less than 8 m)



Note: Figures on curve show kind of soil used for back-filling as follows:

(1) Gravel, Gravelling Soil and Sand
(2) Sandy Soil
(3) Silt and Cohesive Soil ($W_L < 50\%$)

FIGURE 9-5 COEFFICIENT OF EARTH PRESSURE FOR DESIGN
(Supported Type Retaining Wall with a Height less than 8 m)

Ø : Internal Angle of Friction

Gravelly : Ø 35°
Sandy : Ø 30°

α : Angle between imaginary Back Face of Wall and Vertical Line

β : Angle between Slope and Horizontal Line

δ : Angle of Friction between Imaginary Back Face of Wall and Soil

Concrete and Soil : $\delta = \frac{2}{3}\,\phi$

Soil and Soil : $\delta = \phi$

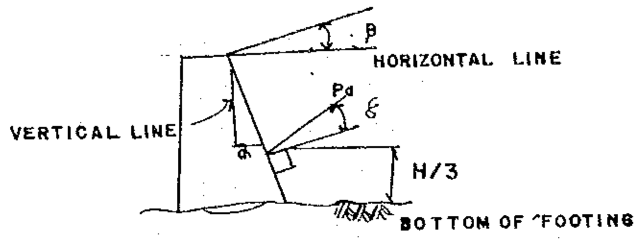


FIGURE 9-6 CONCEPTIONAL DIAGRAM OF ACTIVE EARTH PRESSURE

(ii) Trial Method with Wedge Shape

Refer to APPENDIX 1; DESIGN EXAMPLE NO 3; DESIGN OF RETAINING WALL WITH ANCHORING

; DESIGN EXAMPLE NO 4; DESIGN OF RETAINING WALL BY TRIAL METHOD WITH WEDGE SHAPE

In the case where ground surface is complicatedly irregular. Trial Method with Wedge Shape may be used. As shown Figure 9-7, a sliding plane is assumed. Funicular polygon along the assumed sliding plane can be drawn upon which the resultant earth pressure along the plane can be (known) determined. Following the same way, the resultant earth pressure along a next assumed sliding plane can be calculated. This is carried on until the maximum resultant earth pressure is estimated.

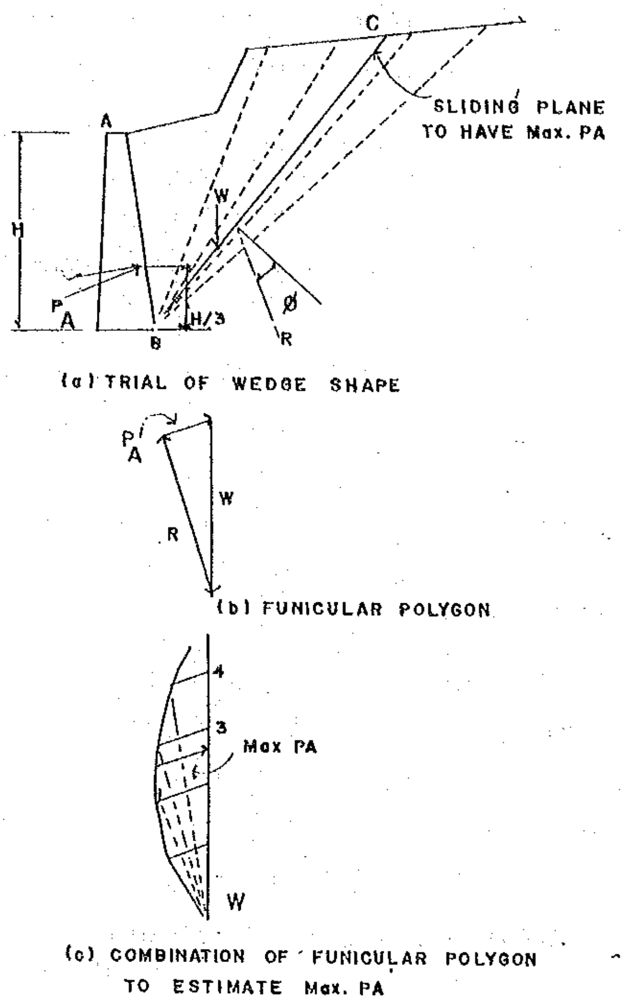


FIGURE 9-7 ANALYSIS OF EARTH PRESSURE
BY TRIAL METHOD WITH WEDGE SHAPE

9.2.4 Earth Pressure for Cut Slope

In case of a cut section, there is sometimes a boundary between backfilled material and cut slope (original ground), at the back of retaining wall. Earth pressure acting on such retaining wall is different from the one backfilled with the same kind of materials.

When a cut slope is unstable, the soil movement at the back of retaining wall may be considered the same in the case of an embankment. Therefore, the method to analyze earth pressure for embankment may be adopted in the case where the actual slide plane in the cut slope can hardly be applied.

In case of a stable cut slope, earth pressure should be analyzed by the Funicular Polygon Method considering the gradient of cut slope, roughness of surface and condition of drainage. Slide may be assumed to occur along the surface of cut slope, as shown in Figure 9-8.

With Funicular Polygon Method, earth pressure for stable cut slope is given by the following formula.

$$P = \frac{W.\ \sin(\emptyset - \delta)}{\cos(\emptyset - \delta - \delta - \alpha)}$$

Where:

P : Earth Pressure

W : Weight of Backfilled Soil (t/m^3)

δ : Angle of friction along surface of cut slope
smooth surface (more than soft rock) . . .
rough surface . . . = $\emptyset$

$\emptyset$: Internal Angle of Friction

δ : Angle of Friction between Imaginary back Face of Wall and Soil

α : Angle between imaginary back face of wall and vertical line

θ : Gradient of Cut Slope (degree)

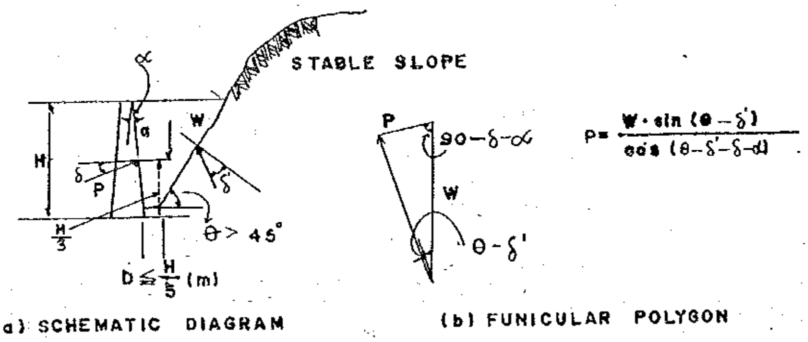


FIGURE 9-8 ANALYSIS OF EARTH PRESSURE FOR CUT SECTION

9.2.5 Earth Pressure during Earthquake

When analysis on the effect of earthquake is required, horizontal seismic intensity for design should be carefully determined based on seismic characteristics of area, condition of foundation, etc. During earthquake, earth pressure for embankment section may be determined by the following Manonobe-Okabe's formula.

$$P_{AE} = \frac{1}{2} \cdot K_{AE} \cdot \gamma \cdot H^2$$

$$K_{AE} = \frac{\cos^2 (\phi - \alpha - \theta)}{\cos\theta . \cos^2 . \cos(\alpha+\delta+\theta) \left[1 + \sqrt{\frac{\sin(\phi+\delta) . \sin(\phi-3-\theta)}{\cos(\alpha+\delta+\theta) . \cos(\alpha-3)}} \right]^2}$$

Where:

K_{AE} : Coefficient of active earth pressure during earthquake

θ : Compound angel of earthquake

$\theta = \tan^{-1} K_n$

K_n : Horizontal seismic intensity for design

δ : Angle of friction between Imaginary Back Face of Wall and Soil

Concrete and Soil : $\delta = \frac{\phi}{2}$

Soil and Soil : Following Formula

$$\tan = \frac{\sin\phi . \sin(\phi+\Delta-\beta)}{1-\sin\phi . \cos(\theta+\Delta-\beta)}$$

Where:

$$\sin\Delta = \frac{\sin(B+0)}{\sin\phi}$$

When : $B + \theta \geq \varphi . . . . \delta = \phi$

For a cut section, Funicular Polygon Method can be applied taking into consideration inertial force of dead load due to earthquake.

Inertial Force due to Earthquake

Inertial force due to earthquake may be estimated by the following formula:

F_e : $K_n \times W$

Where:

F_e : Inertial force due to earthquake

W : Weight of Retaining wall which shall be considered hatched portion as shown in Figure 9-10.

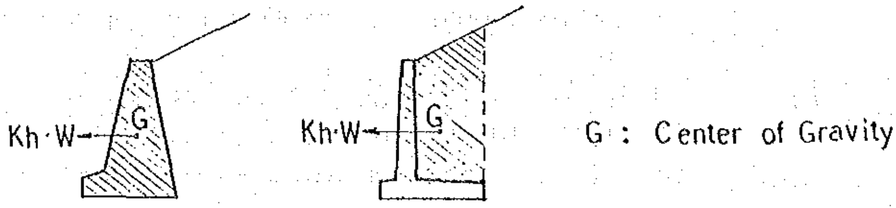


FIGURE 9-9 INERTIAL FORCE OF RETAINING WALL DUE TO EARTHQUAKE

9.3 STABILITY ANALYSIS OF RETAINING WALL

Stability of retaining wall should be analyzed on the basis of the five consideration shown below. However, only 1), 2) and 3) are recommended for ordinary retaining wall, 4) and 5) should be added depending on scale of structure and soil conditions.

1) Stability on sliding
2) Stability on overturning
3) Stability on bearing capacity of bearing ground
4) Stability during earthquake
5) Stability as whole system including embankment and foundation

9.3.1 Stability on Sliding

The force tending to slide a retaining wall along the plane below the bottom slab is the horizontal component of earth pressure. It is resisted by the shear resisting force created between the bearing ground and the bottom of the bottom slab. The passive earth pressure in front of the retaining wall may be also considered as resisting force, but its reliability cannot be expected in long term and thus the passive earth pressure is normally neglected.

The factor of safety F_s against sliding should satisfy the following formula:

$$F_s = \frac{\text{Resisting force against sliding}}{\text{Sliding Force}}$$

$$= \frac{(W+P_V)\tan\delta + C.B}{P_H} \geqq 1.5 \quad . . . . (3.25)$$

Where:

F_s : Factor of safety

P_V : Vertical component of resultant of earth pressure (t/m)

P_H : Horizontal component of resultant of earth pressure (t/m)

tan δ : Coefficient of friction between the bearing ground and bottom slab of retaining wall

$\delta = \phi$ for cast-in-place concrete, and

$\delta = \frac{2}{3}\phi$ for other cases. However, the value of tan δ should not exceed 0.6 when the bearing ground is the soil. Normally, Table 9-4 may be used for the simplified procedure.

ϕ : Angle of internal Friction of foundation ground

C : Cohesion between the bearing ground and bottom slab of retaining wall (t/m). But c = 0 should be used if the coefficient of friction tan δ was obtained from Table 9-4.

B : Width of bottom slab of retaining wall (m).

TABLE 9-4 DESIGN CONSTANT OF BEARING GROUND

Kind of Bearing Ground		Allowable Bearing Capacity (t/m^2)	Coefficient of Friction between Bearing Gravel and Bottom Slab	Remarks	
				q_u (t/m^2)	N-Value
Rock	Hard Rock with few cracks	100	0.7	over 100	-
	Hard Rock with many cracks	60	0.7	over 100	-
	Soft Rock	30	0.7	over 100	-
Gravel	Danse	30	0.6	-	-
	Not Dense	30	0.6	-	-
Sandy	Dense	30	0.6	-	30 ~ 50
	Reasonable Dense	20	0.5	-	15 ~ 30
Cohesive	Very firm	20	0.5	2.0 ~ 4.0	15 ~ 30
	Firm	10	0.45	1.0 ~ 2.0	8 ~ 15
	Reasonably firm	5		0.5 ~ 1.0	4 ~ 8

If the factor of safety is less than 1.5, the width of a bottom slab should be widened. However, when widening of bottom side is not practicable because of the restriction other than engineering considerations, the bottom slab should be placed deeper enough to expect more the passive earth pressure at the front of the structure. With assurance of perfect compaction of backfilling at the front, the stability on sliding can be checked by the following formula. See Figure 9-11.

$$F_s = \frac{(W + P_v) \cdot \tan \delta + c \cdot B + P_p}{P_h} \geqq 2$$

Where:

P_p : Horizontal component of passive earth pressure

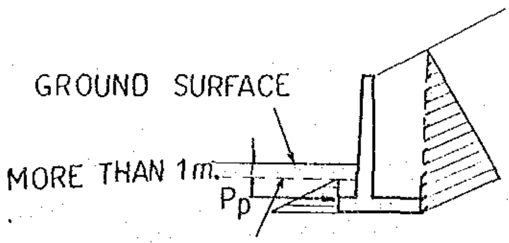


FIGURE 9-10 PASSIVE EARTH PRESSURE EXPECTED AGAINST SLIDING

Where a bearing ground is composed of firm ground or rock, a protuberant can be provided at the bottom of a bottom slab to increase a resisting force against sliding which can be analyzed by the following formula. See Figure 9-12.

$$H_2 = \underline{q1+q3} \cdot \ell_1 \cdot \tan \emptyset + \underline{q2+q3} \cdot \ell_2 \cdot \tan \delta + c\ c \cdot \ell_1$$

$$F_s = \frac{H_k}{P_H} \geqq 1.5$$

Where:

H_k : Resisting Force against sliding

q_1, q_2, q_3 : Ground Reaction (t/m^2) (Refer to Figure 9-12)

$\ell_1, \ell_2,$: Width of bottom slab (m) (Refer to Figure 9-12)

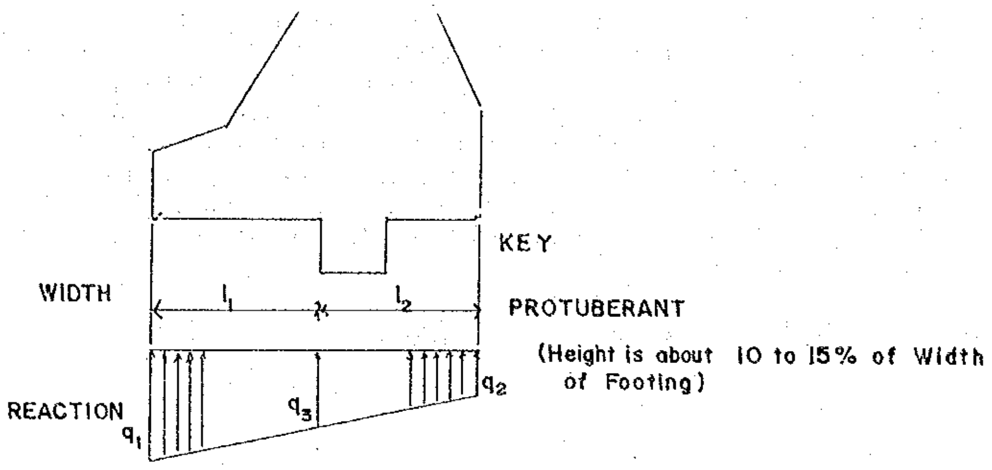


FIGURE 9-11 RESISTING FORCE AGAINST SLIDING WITH PROTUBERANT

9.3.2 Stability on Overturning

Loads due to dead load, surcharge and earthquake act altogether at the bottom of the bottom slab of a retaining wall. The ground reaction at the plane due to these loads varies depending on the point where the resultant of these loads act on the plane.

The distance "d" from the toe to the acting point of resultant "R" can be expressed by the following equation.

$$d = \frac{W \cdot a + P_V \cdot b - P_h \cdot h}{W + P_V}$$

Where:

d : Distance from toe to acting point of resultant (m)

a : Horizontal distance from the toe of retaining wall to the center of gravity of W (m).

b : Horizontal distance from the toe of retaining wall to the point of application of P_V (m)

h : Vertical distance from the heel of retaining wall to the point of application P_H (m).

Distance of eccentricity "e" from the center of the bottom slab to the acting point of resultant "R" can be expressed by

$$e = \frac{B}{2} - d$$

As a condition of stability for overturning, the acting point of the resultant R must be within the central one-third portion of the width B of the bottom slab. That is, the distance of eccentricity must satisfy the following formula:

$$e \leqq \frac{B}{6}$$

9.3.3 Stability on Bearing Capacity of Bearing Ground

Ground reaction can be analyzed by the following formula. See Figure 9-13.

$$q_1 = \frac{P_v + W}{B}\left(\frac{1 + 6e}{B}\right)$$

$$q_2 = \frac{P_v + W}{B}\left(\frac{1-6e}{B}\right)$$

q_1 and q_2 shall be

$$\left.\begin{matrix} q_1 \\ \\ q_2 \end{matrix}\right\} \leqq q_a = \frac{q_u}{F_s}$$

Where:

q_a : Allowable unit bearing capacity of ground

q_u : Ultimate unit bearing capacity of ground

F_s : Factor of safety for bearing capacity of ground

$$F_s = 3$$

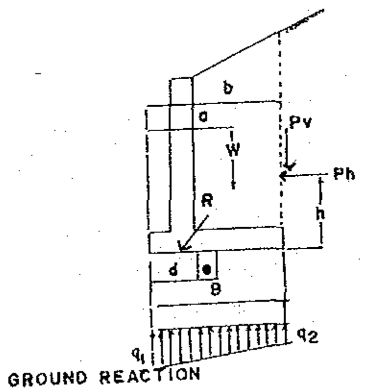


FIGURE 9-12 ANALYSIS OF GROUND REACTION

9.3.4 Stability During Earthquake

The stability of a retaining wall during earthquake can be checked by the method for the normal case but using the earth pressure during earthquake instead of earth pressure for normal conditions and the inertial force during earthquake is taken into account.

The following factors of safety should be used for the calculations of stability during earthquake:

(1) Factor of safety against sliding: $F_s \geqq 1.2$

$F_s \geqq 1.5$ when considering the passive earth p pressure at the front.

(2) Stability on overturning

The acting point of resultant R must be within the central two-third portion of width B of the bottom slab. That is, the distance of eccentricity e must satisfy the following equation.

$$e \leqq \frac{B}{3}$$

(3) Factor of safety for bearing capacity of bearing ground:

$$F_s \geqq 2$$

The ground reaction should be determined by the following equations.

With $e \leqq \frac{B}{6}$, $q_1 = \frac{P_{vE} + W}{B} \left(\frac{1 + 6e}{B}\right)$

With $\frac{B}{6} \leqq 3 \leqq P$ $q_1 = \frac{2 \ (P_{vE} + W)}{3d}$

Where:

P_{vE} = Vertical component of resultant of earth pressure during earthquake.

9.3.5 Stability of the Whole System Including Embankment and Foundation

(1) Retaining Wall on Soft Ground

When a retaining wall is built on soft ground, rapture of the foundation ground soil may sometimes breakout due to the weight of embankment behind the wall. Schematic diagrams of rapture are illustrated in Figure 9-14.

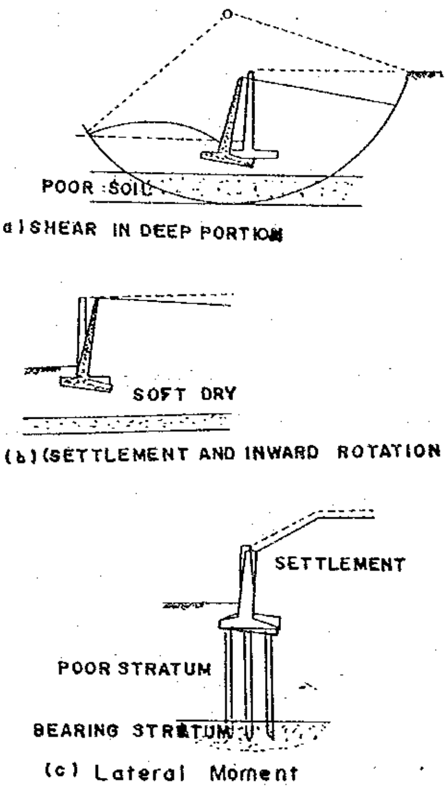


FIGURE 9-13 SCHEMATIC DIAGRAM OF RAPTURE

In this case, stability of retaining wall should be checked including embankment and foundation, as a whole system. Stability analysis with sliced method of circular rapture plane can be applied, as described below.

Refer to 6-3 ; Stability Analysis of Embankment

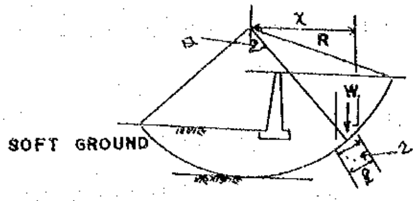


FIGURE 9-14 CIRCULAR RAPTURE ON SOFT GROUND

$$F_s = \frac{\Sigma R \{c'.\ell + \tan \emptyset' \ (W \cos \theta - u.\ell\}}{\Sigma W.x}$$

Where:

F_s : Factor of Safety

C' : Cohesion along circular rapture

Ø' : Angle of Internal Friction along circular rapture

W : Weight of Slice

u : Pore water pressure

(2) Retaining Wall on Slope

In many case, slope itself has problems of stability. Therefore, when constructing retaining wall on slope, the stability of slope including retaining wall and embankment, as a whole, should be examined, adopting the design concepts aforementioned.

9.4 APPLICATION AND DESIGN OF RETAINING WALL

9.4.1 Stone Masonry Retaining Wall

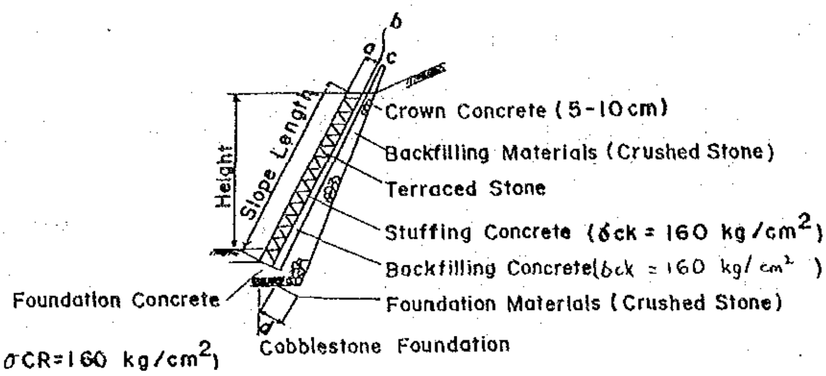
Refer to APPENDIX 2; STANDARD DRAWING NO. 11; SLOPE MASONRY RETAINING WALL

(1) Application

Stone masonry retaining wall is used to protect a slope from small-sized failure near the toe of slope. This type is effective only for small earth pressure acting on a retaining wall slope with gradient steeper than 1.0:1 (generally 0.3:1 ~ 0.6:1) and with firm soil cover. The height of the structure is normally less than 5 m.

(2) Shape

Figure 9-16 below shows a typical section of stone masonry retaining wall.



(a) Rear to Face Length of Terraced Stone
(b) Thickness of Backfilling Concrete (10 ~ 15 cm.)
(c) Thickness of Backfilling Material at Top
(d) Thickness of Backfilling Material at Bottom

FIGURE 9-15 STONE MASONRY RETAINING WALL

(3) Rear to face length of terraced stone

Rear to face length of terraced stone should be determined by height and gradient of a slope. Refer to the standard length shown in Table 9-5.

TABLE 9-5 REAR TO FACE LENGTH OF TERRACED STONE

Height (m)			0~1.5	1.5~3.0	3.0~5.0	5.0~7.0
Gradient		Embankment	0.3:1	0.4:1	0.5:1	0.6:1
		Cut	0.3:1	0.3:1	0.4:1	0.5:1
Rear to Face Length (cm.)	Dry Masonry		35	35	-	-
	Wet Masonry	Stuffing Concrete only	35	35	35	-
		Stuffing Concrete and Backfilling Concrete	35+5* = 40	35+10* = 45	35+15* = 50	35+20* = 55

Note:

* (show) thickness of Backfilling Concrete
\- means not applicable

(4) Backfilling Material

Backfilling material aims to reduce pressure acting on the retaining wall by draining water and thus reducing water pressure.

Standard thickness of backfilling materials for embankment slope is shown in Table 9-6.

TABLE 9-6 THICKNESS OF BACKFILLING MATERIAL

Height		0. ~ 1.5	1.5 ~ 3.0	3.0 ~ 5.0	5.0 ~ 7.0
Thickness (cm.)	Top	20 ~ 40	20 ~ 40	20 ~ 40	20 ~ 40
	Bottom	30 ~ 60	45 ~ 75	60 ~ 100	80 ~ 120

For cut slope composed of firm soil, uniform thickness of 30 to 40 cm. from top to bottom can be recommended, while the thickness shown in Table 9-6 can be applied for loose soil of cut slope.

(5) Notes in Construction

Cobblestone (or crushed stone) should be well placed (as a foundation) to support the concrete foundation. In case of rock foundation, lean concrete with 15 cm. In thickness is more preferred instead of stone foundation.

Joint should be provided every 20 m. although it may vary depending on the soil condition.

Weep hole should be provided at leat 1 per 2 m^2.

When high retaining wall is required, a separated type of stone masonry may be recommended as shown in Figure 9-17.

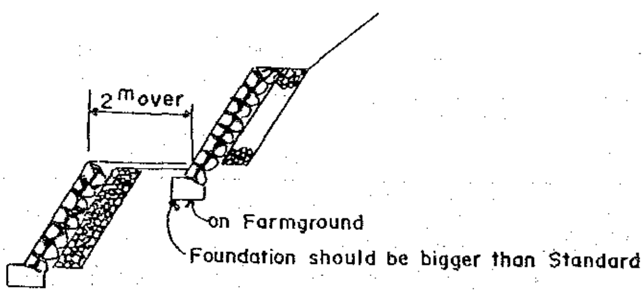


FIGURE 9-16 SEPARATED STONE MASONRY

9.4.2 Gravity Type Retaining Wall

Refer to APPENDIX 2; STANDARD DRAWING NO. 12; GRAVITY TYPE RETAINING WALL

(1) Application

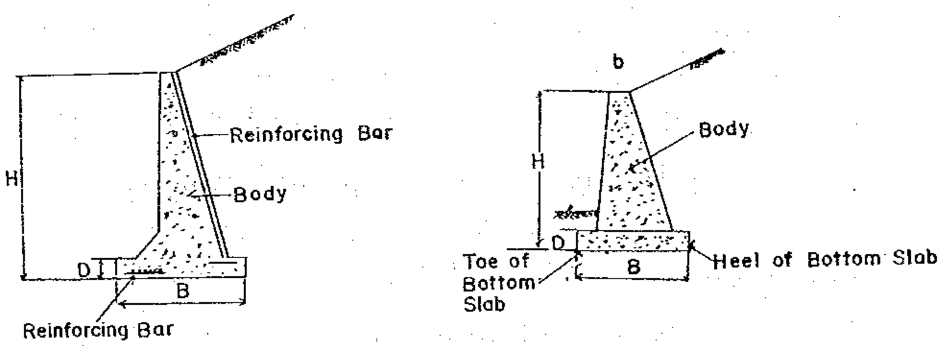
Gravity type retaining wall is mainly used as one of direct restraint work for failure of slope or as a foundation of other slope protection work. This type is often be adopted when the height required is relatively low (less than 5 m.) and strong bearing stratum is assured for a foundation ground.

This type is designed so as to counter against earth pressure by its own weight, in such a way that the resultant of earth pressure and dead load may not create tensile stress of concrete in the section of wall.

In case that tensile stress of concrete will be created, semi-gravity type may be applied providing reinforcing bar to cover tensile stress of concrete.

(2) Shape

The width B of the bottom slab is, in general, about 0.5 to 0.7 times the height of retaining wall, and the width of the crown b is more than 35 cm. enough to have a space for a protection fence. See Figure 9-18.



(a) Gravity Type Retaining Wall (b) Semi-Gravity Type Retaining Wall

FIGURE 9-17 GRAVITY TYPE RETAINING WALL

(3) Design

Stability of retaining wall should be checked by the method mentioned in section 9.3, while structural dimension can be designed under the following method.

Body

Concrete stress at section A-A is checked by a following formula. See Figure 9-19.

$$\sigma_{c1} = \frac{V}{b}\left(1 \pm \frac{6e}{b}\right) \leqq \sigma_{cat},\ \sigma_{cac} \ \text{or}$$
$$\sigma_{c2}$$

Where:

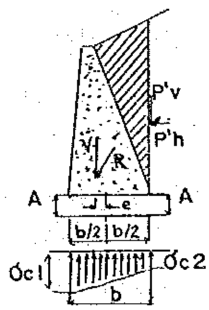
σ_{c1}, σ_{c2} : Concrete stress at section A-A (kg/cm^2)

V : Total of dead load (above bottom slab), surcharge and vertical component of earth pressure P_V (kg/cm)

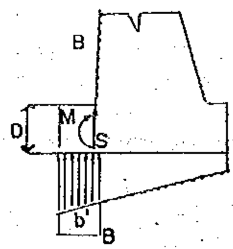
σ_{cat} : Allowable tensile stress of concrete (kg/cm^2)

σ_{cac} : Allowable compression stress of concrete (kg/cm^2)

e : Eccentric Distance



Stress at Section A-A



Stress at Toe of Bottom Slab

FIGURE 9-18 STRESS OF GRAVITY TYPE RETAINING WALL

Toe of Bottom Slab

Concrete stress at section B-B is checked by the following formula.

$$\tau = \frac{S}{A} \leqq \tau_{ca}$$

$$\sigma_c = \frac{M}{Z} \leqq \sigma_{ca},\ \sigma_{cac}$$

Where:

τ_c : Shearing stress of concrete

σ_c : Concrete stress

S : Shearing force at section B-B (kg.cm/cm)

τca : Allowable shearing stress of concrete

M : Bending moment at B-B (kg.cm/m)

Z : Section modulus at B-B (cm^3/m)

A : Section Area at B-B (cm^2/m)

9.4.3 Supported Type Retaining Wall

Refer to APPENDIX 2: STANDARD DRAWING NO. 13; SUPPORTED TYPE RETAINING WALL

(1) Application

Supported type retaining wall is designed as a gravity type structure although it can not stand by itself and, therefore, should be supported by the earth at the rear. This type can counter by its own dead load against earth pressure while being supported. This type is often used as a countermeasure to stabilize a slope in mountainous area.

(2) Shape

Generally, slope ratio at front of wall is 0.3:1 to 0.6:1 and height of wall is about 3 to 13 m. But, as the special case, the wall with a height of 14 m is sometimes designed. See Figure 9.19.

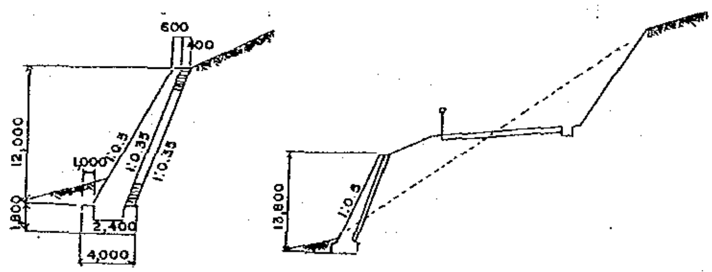


FIGURE 9-19 SUPPORTED TYPE RETAINING WALL

9.4.4 Cantilever Beam Type Retaining Wall

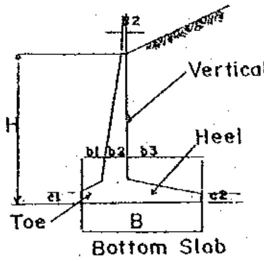
(1) Application

Cantilever Beam Type is used in places where a high wall is required and gravity type or other type is not economical. The height of this type is limited to about 3 m. to 8 m. and the volume of concrete used may be smaller than that of a gravity type.

A cantilever beam type retaining wall consists of a vertical wall and bottom slab which can resist external force as s cantilever beam. By the location of a vertical wall in relation to a bottom slab, this type is sub-classified into an inverted T type and L type, retaining wall.

(2) Shape

Standard section of cantilever beam type is shown in Figure 9-20.

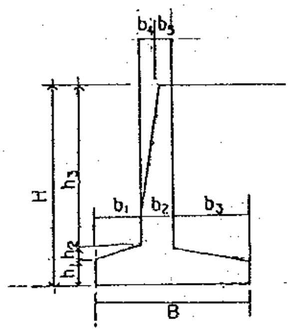


$n \geq \frac{1}{50}$
$B \doteqdot 0.5 - 0.8\ H$
$bl \doteqdot \frac{1}{2}$ to $\frac{1}{5}$ of B
bl, cl, c2 > 30 cm

FIGURE 9-20 CANTILEVER TYPE RETAINING WALL

Table 9-7 shows the standard dimension of inverted T type retaining wall.

TABLE 9-7 DIMENSION OF INVERTED T TYPE RETAINING WALL



TYPE	1-3.0	1-4.0	1-5.0	1-6.0	1-7.0
H	3.000	4.000	5.000	6.000	7.000
h_1	0.150	0.150	0.150	0.200	0.200
h_2	0.400	0.450	0.500	0.500	0.550
h_3	2.450	3.400	4.350	5.300	6.260
B	2.000	2.400	3.500	4.260	5.000
b_1	0.400	0.550	0.700	0.850	1.000
b_2	0.660	0.600	0.650	0.700	0.750
b_3	0.050	0.550	2.150	2.700	3.250
b_4	0.245	0.340	0.435	0.530	0.325
b_5	0.350	0.350	0.350	0.350	0.350

9.4.5 Counterfort and Buttressed Type Retaining Wall

(1) Application

Counterfort type and buttressed type retaining wall are purposely used to reduce the thickness of the vertical wall and bottom slab in the same manner as with those of cantilever type. The wall and slab are designed as a continous plate or beam supported by counterfort and buttressed wall which can also be designed as web plate of a T-Type cantilever retaining wall. The height generally adopted for this type is higher than 6 m.

(2) Shape

Standard type of the walls is shown in Figure 9-21.

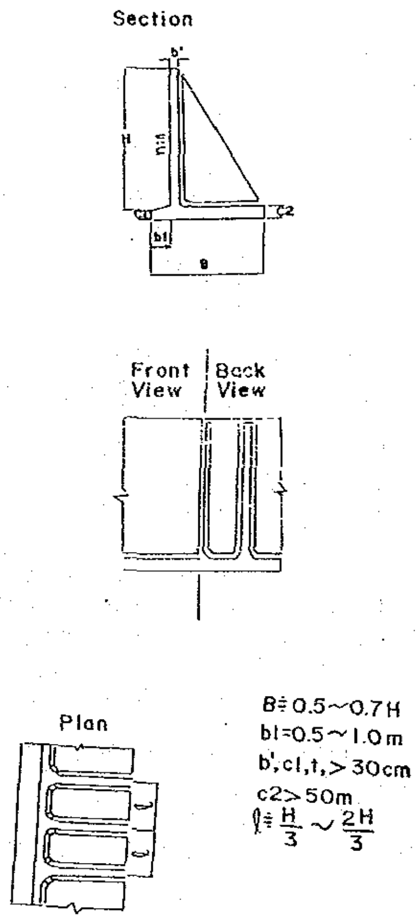


FIGURE 9-21 COUNTERFORT TYPE RETAINING WALL

9.4.6 Gabion Retaining Wall

Refer to APPENDIX 2: STANDARD DRAWING NO. 12: GRAVITY TYPE AND GABION RETAINING WALL

(1) Application

Gabion Retaining Wall is used to protect small size failure at the toe of slope, especially where spring water exists.

As mentioned in section 8.6, gabion is commonly used as one of the protection work rather than as a retaining wall since this type can resist only small earth pressure.

(2) Shape

Mat gabion is generally used for a retaining wall as shown in Figure 9-22.

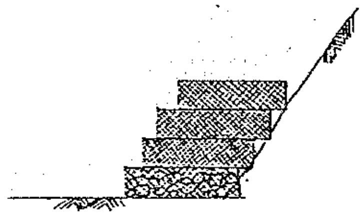


FIGURE 9-22 GABION RETAINING WALL

9.7 CONSTRUCTION OF RETAINING WALL

Retaining wall should be carefully constructed since this structure is designed to retain the extensive earth pressure and therefore the failure of this structure may result in the severe damage not only to the road structure but to the users as well.

The notes which should be strictly observed during the construction of the retaining wall are discussed in this section.

9.7.1 Foundation Work

(1) Where ton bearing ground is a bedrock, the bedrock should be cut to a depth required for placing a footing. The cut surface of the bedrock should be cleaned and then the spread footing may be placed. See Figure 9-23 (a).

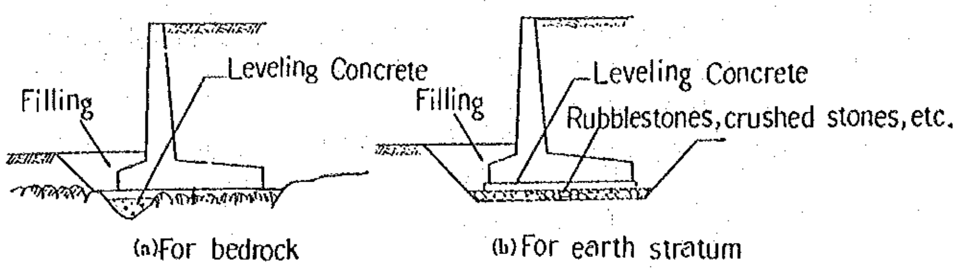


FIGURE 9-23 SPREAD FOOTING FOUNDATION

(2) Where the bearing ground is earth or gravel, rubblestones should be laid over the excavated surface and rolled fully and uniformly. Leveling concrete mix should be poured over the rubblestones, and then the spread foundation may be placed over it. See Figure 9-23 (b).

(3) Where the bearing ground surface is slanted, the portion at the valley side should be cut in the form of steps and the rock should be replaced with concrete to the bedrock line to form a horizontal, uniform foundation. The body of the retaining wall should then be directly built over the foundation. See Figure 9-24.

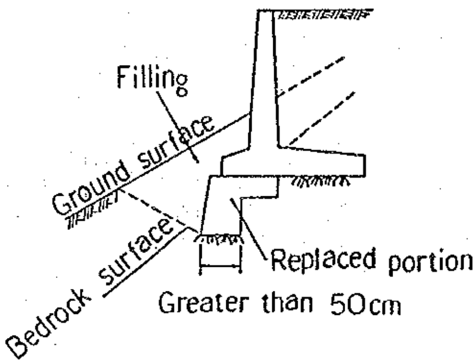


FIGURE 9-24 GROUND STEPPING METHOD

(4) Where the bearing ground is made up of poor materials, a pile foundation is generally adopted. However, if the poor stratum is thin, it is recommended to replace this with a better material such as good quality gravelly soil or the like, to provide a uniform bearing ability so that the retaining wall may be built directly over the replaced material. See Figure 9-25.

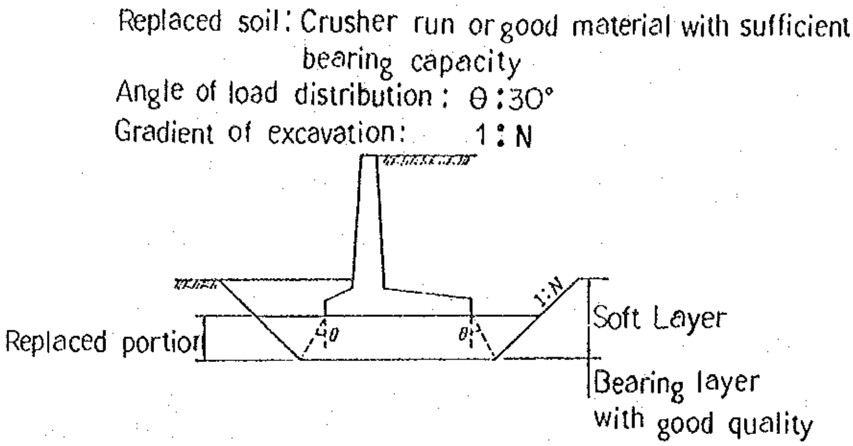


FIGURE 9-25 GROUND REPLACING METHOD

9.7.2 Concrete Work

(1) Concreting work for both the footing and wall should be done as much as practicable monolithically. Nevertheless, goove, tennon, half-lap construction joint or steel dowel should be provided at the joint if this can not be avoided.

(2) Construction joint of wall should be provided at every 10 m or less as shown in Figure 9-26 (a). Reinforcing bar shall not be cut at the joint.

(3) Expansion joint of wall should be provided at every 10 m or less for gravity type and at every 15 to 20 m. for cantilever type retaining wall. See Figure 9-26.

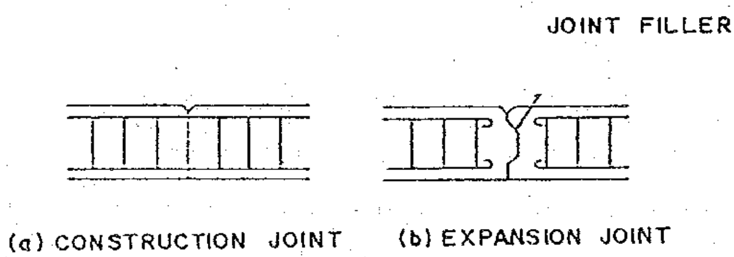


FIGURE 9-26 JOINT OF WALL

9.7.3 Backfill Work

(1) Backfilling should not be allowed until the structure become stable and strong enough to resist the earth pressure.

(2) Only selected quality materials should be used to backfill the retaining wall.

(3) Where the back of the retaining wall is used as a road, the selected materials should be placed as shown in Figure 9-27.

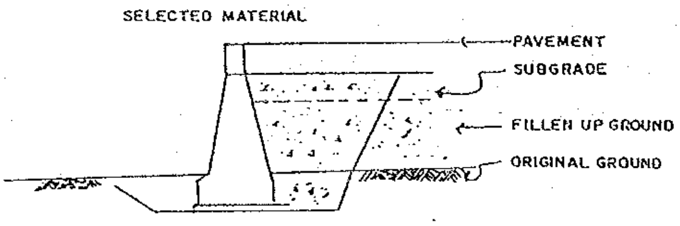


FIGURE 9-27 BACKFILL OF SELECTED MATERIAL

(4) Compaction is preferably done with heavy equipment such as 0.5 t vibrating compactor or vibrating roller more than 1 t for the lower portion and tire roller for the upper portion of backfilling. For the narrow portions, small size compactor may be used.

(5) The thickness of a layer for the compaction should be less than 20 cm.

(6) Rain water should be perfectly prevented from flowing into the portion of backfilling. Drain or closed conduits should be provided in order to drain the seepage water.

PART IV COUNTERMEASURES FOR ROAD DISASTERS

CHAPTER 10 COUNTERMEASURES FOR CUT SLOPE FAILURES

10.1 TYPES OF COUNTERMEASURES

Countermeasures for cut slope failures are classified into the following six types:

- Drainage Work
- Protection Work
- Earth Work
- Structural Work
- Catch Work
- Avoiding Protection Work

Each of these is sub-classified into several types of works as listed in Table 10-1, indicating the purpose, application and typical illustrations.

The purposes and the application mentioned in Table 10-1 together with the characteristics of each type briefly discussed in Section 10.3 may be referred to for the selection of countermeasures.

10.2 SELECTION OF COUNTERMEASURES

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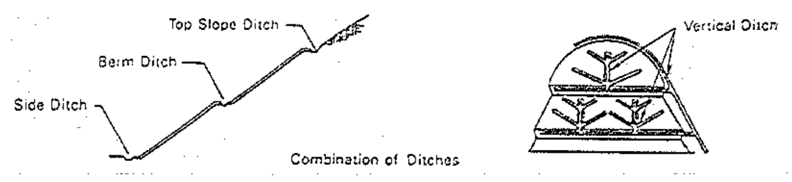
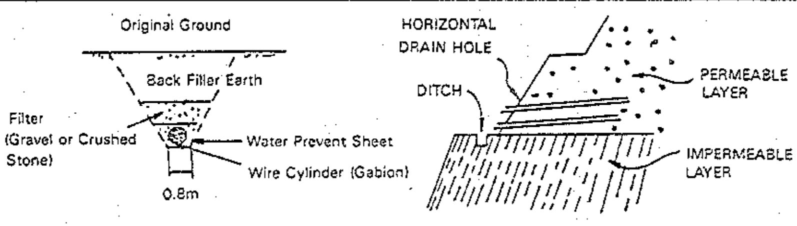
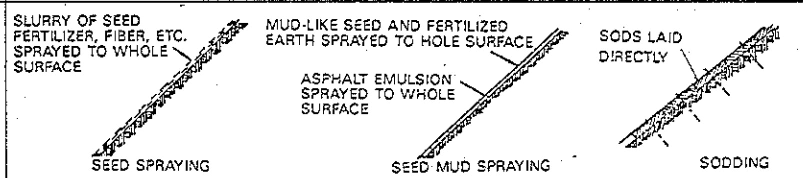
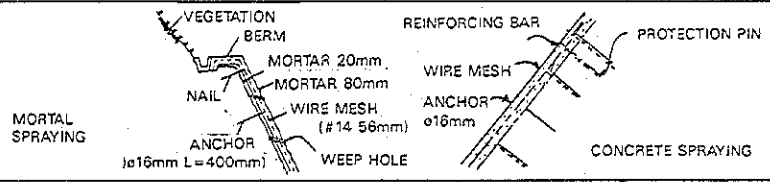
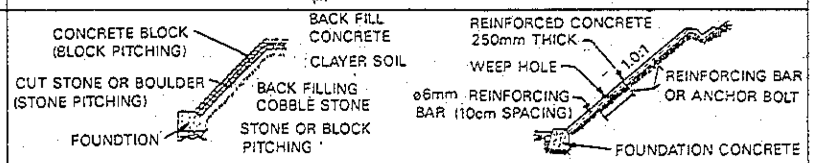
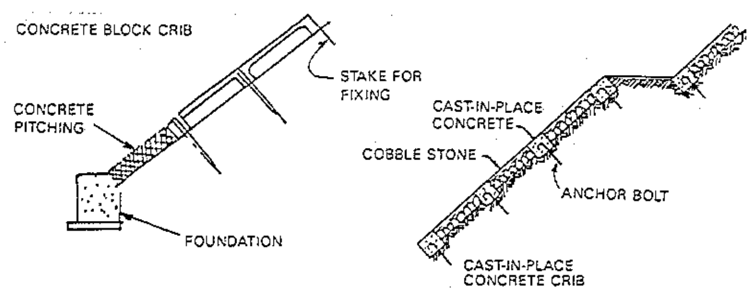
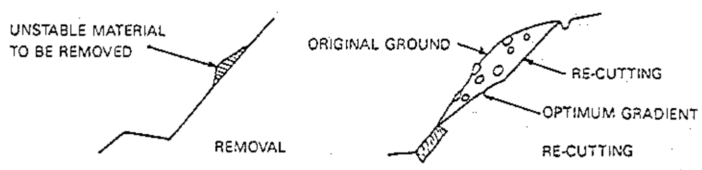
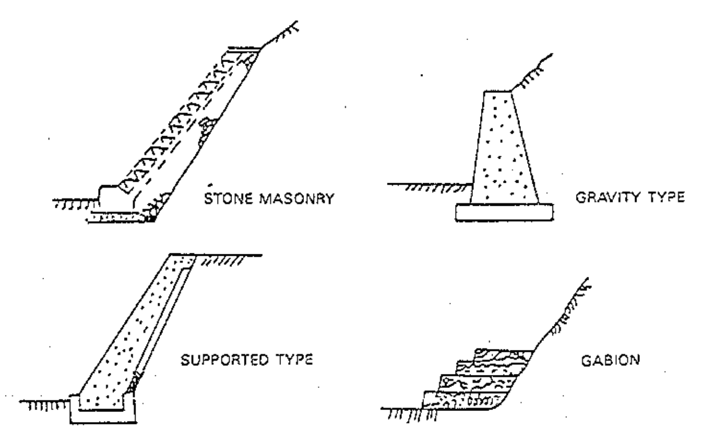
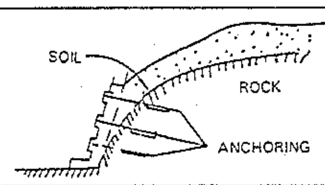
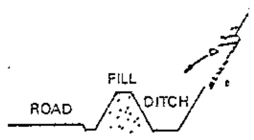
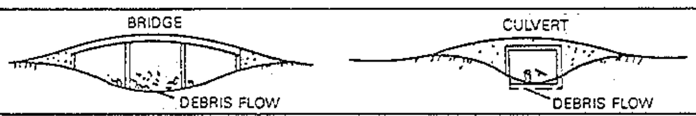
In selecting proper countermeasures, the following elements should be taken into consideration:

a) Causes of failure

- Primary Causes
  - Topography
  - Geology
  - Others

- Inducement Causes
  - Surface Water
  - Groundwater
  - Precipitation
  - Others

Table 10-1 COUNTERMEASURES FOR CUT SLOPE FAILURE

	Classification	Type of Work	Purpose	Application	Illustration
Drainage Work	Surface Drainage	Top slope Ditch	To collect surface water running directly on slope surface and thus prevent erosion and scouring of slope surface.	Required for almost all cases of slope protection, especially for slope with broad area or water concentration. Usually applied together with other countermeasures.	
		Berm Ditch			
		Side Ditch			
		Vertical Ditch			
	Subsurface Drainage	Subsurface Drainer	To drain groundwater, spring water and seepage water and lower pore with pressure and thus stabilize stability of slope.	Effective to drain water near ground surface. Generally used in combination with surface drainage.	
		Horizontal Drain Hole		Effective for slope where groundwater level is higher than plane of failure.	
Protection Work	Vegetation	Seed Spraying	To firmly bind materials of slope surface and thus prevent slope from erosion, scouring and weathering.	Mainly applied to slopes composed of soil or strongly weathered rock. When applied, gradient is preferred to be less than 0.8:1. It improves aesthetics view of the environment.	
		Seed Mud Spraying			
		Sodding			
	Spraying	Mortar Spraying	To cover whole surface of slope with mortar or concrete sprayed by concrete gun and thus prevent slope from erosion, scouring and weathering.	Mainly applied to slope of. . Easily weatherable rock with no spring water or not wet. . Weathered rock which may be stripped off. . Soil not suited for vegetation.	
		Concrete Spraying			
	Pitching	Stone or Block Pitching	To cover slope with stone, or concrete block or cast-in-concrete and thus prevent slope from erosion, scouring, weathering and slight surface failure.	Applied to slope gentler than 45°. Stone pitching is widely adopted.	
		Concrete Pitching			
	Crib	Concrete Block Crib	To prevent slope from erosion, scouring, weathering and slight surface failure. — Resisting force against earth pressure may not be expected.	Applied to slope gentler than 45°. Effective for slope with spring water.	
		Cast-in-place Concrete Crib			
		Sprayed concrete crib	Resisting force against earth pressure may be expected depending on size and space of crib.	Applied to slope steeper than 45°. Effective for weathered rock and large slope with spring water. (*1, *2)	
	Earth Work	Removal	To stabilize slope by completely or partially removing unstable materials on slope.	Basic method. Reliable when perfectly enforced. Applied together with drainage, vegetation and other protection works. Application is sometimes limited because of traffic interruption.	
		Re-cutting	To stabilize slope by cutting to optimum gradient.		
Structural Work	Retaining Wall	Stone Masonry Retaining Wall	To protect slope from small size failure, especially, near toe of slope.	Effective only for small earth pressure. Applied to slope with gradient steeper than 45° and with firm soil. Height less than 7 m.	
		Gravity Type Retaining Wall	To directly restraint slope failure or used as a foundation of other works.	Strong bearing ground is required. Height less than 5 m.	
		Supported Type Retaining Wall	To directly restraint slope failure and prevent erosion, scouring and weathering.	Applicable for soil with loose solidification. It can be constructed in limited area. Height less than 8 m.	
		Gabion Retaining Wall	To protect slope from small size failure, especially near toe of slope.	Effective for slope with seepage or spring water.	
	Anchoring	Rock Bolt	To directly restraint slope failure. Usually applied together with concrete pitching crib, etc.	Mainly applied to slope with strongly weathered rock or rock with many cracks and joints. Rock bolt is for small tension against anchoring, while p.c. is for high.	
		P.C. Anchor			
	Catch Work	Catch Fill and Ditch	To prevent spread of damage providing ditch and fill or wall to catch failured materials. Occurance of failure can not be prevented.	Applied when other countermeasures are difficult or costly. Wide space for deposite is required between road edge and toe of slope.	
		Catch Wall			
	Avoiding Problem Work	Route Relocation	To avoid problem by relocating route or pass over disaster site with bridge.	Applied when other countermeasure are difficult or costly.	
		Bridge			

Note: *1. Irregularity of slope surface shall be corrected. Form is required.

*2. Irregularity of slope surface is not necessary to correct. Form is required. Concreting is done by spraying with gun.

b) Characteristics of Countermeasures

- Purpose and Effectiveness
- Stability and Durability
- Construction
- Maintenance
- Others

c) Impact

- Traffic
- Social
- Environmental
- Others

In many cases, several countermeasures may be proposed in one disaster spot and thus the combined use of two or three measures is rather common.

(1) Drainage Work

The causes of cut slope failure by the effect of water may be divided into two: first, erosion and scouring due to surface water running down on slope surface; and second, sliding of the slope due to decrease of shearing strength and increase of pore water pressure because of the existence of groundwater. Cause of failures is mostly on the first case. Thus, drainage work (especially surface drainage) is considered vital for slope protection. Ditching is the most common method used for surface water drainage. The different types of ditches are described below:

- Top Slope Ditch. This is recommended at the top of the slope when running water from adjacent area is expected. The water accumulated from the ditch is normally directed outside the slope although this is sometimes drained down a vertical ditch constructed on the face of the slope.

- Berm Ditch. For wider and higher slopes a considerable amount of surface water flows down the slope surface causing erosion and scouring. To prevent this, the berm ditch is recommended on the berm of the slopes. For the slopes where re-cutting is required berm ditches should be provided on all berms considering the high rainfall intensity in the Philippines.

- Vertical Ditch. Deep scouring due to surface water is often observed for concave-shaped cut slopes. In this case, vertical ditches should be provided. This is also used to drain water collected from top slope ditch and/or berm ditch. At the bottom of the ditch, a catch basin should be designed and connected to the existing dide ditches, new side ditches should be designed and connected with available cross drain structures.

(2) Protection Work With Vegetation

Protection work with vegetation is relatively cheap and constributes to aesthetics in the environment. For this reason, whenever possible, vegetation should be fully utilized as a protection measure. Seed spraying with equipment may be recommended because of the following reasons:

. Environmental aspect
. Cut and short construction period
. No disruption of traffic during construction

(3) Protection Work With Structures

Protection Work with structures such as spraying, pitching and crib can be applied for the slope where vegetation cannot grow, or when the stability of slope cannot be assured for a long period of time with vegetation especially for the following cases:

. Where gradient of slope is steeper than 0.8:1
. Where slopes are composed of hard rock, soft rock with a little weathering of soft rock with a few cracks or highly acidic soil.
. Where slope have extensive spring water.

Mortar and Concrete Spraying

Spraying of mortar and concrete directly in the face of the slope is considered one of the most effective and fastest way to do slope protection works. However, mortar spraying is not recommended in the Philippines because this can not be considered as a permanent structure due to varying high temperature and rainfall intensity. Concrete spraying is positively recommended because of its strength against earth pressure, short construction period and it is more economical than other protection works with structures. Another advantage is that the irregularity of the slope surface is not required to be corrected prior to its application.

Pitching

Pitching is classified into stone pitching, block pitching and concrete pitching according to materials to be used. Concrete pitching work can be used as control work to resist big earth pressure when applied with rock bolt and anchor.

Although these works can be carried out in the Philippines, this is not recommended for general adoption as these are more expensive than concrete spraying. Furthermore, the construction period is longest as correction for the irregularity of slopes is required.

Crib

Crib is classified into pre-cast concrete block, cast-in-place concrete crib and sprayed concrete crib. The pre-cast concrete crib is not produced in the Philippines and thus is not considered practical to be used in the country.

Nevertheless, structural dimension of cast in concrete crib should be principally designed, depending on the degree of weathering of slopes, the condition of cracks and slope gradient. When cross point of crib is anchored by rock bolt or p.c. anchor, cribwork can be considered as one of the control works because this can resist earth pressure. The space between cribs is usually filled with soil and vegetation. However, stone pitching is advised for the slope on which spring water exists and concrete pitching for the slope strongly weathered.

As mentioned above, Pre-Cast and Cast-in-Place concrete crib is usually applied after the correction of the irregularity of surface. Recently, however, sprayed concrete crib is used because of the advantage that the correction of irregularity of the slope is not required and the form for concreting is not necessary. This work is done in such a way that flexible form made of wire is placed on irregular surfaces of slopes and reinforcing bars are formed inside. Concreting is done inside the frame by spraying. This work can be accomplished in shorter period of time since there is no need to correct irregularity of the slope surface and concreting can be done with concrete spraying. Furthermore, this can resist earth pressure when this is adopted with rock bolt and p.c. anchor.

(4) Earth Work

Earthwork basically consists of removal and re-cutting of earth from the slope surface. Unstable materials have to be removed initially before any countermeasure will be applied. Re-cutting is a basic method applied to the slopes which are steep and unstable. The problem in the application of this method is the difficulty to ensure continuous traffic flow during the process especially for high slopes which involves a huge amount of excavation. Therefore, control works by structure such as slope protection which can resist slight earth pressure and retaining wall may be recommended as countermeasures to ensure the stability of the slope instead of re-cutting. However, there are some cases where re-cutting has to be adopted especially in slopes made up of loose soil.

(5) Structural Work

Structural works consist of retaining wall and anchoring. Retaining wall is mainly used for resisting earth pressure. This is applied at the toe of the slopes with steeper gradient. This work is classified into stone masonry, gravity type, supported type and gabion retaining wall. Among these, the recommendable types are stone masonry and supported type. Anchoring is usually used with retaining wall or crib.

(6) Catch Work

Catch work consists basically of providing some facilities to prevent the spread of damage by catching failured materials falling from the side slopes. The application of this method is limitted only in cases where other countermeasures are difficult and costly or wide space for deposits between a road edge and a toe of slope can be provided.

(7) Avoiding Problem Work

Realigment of the existing road section or bridge may be resort to when the adoption of any or a combination of the countermeasures or protection works previously described is considered technically unfeasible. In doing so, several alternative alignments should be considered and evaluated so that the same problem in the former alignment are avoided.

CHAPTER 11 COUNTERMEASURES FOR EMBANKMENT SLOPE FAILURES

11.1 TYPES OF COUNTERMEASURES

Countermeasures for embankment slope failures are classified into the following four types:

- Drainage Work
- Protection Work
- Earth Work
- Structural Work

Each of these works is sub-classified into several types of works as listed in Table 11-1 indicating the purpose, application and typical illustrations.

The purpose and the application described in Table 11-1 together with their characteristics discussed in Section 11.3 may be referred to for the selection of countermeasures.

11.2 SELECTION OF COUNTERMEASURES

The elements for the selection of countermeasures for embankment slope failures are basically the same process to that of selecting countermeasures for cut slopes described in Section 10.2

(1) Drainage Work

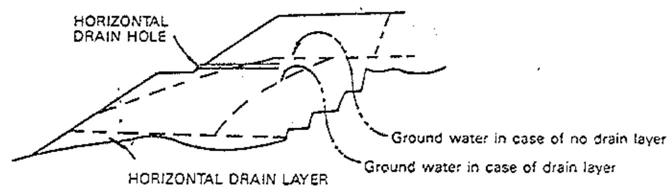
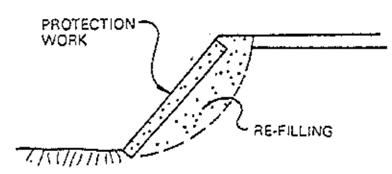
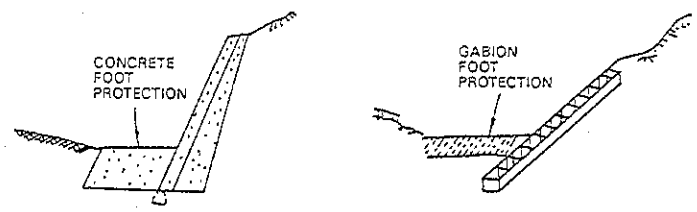
Surface Drainage

Generally, deterioration of embankment slopes is often attributed to scouring due to concentration of surface water on the roadway. Drainage system, therefore, should be planned with the following considerations:

- Side Ditch. Water on the road surface is generally concentrated at the inner side of curved roads with longitudinal gradient which tends to spill over at any place down the embankment resulting to the scouring of the slope. In no case, therefore, sufficient side ditches must always be provided and the outlet planned to avoid local scouring.

- Berm Ditch. Berm ditches are not always provided on the existing embankments. However, beam ditch should be designed for all slopes where re-filling is planned.

Table 11-1 COUNTERMEASURES FOR EMBANKMENT SLOPE FAILURE

Classification		Type of Work	Purpose	Application	Illustration
Drainage Work	Surface Drainage	Berm Ditch Side Ditch Vertical Ditch	Same as Countermeasures for Cut Slope Failure	Same as Countermeasures for Cut Slope Failure	Same as Countermeasures for Cut Slope Failure
Drainage Work	Subsurface Drainage	Subsurface Drainer	To drain groundwater, spring water and seepage water and lower pore water pressure and thus stabilize stability of slope.	Effective to drain shallow surface water.	
		Horizontal Drain Hole		Mainly applied to high embankment which is already or may be saturated. Effective for slope where groundwater level is higher than plane of failure.	
		Horizontal Drain Layer			
Protection Work	Vegetation	Seed Spraying Seed Mud Spraying Sodding	To firmly bind materials of slope surface and thus prevent slope from erosion, scouring and weathering.	Should be applied to any slope. It also improves aesthetics view on environmental aspect.	Same as Countermeasures for Cut Slope Failure
Protection Work	Pitching	Stone or Block Pitching	To prevent erosion and scouring slight resisting force to protect surface failure may be expected.	Mainly applied to slope gentler than 45° of high embankment susceptible to scouring.	Same as Countermeasures for Cut Slope Failure
Protection Work	Crib	Concrete Block Crib Cast-in-place Concrete with form	To prevent erosion, scouring and slight surface failure. Resisting force against earth pressure may not be expected for block crib, but expected for cast-in-place crib.	Applied to slope with broad area or steeper than 45° where vegetation can not be applied or not effective.	Same as Countermeasures for Cut Slope Failure
Earth Work		Re-Filling	To fill washed-out and broken-off portion of slope with earth and then, usually cover surface with protection in order to prevent further failure.	Applied to collapsed slope. Usually applied with other measures such as vegetation or pitching. For scouring due to river stream, concrete crib is also used.	
Structural Work	Retaining* Wall	Stone Masonry Retaining Wall Gravity Type Retaining Wall Supported Type Retaining Wall Gabion Retaining Wall	Same as Countermeasures for Cut Slope Failure	Same as Countermeasures for Cut Slope Failure	Same as Countermeasures for Cut Slope Failure
Structural Work	Foot Protection	Concrete Foot Protection Gabion Foot Protection	To protect foot of retaining wall or other protection work.	Applied to foot which may be scoured by river stream.	

* Retaining wall is sometimes called as revetment, when it is used to protect scouring of slope due to river stream.

- Vertical Ditch. Vertical ditch should be planned at points where concentrated surface water flows down on embankment slope or to guide the flow of water that is collected from berm ditches.

Subsurface Drainage

Embankment can easily fail due to the effect of groundwater. When constructing new embankment or planning the re-filling, horizontal drain layer should be always provided to drain seepage water.

(2) Protection Work with Vegetation

Seed spraying is recommended for all slopes except those covered by retaining wall or pitching.

(3) Protection Work with Structures

Stone pitching may be recommended as a typical method of pitching for the slopes less than 45°. Crib work may be used with p.c. anchor for steep slopes to resist earth pressure.

(4) Earth Work

Re-filling as the earth work for embankment slope failure is recommended for the slopes without any economical remedial measures. This is usually applied with other measures such as vegetation or pitching.

(5) Structural Work

Retaining Wall

Types of retaining wall recommended are:

- Stone Masonry Retaining Wall
- Gravity Type Retaining Wall
- Supported Type Retaining Wall
- Gabion Retaining Wall

These types should be carefully selected considering the characteristics of each type.

Stone masonry type should be given the priority in the selection because it is economical and can also resist earth pressure.

Gabion retaining wall is recommended for the slope where no firm bearing ground exists and extensive seepage water exists.

Foot Protection

Embankment slope along a river is easily scoured by the river stream even protected with protection work such as pitching. In this case, the foot of the slope or the structural work should be protected with the foot protection. This type is usually made of concrete or gabion.

CHAPTER 12 COUNTERMEASURES FOR FALL

12.1 CHARACTERISTICS OF FALL

Rock or debris fall occurs when this is detached from bedrock mass or when pebbles, cobbles, or boulders rise to the surface of a slope and become unstable. The bedrock of the former at this point usually has developed joints, schistosities or beddings, while a slope of the latter case consists of talus, volcaniclastic material or gravel layer with loose solidification.

12.1.1 Energy of Falling Rock

A falling rock can arrive at the base of a slope by sliding down, rotating (rolling) and jumping (free falling). Thus, the energy or rock falling down on slope is largely governed by nature and condition of slope. For the design of rock fall protection, the energy of falling rock may be presumed with the formula which has been verified for its adequacy by experiments, as discussed in this section.

1) Velocity of Falling Rock

Generally, the types of motion of falling rocks on the slope can be divided into sliding, rotating and jumping as shown in Figure 12-1.

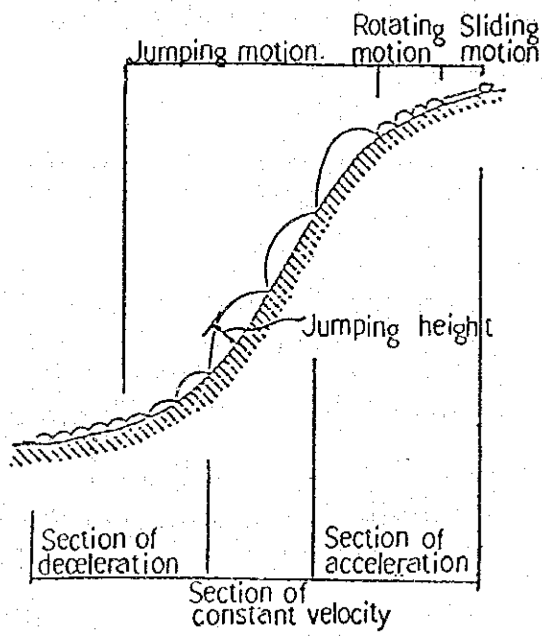


FIGURE 12-1 MOTION OF FALLING ROCK

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The velocity of falling rocks moving down a slope becomes highest during jumping motion.

According to the results of experiments, the velocity of a falling and rebounding rock along a slope is smaller than that of the freely falling stone in the air from the same height. The following relation is observed between the falling and rebounding and the freely falling rock, which was empirically derived:

$$V = \alpha \cdot \sqrt{2gH}$$

Where;

V	:	Velocity of a falling and rebounding rock
$\sqrt{2gH}$	:	Velocity of a freely falling rock in the air
α	:	Coefficient of reduction
g	:	Acceleration due to gravity
H	:	Falling height

The value of coefficient of reduction varies depending upon the soil of slope, lithology, irregularity, gradient and shape of falling stone.

The coefficient of reduction is given by the following formula using equivalent coefficient of friction.

$$\alpha = \sqrt{1 - \frac{\mu}{\tan \theta}}$$

Where;

μ	:	Equivalent Coefficient of Friction
θ	:	Gradient of Slope

From the above formula the speed of a falling and rebounding rock can be expressed by the following equation.

$$V = \sqrt{2.g \left(1 - \frac{\mu}{\tan \theta}\right) . H}$$

As shown in Table 12-1, the equivalent coefficient of friction derived from the results of experiments conducted for several type of slopes may be used for design.

TABLE 12-1 EQUIVALENT COEFFICIENT OF FRICTION

Class	Characteristics of Falling Stones and Slopes	Value of μ Used for Design	Range of μ Obtained from Experiments
A	Hard rocks, round shape, small concaves and convexes, no standing trees	0.05	$0 \sim 0.1$
B	Soft rocks, square to round shape, medium to large concavities and convexities, no trees standing	0.15	$0.11 \sim 0.2$
C	Sediment, talus, round to square shapes, small to medium concaves and convexes, no standing trees	0.25	$0.21 \sim 0.3$
D	Talus, talus with boulders, square shape, medium to large concaves and convexes, with or without standing trees	$0.31 \sim (0.4)$	$0.31 \sim (0.6)$

(2) Kinetic Energy of Falling Rock

Kinetic energy of falling rock is required when designing rock fall protection work.

Kinetic energy of a falling rock is the sum of linear velocity energy and rotation energy as expressed in the the following formula:

$$E = E_v + E_r$$

Where;

E : Kinetic energy of falling rock

E_v : Linear velocity energy of falling rock ($= 1/2\ mV^2$)

E_r : Rotation energy of falling rock ($= 1/2\ IW^2$)

Using rotation energy ration β, E is expressed with the following equation.

$$E = (1+\beta)\ E_v$$

$$= (1+\beta)\ (1 - \frac{\mu}{\tan\theta})\ .W.H$$

Where;

β : Rotation Energy Ration ($\beta = E_r/E_v$)

$$(1+\beta)\ (1 - \frac{\mu}{\tan\theta}) \leqq 1.0$$

$$E_v = \frac{1}{2} \cdot \frac{W}{g} \cdot V^2$$

According to the results of previous experiments, the ratio of E_r to E_v or β, is in the range of 0.1 to 0.4 but most data show that it does not exceed 0.1, so that $\beta = 0.1$ is frequently used for design.

12.1.2 Jumping Height of Falling Rock

The jumping height of falling rock during jumping motion is greatly affected by the concavities and convexities on a slope and the conditions of exposed rocks and the size of trees. Therefore, the jumping height should be assumed taking full account of these conditions.

In general, rock trajectory is assumed as shown in Figure 12-2.

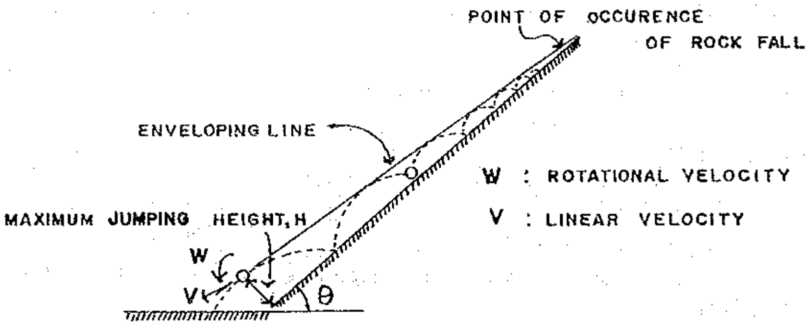
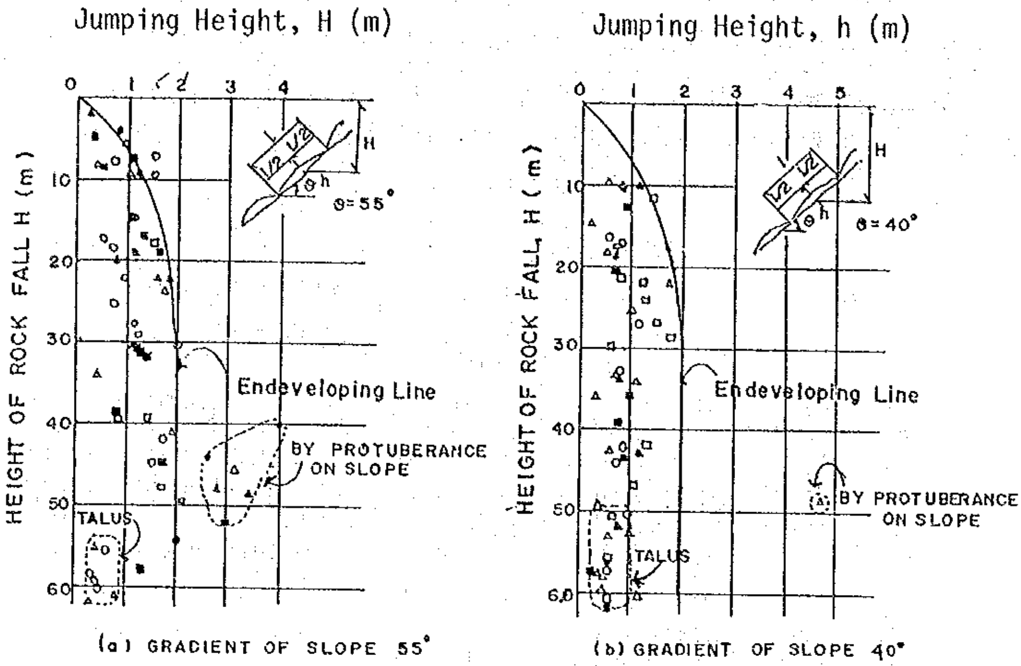


FIGURE 12-2 CONCEPTIONAL DIAGRAM OF ROCK TRAJECTORY

From the results of experiments, the jumping height of the falling rock increases as the falling height becomes higher, but does not exceed 2.0 m for ordinary slopes. However, it should be noted that the jumping height may occasionally exceed 2.0 m if there is a portional protection on the slope; bedrock is exposed; or on a very irregular slope. Nevertheless, on ordinary slopes, a jumping height of 2.0 m is often used as the acting position of the design external force for the rock fall protection works. Figure 12-3 shows the result of test.

FIGURE 12-3 JUMPING OF FALLING ROCK



Note: ○ Mass / ● Plate 30 cm. △ Mass / ▲ Plate 50 cm. □ Mass / ■ Plate 70 cm.

Based on the result of the tests, the trajection of falling rock may be summarized as follows.

- The higher the height of rock fall is, the greater the jumping height becomes.
- In most cases (80 to 85%) for ordinary slopes, maximum jumping height is less than 2 m.
- Where there exists protuberances on a slope, jumping height may be higher than 2 m.

12.1.3 Impact Force Due to Rock Fall

For the design of protection work for rock fall, a dynamic impact force due to rock fall should be converted to a static force. Several formulae are proposed for the analysis of this force.

(1) Theoritical Formula based on Hertz's Theory (Manual on Dynamic Mechanics Japan)

The formula is introduced based on Hertz's Theory with the assumption that 1) a rock is round 2) the surface where a rock crashes is plane and 3) unit weight of rock is 2.6 t/m^3.

$$P_{max} = 2.455 \cdot W^{2/3} \cdot \lambda^{2/5} \cdot H^{3/5}$$

Where;

Pmax : Maximum Impact Force (t)

W : Weight of Rock (t)

H : Height of Rock Fall (m)

λ : Lame's Constant (t/m^2)

Very Soft . . . . 100 t/m^2

Soft . . . . 300 ~ 500 t/m^2

Hard . . . . 1000 t/m^2

Lame's constant normally used is less than 100 t/m^2. However, this value was derived from the results of experiments using sand layers having a proper thickness as shock absorbing material. Therefore, if the conditions are different from those described above, the value of λ should be determined by test.

(2) Experimental Formula
(Steel Fabricators Association)

This formula is established based on the result of experiment conducted for steel rock shed with the absorption layer of sand 30 cm. in thickness. A weight used was 0.3 ~ 1.0t and height of fall was 3 ~ 10 m.

$$P = W \cdot \frac{\ddot{\delta}}{g}$$

Where;

P : Impact Force (t)

W : Weight of Rock (t)

δ/g : Acceleration of Impact (cm/sec^2)

g : Acceleration of Gravity (cm/sec^2)

$\ddot{\delta}$: Acceleration of Impact (cm/sec^2)

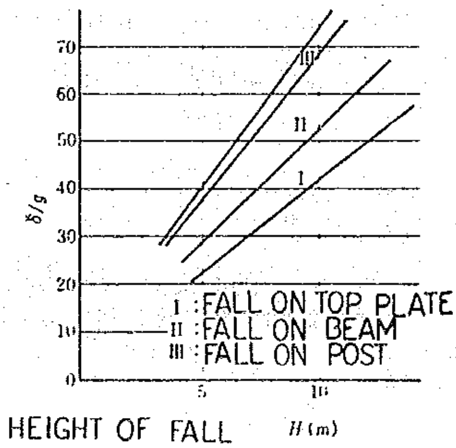


FIGURE 12-4 HEIGHT OF FALL AND ACCELERATION OF IMPACT

(3) Yoshida's Formula

This formula is also predicted based on the results of experiments conducted for prestressed concrete rock shed. Thickness of sand layer as a absorption was 30 to 150 cm., a weight is 0.3 to 1.0t and height of fall was 1 to 14 m.

$$P = \frac{W}{G} \cdot \frac{2}{T_o} \sqrt{2.g.H}$$

Where;

P : Impact Force (t)

W : Weight of Rock (t)

g : Acceleration of Gravity (m/sec^2)

H : Height of Fall

T_o : Stationary Time of Rock (sec)
Refer to Table 12-2

TABLE 12-2 STATIONARY TIME OF ROCK, T_o

A b s o r p t i o n	T_o (sec)
Ordinary Sand	0.0102W +0.0755
Sea Sand	0.0051W +0.0614
Mountain Sand	0.0220W +0.0485

12.2 TYPES OF COUNTERMEASURES

Countermeasures for fall are classified into the following six types.

- Drainage Work
- Protection Work
- Earth Work
- Fixing Work
- Catch Work
- Rock Shed

Each of these work is sub-classified into several types of work as listed in Table 12-3 indicating the purpose, applications and typical illustrations.

Drainage work, protection work and earth work are discussed in Chapter 7, 8 and 10 respectively. Others are described in this chapter.

The purpose and the application described in Table 12-.3 may be referred for the selection of countermeasures together with their characteristics discussed in section 12.3

12.3 SELECTION OF COUNTERMEASURES

In selecting countermeasures for fall, factors are to be considered:

a) Cause of Failure

- Primary Causes
  - Topography
  - Geology
  - Others
- Inducement Causes
  - Precipitation
  - Wind
  - Others

b) Characteristics of Countermeasures

- Purpose and Effectiveness
- Stability and Durability
- Construction
- Maintenance

c) Impact

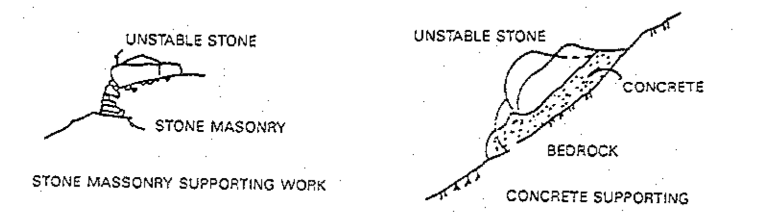
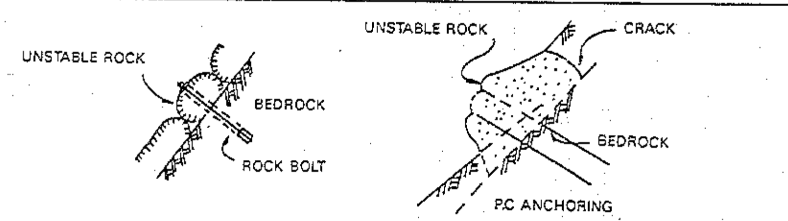
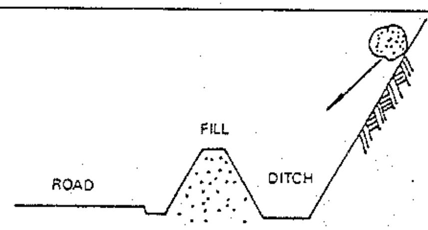
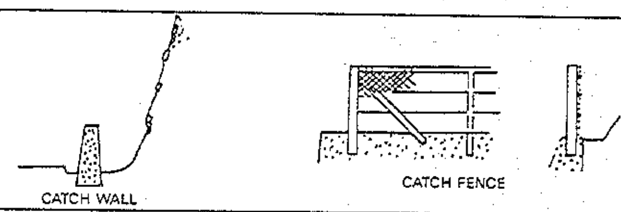
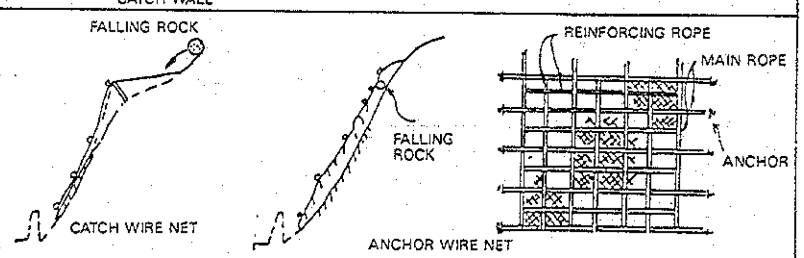
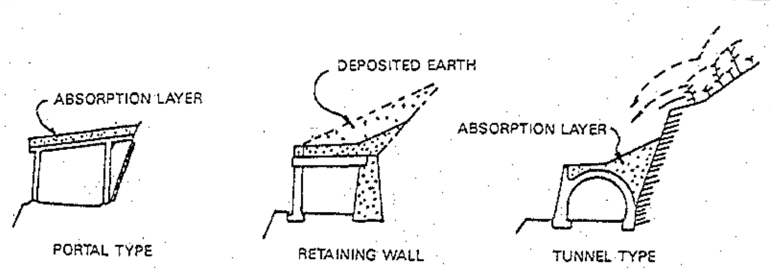
- Traffic
- Social
- Environmental

In many cases, several countermeasures may be selected for spot and thus the combined use of two or three measures is rather common. The characteristics of earth countermeasure is briefly described as follows.

(1) Drainage Work

For slopes suspicious of fall due to surface water, drainage work such as top slope ditch, berm ditch and vertical ditch should be applied. However, where slopes are composed of hard rock, these may not be required because hard rock may not be eroded and scoured due to water.

Table 12-3 COUNTERMEASURES FOR FALL

Classification		Type of Work	Purpose	Application	Illustration
Drainage Work	Surface Drainage	Top Slope Ditch			
		Berm Ditch			
		Vertical Ditch			
	Vegetation	Seed Spraying			
		Seed Mud Spraying			
		Sodding			
Protection Work	Spraying	Mortar Spraying	Same as Countermeasures for Cut Slope Failure		Same as Countermeasures for Cut Slope Failure
		Concrete Spraying			
	Pitching	Stone or Block Pitching	It also aims to prevent rocks from separating and detaching from ground or bedrock.		
		Concrete Pitching			
	Crib	Concrete Block Crib			
		Cast-in-Place Concrete Crib with form			
		Sprayed concrete crib			
Earth Work		Removal	Same as Countermeasures for Cut Slope Failure		Same as Countermeasures for Cut Slope Failure
		Re-cutting			
Fixing Work	Supporting	Stone Supporting	To fix unstable rock supporting with stone or concrete.	Mainly applied to big and supportless rock difficult to remove. Base of supporting shall be firmly shored.	
		Concrete Supporting			
	Anchoring	Rock Bolt	To fix unstable rock anchoring to bedrock with rock or p.c. wire.	Mainly applied to big, hard and supportless rock difficult to remove. Anchoring shall be made into firm bedrock. Rock bolt for relatively small rock, while p.c. for boulders.	
		P.C. Anchor			
Catch Work		Catch Fill and Ditch	To prevent spread of damage by providing fill and ditch, wall or fence to catch falling materials. Occurrance of fall can not be prevented.	Wide space for deposite is required between road edge and toe of slope.	
		Catch Wall		A little wide space for deposite is required between road edge and toe of slope. Space for wall or fence is narrower than for fill and ditch.	
		Catch Fence			
		Catch Wire Net	To prevent spread of damage covering slope by net with pocket to catch falling rocks.	Applied where no space for deposite. Unsuitable to soil and rock slope which are easily weathered.	
		Anchor Wire Net	To provide resisting force to fall directly by covering slope with net but inefficient to prevent erosion and scouring.		
Rock Shed		Concrete Rock Shed	To avoid damage by covering whole width of road with shed.	Mainly applied to a large scale of fall. Applied only when other countermeasures are difficult and costly.	
		Steel Rock Shed			

(2) Protection Work

For slopes composed of materials that are easily eroded, scoured or weathered, protection works is more recommendable rather than catch work. The protection work recommended are seed spraying, concrete spraying and sprayed concrete crib.

(3) Earth Work

Earth work as the countermeasures for fall is classified into removal and re-cutting.

Removal work is one of the basic methods and should be adopted prior to execution of any protection work such as installation of anchored wire net. This work is frequently used while the fixing work is not applicable.

Re-cutting is applied for over-hanging slopes or when the gradient of the slope is very steep.

(4) Fixing Work

Fixing work is applied for the slope where big and supportless rocks exist and the removal of those judged costly and difficult.

(5) Catch Work

Fall generally occurs from slopes composed of hard rocks with developed cracks or joints, even though there is no erosion, scouring and weathering. For these slopes, catchwork may be adopted, especially if the gradient is steep and re-cutting is not practical.

This type is also used when proper countermeasures can not be applied due to limitation within the area of the slope.

(6) Rock Shed

Rock shed is adopted for slope where proper countermeasures can not be applied within the area of the slope or those that are adjudged costly and difficult. Therefore, this type is usually adopted to large-scale of fall.

12.4 FIXING WORK

Fixing work for fall aims to prevent rock from falling by fixing unstable rock with bedrock. This can be classified into several types:

- Supporting
- Anchoring
- Hanging

12.4.1 Supporting

Unstable rock is fixed by supporting the lower portion or the surrounding of the rock. Concrete or stone masonry work is usually used for supporting method. This method is effective for the gentle slope where there are many unstable rocks which can not be easily removed. See Figure 12-5.

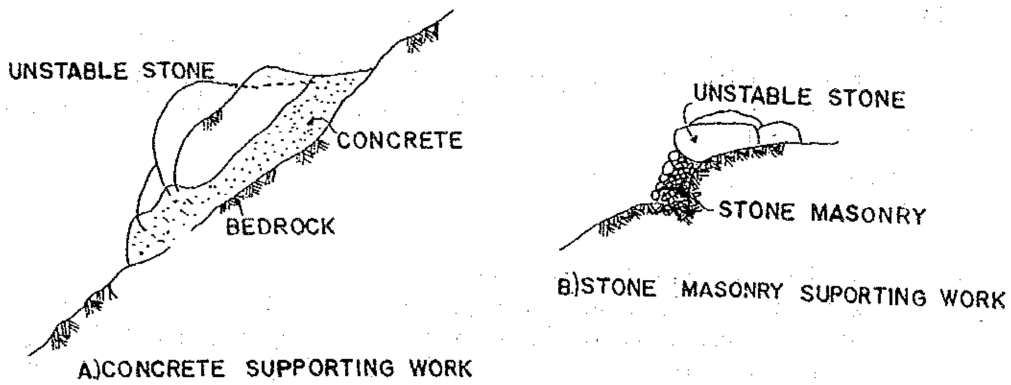


FIGURE 12-5 SUPPORTING WORK

12.4.2 Anchoring

Unstable rock is fixed by anchoring with bedrock, using rock bolt or P.C. anchor which is inserted into holes of the unstable rock drilled by boring machine.

Rock bolt is used for rather small size rocks, while P.C. anchor is adopted for large size rocks which may require long bolts with high tensile strength. See Figure 12-6.

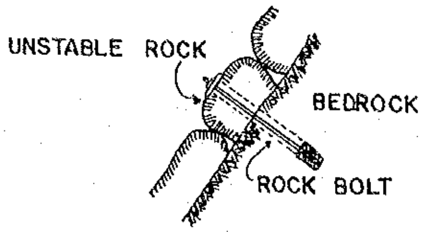


FIGURE 12-6 ANCHOR WORK

12.4.3 Hanging

Unstable rock is fixed with grid-striped wire rope or several ropes by hanging or covering. This is useful for large unstable rock , but it is considered rather temporary work. See Figure 12-7.

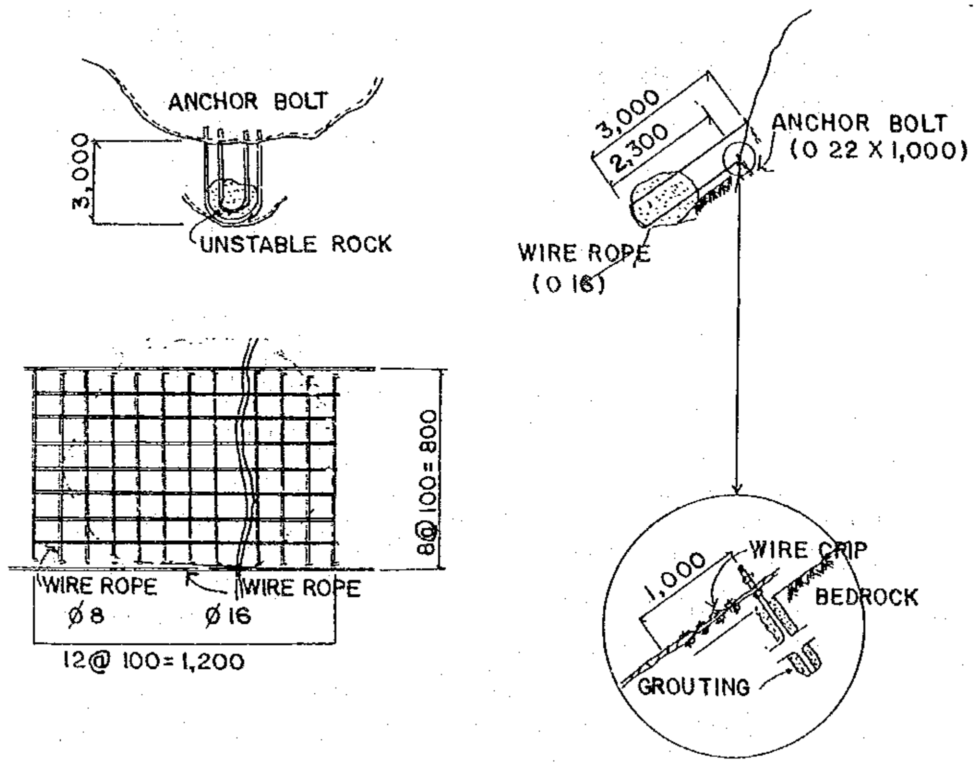


FIGURE 12-7 HANGING

12.5 CATCH WORK

Catch work aims to prevent spread of damage and not to prevent occurrence of fall. It is classified into the following:

- Catch Fill and Ditch
- Catch Wall
- Catch Fence
- Catch Wire Net
- Anchor Wire Net

Detail on catch type is discussed in this section.

12.5.1 Catch Fill and Ditch

Refer to APPENDIX 2; STANDARD DRAWING NO.14; CATCH FILL AND DITCH

Catch fill and ditch are usually used at the place where roadside is wide enough to provide a flat pocket for falling rock. The advantage of this type is that it can be constructed easily and economically since materials such as concrete and steel may not be required. See Figure 12.8 below.

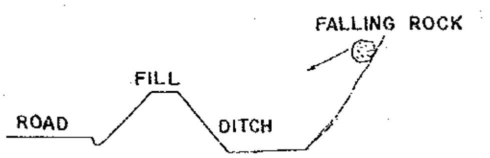


FIGURE 12-8 CATCH FILL AND CATCH DITCH

Height and width of a catch fill and catch ditch may be designed in consideration with velocity of falling rock, height of jumping and refusing of fill and ditch.

12.5.2 Catch Wall

Refer to APPENDIX 2; STANDARD DRAWING NO 15; CATCH WALL

Catch wall is used to prevent rocks from falling onto road, and usually constructed at roadside.

A space (pocket) is desirable to provide at the back of catch wall so that fallen rocks and collapsed earth can be piled up. Catch wall may be set up at the place where road shoulder is wide and slope is gentle. See Figure 12-9.

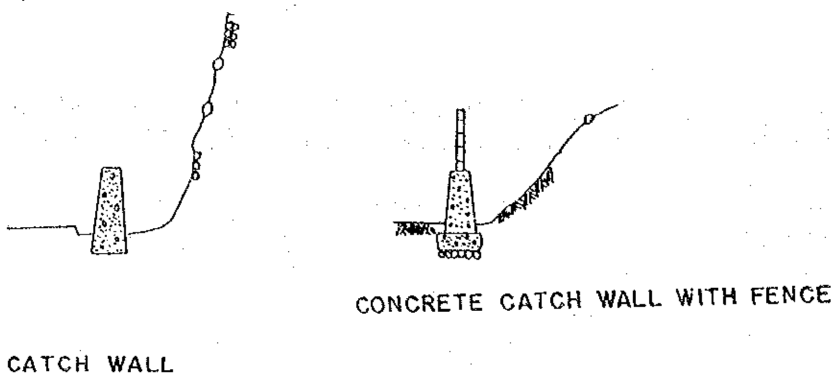


FIGURE 12-9 CATCH WALL

Design

Catch wall is a kind of gravity type retaining wall and is designed in such a way that kinetic energy of falling rock or collapsing earth can be retained by displaced energy of concrete body and foundation, as shown in Figure 12-10.

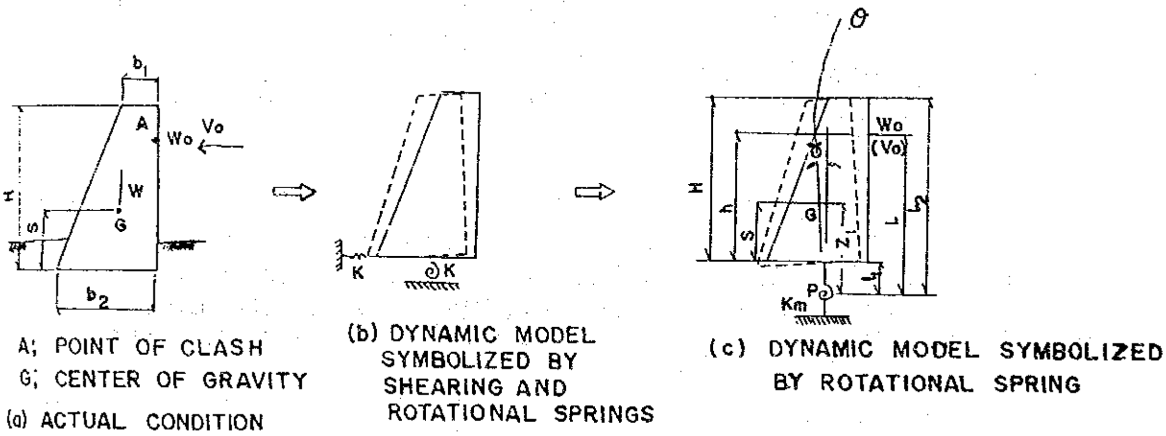


FIGURE 12-10 CONCEPTIONAL MODEL FOR DESIGN OF CATCH WALL

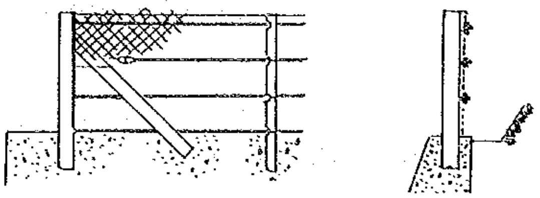
In the design, it is assumed that only one rock will crash against wall. Effective width of wall to resist a crashing force is four times the height of the wall.

Velocity of falling rock can be estimated in accordance with the method mention in section 12-1; Energy of Falling Rock.

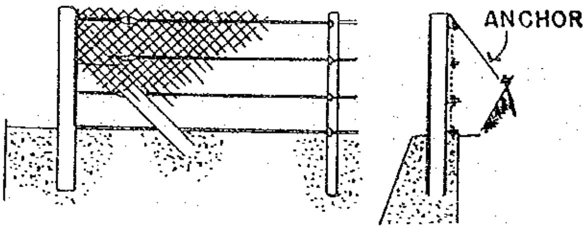
12.5.3 Catch Fence

Refer to APPENDIX 1; DESIGN EXAMPLE NO. 5; DESIGN OF CATCH FENCE
APPENDIX 2; STANDARD DRAWING NO. 16; CATCH FENCE

Rock fence is useful only against small size rock fall.
Examples of rock fence are shown in Figure 12-11.



(a) STRAIGHT POST



(b) POST WITH ANCHOR

FIGURE 12-11 ROCK FENCE

Usually, rock fence is set up at the road shoulder or at the lowest berm, but it is also advisable to set at the upper berm to absorb energy of falling rock for large scale slope, as shown in Figure 12-12.

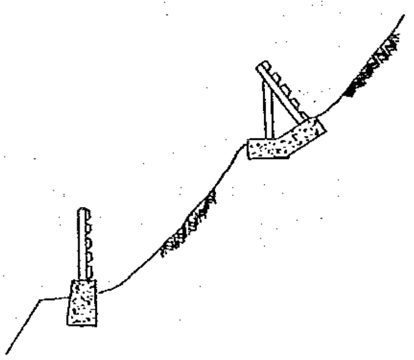
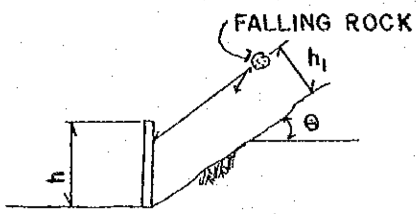


FIGURE 12-12 DOUBLE LINES OF ROCK FENCE

Height of Fence

Height of fence should be decided judging from jumping height of falling rock, as follows. Jumping height is usually less than 2 m.

i) Without flat space



$h > h_1 \cdot \sec\theta$

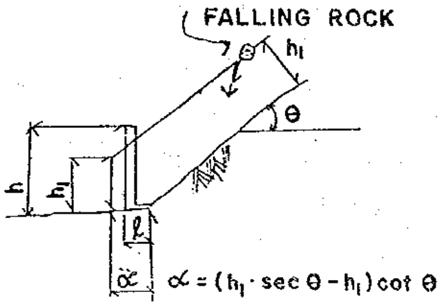
Example

$h_1 = 2^m$

$\theta = 60^\circ$

$h > 4.0^m$

ii) $0 < \ell < \alpha$



$h > h_1 \sec\theta - \ell \tan\theta$

Example

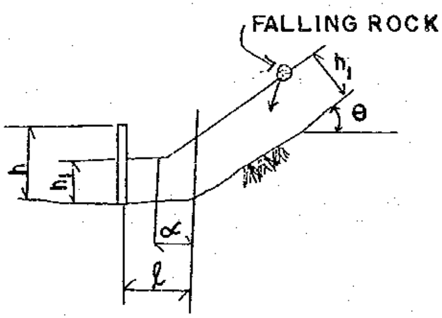
$h_1 = 2^m$

$\theta = 60^\circ$

$\ell = 0.7$

$h > 2.8^m$

iii) $\ell > \alpha$



$h > h_1$

Example

$h_1 = 2^m$

$\theta = 60^\circ$

$\ell = 1.5^m$

$h = 2^m$

12.5.4 Catch Wire Net

Refer to APPENDIX 2; STANDARD DRAWING NO. 17; CATCH WIRE NET

Presently, the two types of rock fall prevention net are widely used. One is called cover type (or Anchor Wire Net) see Para. 12.5.5 and the other is pocket type (or Catch Wire Net).

Catch wire net aims to prevent spread of damage of covering a slope with wire net or with pocket. This type is installed in such a way that the upper end portion of the net is separated from the surface of the slope. Falling stones from the upper portion of slope are caught by the gap between the net and slope, and the energy of the falling rock is absorbed when the stone crash against it. See Figure 12-12.

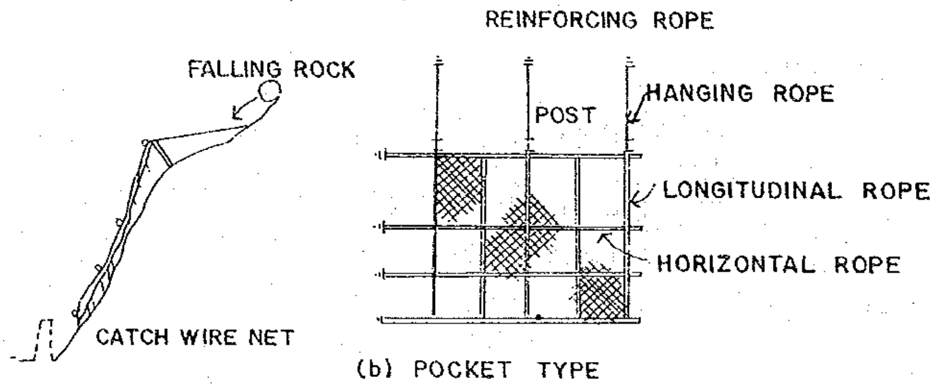


FIGURE 12-13 (1) CATCH WIRE NET

Design

Catch wire net is designed with the following considerations:

i) Energy of the falling rock

ii) Energy absorbable by the net in such a manner that it will be able to withstand the energy of the falling rocks.

iii) Strength and stability of anchor on the assumption that the breaking load of the rope will act to the anchor.

12.5.5 Anchor Wire Net

Refer to APPENDIX 2; STANDARD DRAWING NO. 18; ANCHOR WIRE NET

Anchor wire net aims to restrain unstable rock by the tension of a net and the friction between rocks and the ground. But this type can not provide a complete protection to prevent erosion and scouring. Typical example is shown in Figure 12-13.

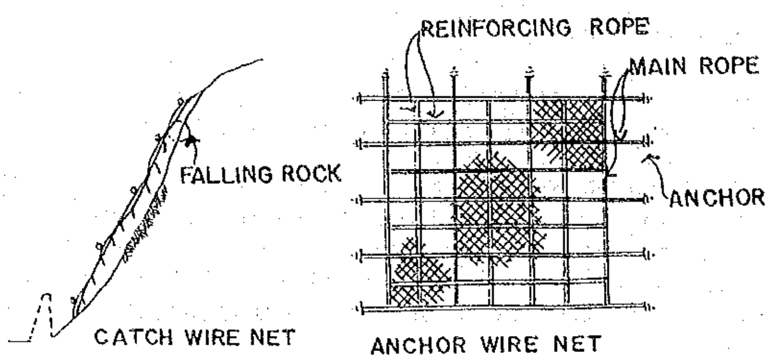


FIGURE 12-13 (2) ANCHOR WIRE NET

Design

The design of anchor wire net is performed with the following procedure.

i) Determine the diameter of vertical rope capable of resisting its own deadweight and the weight of falling rocks corresponding to one span of vertical ropes.

ii) Determine the diameter of horizontal ropes capable of resisting the weight of falling rocks and weight of net assuming that they are uniformly distributed in 3 spans in the direction of the slope.

iii) To determine the kind of net (diameter of strand) capable of resisting the weight acting to the set.

iv) To calculate the strength and stability of anchor on the assumption that all of the load to the rope will act to the anchor.

12.6 ROCK SHED

Refer to APPENDIX 2; STANDARD DRAWING NO. 19; ROCK SHED

Rock shed aims to cover the whole width of a road to prevent rocks from falling onto the road. Rock shed is used for the following cases.

i) Large scale steep slope where rocks are prone to fall is continued and roadside space is narrow.

ii) Falling rocks are so big and falling area is so wide that rock fence may not prevent them.

iii) Height of falling of rock is so high that falling rock may jump over a fence.

(1) Types of Rock Shed

Rock shed is classified into concrete and steel in accordance with the materials to be used.

There are several types of rock shed such as portal, retaining wall, arch, pocket and tunnel when classified with its shape. Examples of some which are oftenly adopted are shown in Figure 12-14. Materials used for member of structures are steel, reinforced concrete and prestressed concrete.

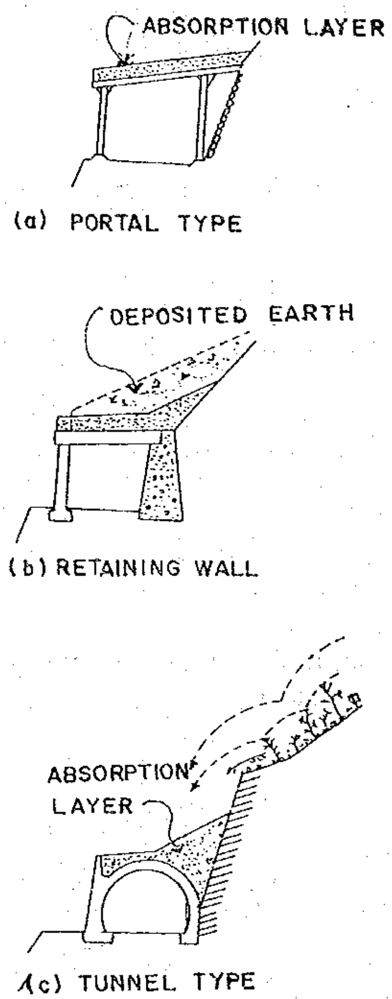


FIGURE 12-14 ROCK SHED

As a rock shed for a road where a slope exists at one side and a valley the other side, the following type may be recommended. See Figure 12-15.

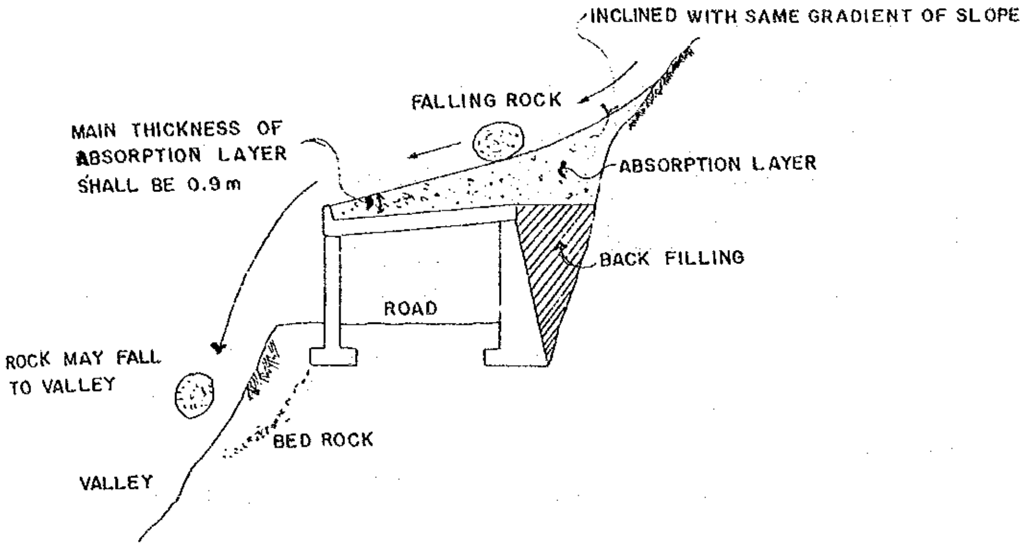


FIGURE 12-15 ROCK SHED FOR A ROAD IN BETWEEN A MOUNTAIN AND A VALLEY

(2) Design

A structure standing up to withstand the impact force must be designed estimating the absorption energy derived from elastic and plastic deformation of members and the ultimate supporting capacity of the structure. Since this method based on the theory of energy is not yet established for the design of huge structures such as rock shed, the simplified method may be used as described hereunder.

Impact Load

$$P = 15.49\, W^{2/3} \cdot H^{3/5} \cdot \alpha$$

Where:

P : Impact Force (t)

W : Weight of Falling Rock (t)

H : Height of Fall (m)

α : Factor of Increase in accordance with thickness of absorption layer (h)
h shall be 0.9 m so that α is 1.0

Height of Fall

In case of free fall

$H' = H$

In case of rolling or sliding down

$$H' = \left(1 - \frac{\mu}{\tan \theta}\right) \cdot H$$

Where:

H : Height of fall for design

H : Vertical height of fall

θ : Angle of slope

μ : Coefficient equivalent to friction

Dispersion of Impact Load

Further in the design, the impact load may be assumed to act on the most influential point and be uniformly dispersed within the range of 45 degree by a shock absorbing material, as shown in Figure 12-16.

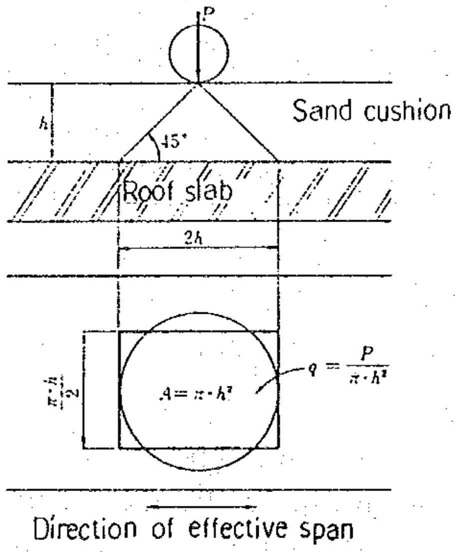


FIGURE 12-16 DISPERSION OF IMPACT LOAD

Deposited Materials

The weight of collapsed sediment deposited on roof should be considered in the design. A 30-degree gradient composed of collapsed sediment is assumed, as shown in Figure 12-17. However, absorbing effect by this material must also be considered. Therefore, this weight should not be considered with the impact force of falling rock at the same time.

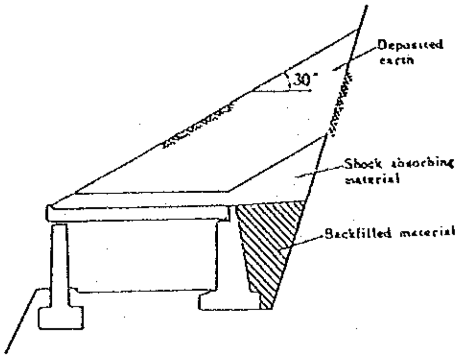


FIGURE 12-17 WEIGHT OF DEPOSITED MATERIALS