# CHAPTER 13 COUNTERMEASURES FOR LANDSLIDE

## 13.1 CHARACTERISTICS AND STABILITY ANALYSIS OF LANDSLIDE

### 13.1.1 Characteristics of Landslide

Landslide occurs at a concentrated area with a specific geological formation generally with the following characteristics.

- Tertiary mudstone area and tuff zone
- Area parallel to geological tectonic line in paleozonic and mesozonic rocks and metamorphic zone.

In almost all cases (about 80 per cent) of landslide, the sliding mass consists of soil such as talus, colluvial deposits and sediment with gravel of volcanic material. And a sliding plane is near the surface of a bedrock.

An area where a landslide occurred shows a specific feature of topography. At the top, a steep slope with gradient of more than 30 degrees exists and at the middle a platform with gentle gradient of about 10 to 20 degrees. And at the lower portion, there are usually a steep slope, sometimes scoured by a stream of a river. A landslide, often breaks out at an area with a certain topographic feature, usually at a platform inclined 5 to 20 degrees.

The activity of a landslide basically consists of a continuity and a relapse. The speed of sliding is from several 10 cm. per day for rock slide to a few centimeter or milimeter per day for soil mass. A mass usually slides keeping the original shape with few disturbances. A sliding mass has an average thickness of 20 m. and may involve from 1 to 100 ha.

Landslide is normally induced by the effects of groundwater due to rainfall over a long period, heavy rain and/or earthquake. Prior to the outbreak of a landslide, cracks, cave-ins rises and changes of groundwater are developed and observed.

The characteristics of a landslide are summarized in Table 13-1.

TABLE 13-1 CHARACTERISTICS OF LANDSLIDE

| | Landslide |
|---|---|
| Geology | It occurs at areas with the following conditions.<br>. Tertiary mudstone area, Tuff zone<br>. Geological tectonic line<br>. Remarkable volcanic phenomenon |
| Soil | Sliding plane is usually in cohesive soil. |
| Topography | It occurs at platform with gentle gradient of 5 to 20°. A platform is located at the top of a slope. |
| Activity | Continuity and Relapse |
| Speed of Sliding | Generally slow about 0.01 to 10 mm/day |
| Sliding Mass | Slides keeping a original shape.<br>Average thickness 20 m.<br>Area involved 1 to 100 ha. |
| Inducive Mass | Groundwater due to rainfall of long period.<br>Heavy Rain<br>Earthquake |
| Symptoms prior to sliding | Occurence of cracks, cave-ins rise and change of groundwater. |

13.1.2 Preliminary Review of Slope Stability

When necessary data to evaluate a landslide are not available, but tentative judgement on selection of countermeasures to be applied is required, the following method to roughly review the stability of the slope can be adopted:

(1) Assumption of shape of slip

In the absence of any data, the sectional shape of ground surface and depth and shape of slip plane may be approximated based from observations on the features appearing on the ground surface.

However, the sectional shape of the ground suface can be surveyed along a main course of traverse near the center of landslide area.

(2) Rough comparison in selection of countermeasure

A suppressive force to restraint a landslide, in terms of increasing the present factor of safety for existing slope ($F_{so}$) to a design factor of safety ($F_{sp}$), can be roughly assess with the following formula.

$$P = (F_{sp} - F_{so}) \cdot \Sigma W \cdot \sin\theta$$

Where:

| | | |
|---|---|---|
| $P$ | : | Suppressive Force |
| $F_{sp}$ | : | Design Factor of Safety |
| $F_{so}$ | : | Present Factor of Safety<br>This shall be assessed as 1.0 |
| $\Sigma W \cdot \sin\theta$ | : | Thrust of Mass in the direction of Slip Plane (t/m) |

A countermeasures to be applied may be roughly judged as follows.

a) $P < 150$ t/m ---------- Controllable by ordinary countermeasures

b) 150 t/m $< P <$ 300 t/m ----- May be suppressible by large-scale earth work (Earth Removal or Counter Weight Fill)

c) $P > 300$ t/m ---------- May be impossible by countermeasure except by special method

### 13.1.3 Stability Analysis of Slope

(1) Analysis of Geological Profile

Preparation of geological profile

In preparing a geological profile, the underground structure as deduced from boring logs and other data should be shown in a topographical profile along a main course of traverse.

Informations to be shown in the geological profile include surface soil, horizontal and dip of bedrock, classes of bedrock and colluvial deposit, classes of soil, faults, distribution of fractured zone, and aquifer.

Determination of location and shape of sliding plane

The location and shape of sliding plane can be determined by connecting the deepest line in sliding mass measured or influenced based on boring data.

For convenience of calculation, a sliding plane can be treated approximately an arch or sometimes, compound arc or a combination of arch andstraight line.

Preparation of counter map of bedrock

The counter map to show the surface of bedrock and weathered zone should be prepared based on boring data along a main and auxiliary courses, using a 1/500 topographic map.

Distribution of pore water pressure

Pore water pressure is preferred to be surveyed with water pressure gauge or piezometer. However, the highest groundwater level in the pore hole may be used for the convenience of calculation.

Division of landslide blocks

To accurately interfere landslide block, topographic map, counter map of bedrock, and data measured by ground plant rule are required. When those data are not available, division of landslide blocks may be made by engineers with experience approximated based on experience.

(2) Stability Calculation

(Refer to Section 6, for detailed explanation)

Formula

Stability calculation of slope may be done by Slicing Method as described hereafter.

$$F_s = \frac{\sum(P - V) \tan \phi + C . \sum \ell}{\sum T}$$

Where;

$F_s$ : Design factor of safety

P : Normal reaction acting to the bottom plane of slice $P = W . \cos \phi$ (t/m)

T : Tangential force acting to the bottom plane of slice $T = W . \sin \phi$ (t/m)

| | | |
|---|---|---|
| $V$ | : | Pore water pressure acting to the slice<br>$V = A_w \cdot W$ (t/m2) |
| $\ell$ | : | Length of arch of sliding surface cut by each slice (m) |
| $\phi$ | : | Angle of internal friction (degree) |
| $C$ | : | Cohesion ($t/m^2$) |
| $W$ | : | Weight of a slice (t/m) |
| $\theta$ | : | Inclined angle of the bottom plane of slice (degree) |
| $A_w$ | : | Area of a slice under groundwater ($m^2$) |
| $\gamma_w$ | : | Unit weight of water ($t/m^3$) |

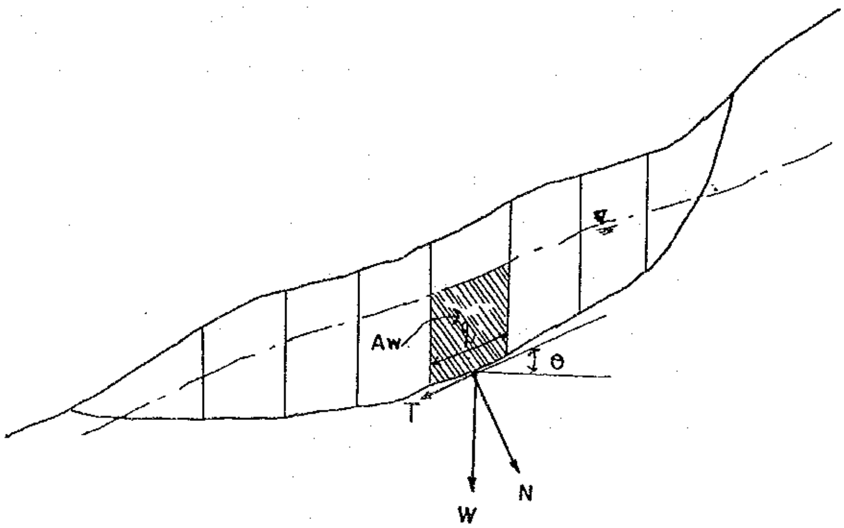



FIGURE 13-1 STABILITY CALCULATION

## Division of slices

Sliding mass should be divided into several slices considering topographic characteristic. A width of each slice should be less than the thickness of the corresponding landslide layer.

## Factor of Safety

As a rule, the factor of safety of a slope which a countermeasure for landslide is proposed should be assumed as 1.00. This factor should be used for an old landslide, but currently stable slope and also for a slope which a landslide fluctuation has been broken out and how it is barely balanced.

Design factor of safety should be determined as mentioned in Section 12.1.3.

Unit Weight of Soil

Unit weight of soil should be 1.8 $t/m^3$ except for some soils which should be actually measured.

Strength of slip plane

Based on the assumption that factor of safety is 1.0 for the existing slope, a linear equation pertaining to cohesion C, and angle of internal friction, Ø, can be obtained, as shown in Figure 13-2. At first, C is determined in accordance with a thickness of landslide, from Table 13-2 which was empirically established. On the other hand, the value Ø is determined from Figure 13-2.

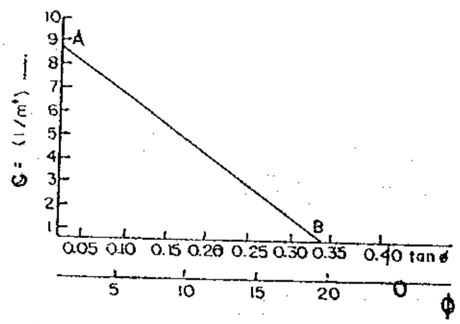



FIGURE 13-2 LINEAR EQUATION PERTAINING TO C AND Ø

TABLE 13-2 VERTICAL THICKNESS OF LAYER AND COHESION

| Vertical Thickness of Layer (m) | Cohesion ($t/m^2$) |
|---|---|
| 5 | 0.5 |
| 10 | 1.0 |
| 15 | 1.5 |
| 20 | 2.0 |
| 25 | 2.5 |

Note: Vertical thickness of layer of landslide means the maximum vertical thickness of sliding mass.

### 13.1.4 Design Factor of Safety

The design factor of safety of the countermeasure adopted for slope stabilization should be assumed equals to 1.0 for an existing slope. Nevertheless, the design factor of safety should be decided in consideration with requirements after completing countermeasures works, as shown in Table 13-3.

TABLE 13-3 DESIGN FACTOR OF SAFETY

| | |
|---|---|
| With mainly control work (without structure) | 1.05 ∿ 1.1 |
| With mainly prevention work (with structure) | 1.1 ∿ 1.2 |

The range of figures given in Table 13-3 provide the proper choice taking into account the traffic condition, importance of road and impact of landslide.

The following can serve as basic guidelines in deciding the design factor of safety to be used as major countermeasures for landslide.

1) Earth Removal Work

Earth removal should be done mainly on levees in the head portion. This work is desired to be performed with subsurface drainage or any other prevention work.

In this case, the safety factor for earth removal work alone shall be more than 1.05. This can be further increased by subsurface drainage or any other countermeasure work that is proposed to be done.

2) Counter Weight Fill Work

This work is very effective prevention measure for all types of landslides except mudflow type landslide of clayey soil. Stabilization of a slope by this work can be expected by a several per cent of increase of factor of safety.

3) Combination work or earth removal and counter weight fill

When a complete prevention is desired, factor of safety for this combination work should be more than 1.05 which should further increase with additional groundwater drainage or other prevention work.

4) Prevention Work

The design factor of safety that should be assumed in the design for prevention work by pile system should be only by more than 1.10 for normal cases and 1.20 in cases where the possiblity of sliding movement is high.

In case of a combination of piling work and earth removal, the design factor of safety is desirable to be more than 1.10 to 1.20. For a continuation of piling work and subsurface drainage, the factor of safety for the piling should be more than 1.20 and the increase by drainage work may be considered as extra element for safety.

In case of a combination of piling work and earth removal, the design factor of safety is desirable to be more than 1.10 to 1.20. For a combination of piling work and subsurface drainage the factor of safety for the piling only should be more than 1.20 and the increase by drainage work may be considered as extra element for safety.

## 13.2 TYPE OF COUNTERMEASURES

Countermeasures for landslide are classified into the following four (4) types.

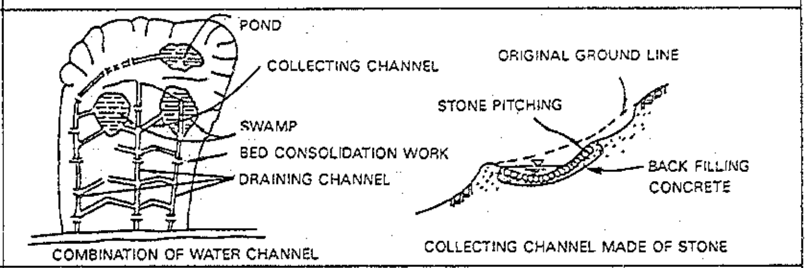
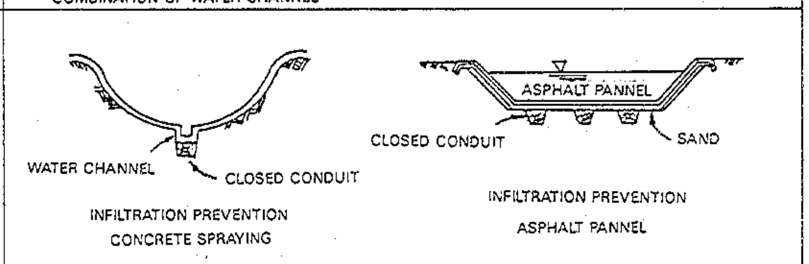
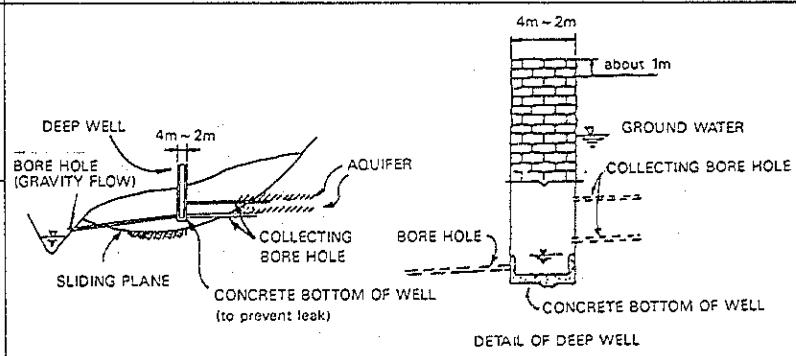
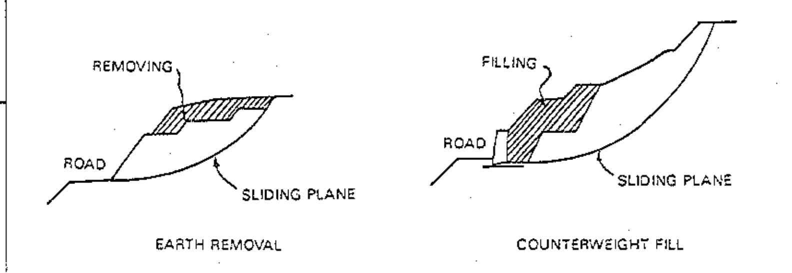
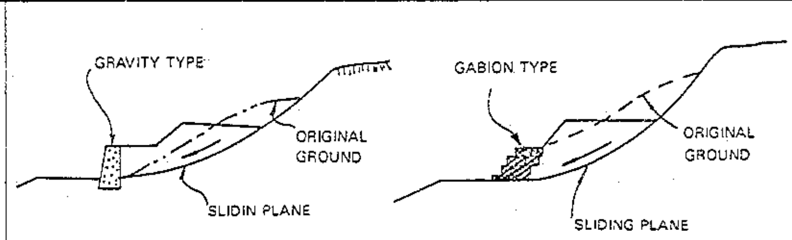
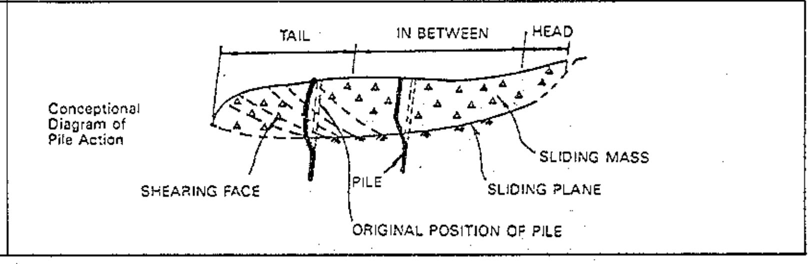
- Drainage Work
- Protection Work
- Earth Work
- Structural Work

Each of these works is sub-classified into several types of works. Major types of work are listed in Table 13-4, indicating the purpose, application and typical illustrations.

The details of Drainage Work, earth work and piling are discusssed in Section 13.4, 13.5 and 13.6 of this Chapter, respectively. Other works such as vegetation and retaining walls have been discussed in Section 8.2 and Chapter 9, respectively.

The procedure in selecting countermeasures is briefly discussed in Section 13.3 and the application mentioned in Table 13-4 may be reffered to as well in the process of selection.

## Table 13-4 COUNTERMEASURES FOR LANDSLIDE

| Classification | | Type of Work | Purpose | Application | Illustration |
|---|---|---|---|---|---|
| Drainage Work | Surface Drainage | Water Channel | To quickly collect and discharge precipitated rain inside landslide area in order to prevent seepage water. | Applied to all cases. Water channel consists of collecting channel and draining. Effective channel network is required. |  |
| | | Infiltration Prevention | To cover cracks with cement, clay or other materials in order to prevent seepage of water into cracked portion inside landslide area. | Applied to call cases. Effective for cracked portion where seepage water easily infiltrates and on swamp or water route. |  |
| | Subsurface Drainage | Subsurface Drainer | To drain groundwater and thus lower its level and pore water pressure. | Effective where groundwater level is higher than sliding plane. |  |
| | | Horizontal Drain Hole | | | |
| | | Deep Well | | Applied when drain hole is too long or crowdedly placed near bedrock. | |
| Protection Work | Vegetation | Seed Spraying | To prevent seepage of surface water into slide mass and also to protect slope from erosion and scouring. | Applied to all cases, whenever applicable. Applied to bare area. | Same as Countermeasures for Cut Slope Failure |
| | | Seed Mud Spraying | | | |
| | | Sodding | | | |
| Earth Work | | Earth Removal | To stabilize slope by removing a partial or whole earth of sliding mass, usually head portion of sliding mass. | Reliable and effective method. Applied to many cases. |  |
| | | Counterweight. Fill | To control movement force of landslide by weight and shearing strength of fill. Filling of earth shall be executed at tail portion of landslide. | Wide area is required at toe of slide for construction. Groundwater shall be completely discharged. | |
| Structural Work | Retaining Wall | Gravity Type Retaining Wall | To control movement force of landslide, increasing resisting force by shear strength and weight of fill and wall. Anchoring is sometimes used to increase resisting force of wall against thrust of landslide. | Mainly applied to small scale landslide or secondary failure at tail portion of a large scale landslide. Gabion wall is mainly used as counterweight for tail portion of landslide. |  |
| | | Gabion Retaining Wall | | | |
| | Piling | Precast Concrete Pile | To control movement force of landslide by bending movement and shearing strength of pile. Anchoring is sometimes used to increase resisting force of pile against thrust of landslide. | Mainly applied to landslide where sliding plane is deep. |  |
| | | Cast-in-Place Concrete Pile | | | |
| | | Steel Pile | | | |

## 13.3 SELECTION OF COUNTERMEASURES

The characteristics of countermeasures for landslide to be considered in selecting the most appropriate countermeasures are discussed below

### (1) Drainage Work

Surface drainage should be applied to all cases when surface waterflows into landslide area.

Subsurface drainage is most commonly adopted in cases where groundwater is extensive and the level is high. Closed conduit is effective to drain groundwater near on ground surface. Horizontal drain hole method is widely adopted for both cases, shallow and deep groundwater. For large scale landslide with extensive volume of water and where horizontal drain hole is judged uneconomical, deep well is normally applied.

### (2) Earth Work

Earth removal is generally accepted as a reliable and effective method of countermeasure. This is widely used for small and medium scale landslide. However, excavated surface should be protected by vegetation.

Counterweight fill aims to control movement of landslide force by the weight of fill. This method is simple and therefore widely applied to slopes where there is space for the filling at the toe of embankment. Prior to the execution of counterfill work, groundwater should be completely discharged.

### (3) Structural Work

Retaining wall is mainly applied to small scale landslide and secondary failure at the tail portion of a large scale landslide. Gabion retaining wall is recommended when the seepage of groundwater is anticipated.

Piling is applied in either case where the sliding plane of landslide is deep or there is no space where counterfill work can be applied.

### (3) Recommended Countermeasure for specific causes and type of soil

Countermeasures to be recommended for specific causes and type of soil or rock sliding are summarized in Table 13-5.

TABLE 13-5 RECOMMENDED COUNTERMEASURE FOR LANDSLIDE

| Main Causes | | Soil or Rock | Countermeasure | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | A | B | C | D | E | F |
| Natural Causes | • Infiltration of rainfall. Increase in groundwater<br>• Erosion by river stream | Bedrock | ○ | △ | ◎ | ◎ | ○ | ◎ |
| | | Weathered Rock | ◎ | △ | ◎ | ◎ | ○ | ◎ |
| | | Colluvial Deposit | ◎ | ○ | ◎ | ○ | ◎ | ○ |
| | | Landslide in Clayey Soil | ◎ | ◎ | ○ | △ | ◎ | △ |
| Artificial Cause | Cutting Work | Bedrock | △ | △ | ○ | ◎ | ◎ | ◎ |
| | | Weathered Rock | △ | △ | ○ | ◎ | ◎ | ◎ |
| | | Colluvial Deposit | ○ | ○ | ○ | ◎ | ◎ | ◎ |
| | | Clayey Soil | ◎ | ◎ | ○ | △ | ◎ | ○ |
| | Filling Work | Colluvial Soil | △ | △ | ○ | △ | ◎ | ◎ |
| | | Clayey Soil | △ | △ | △ | △ | ◎ | ○ |

NOTE:

A : Surface Drainage
B : Drainage For Shallow Groundwater
C : Drainage for Deep Groundwater
D : Earth Removal
E : Counterweight Fill
F : Piling

◎ : Method most frequently used

○ : Method most often used

△ : Method seldom used

## 13.4 DRAINAGE WORK

Refer to CHAPTER 7; DESIGN OF DRAINAGE

### 13.4.1 Surface Water Drainage

Surface water drainage aims to eliminate seepage water of rain, lakes and ponds from flowing into landslide area. The two kinds of drainage works, commonly used are the water channel and infiltration prevention works.

(1) Water Channel

To quickly collect rain precipitation inside lanslide area, water channel network should be well planned by combining the collection and draining channels, together map can be used as a base map for planning.

Example of water channel network is shown in Figure 13-3.

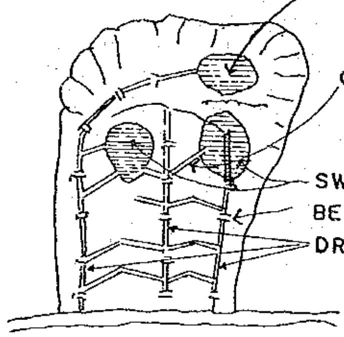



FIGURE 13.3 WATER CHANNEL NETWORK

Collecting Channel

Collecting channel is usually constructed across a slope to collect rainwater and surface water. The width of the channel should be relatively wide and out shallow.

Materials for the channel work can be hume pipe, centrifugal reinforced concrete pipe or corrugated pipe or stone as shown in Figure 13-4.

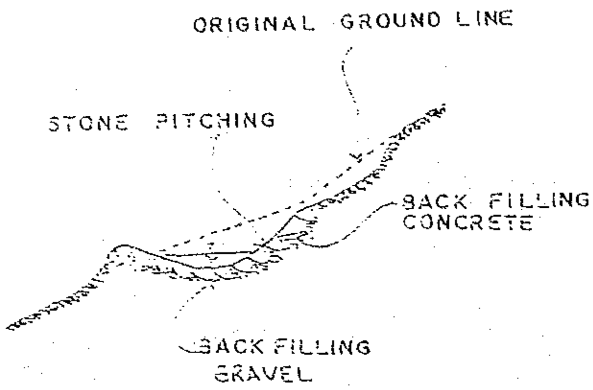
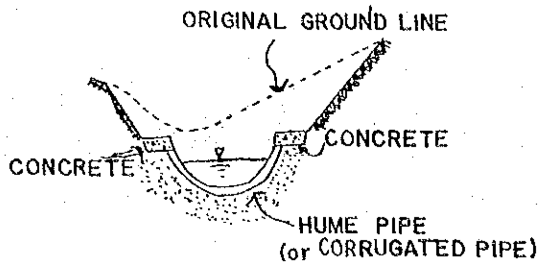



FIGURE 13-4 COLLECTING CHANNEL MADE OF STONE

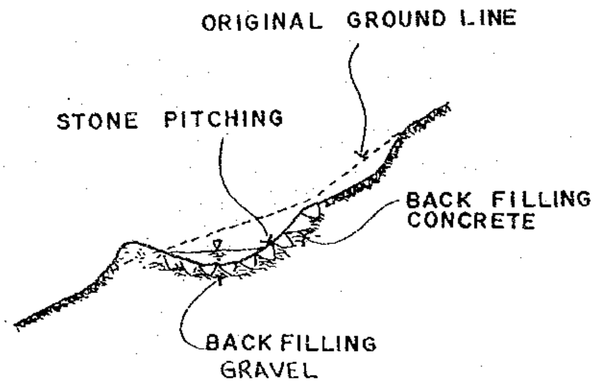
Draining Channel

Draining channel aims to provide a quick and perfect draining of collected water outside of the slope area. The section should be designed based on run-off calculation and the gradient must be a relatively steep.

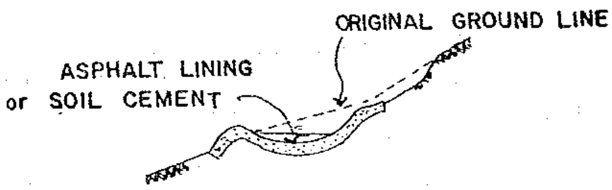
Bed consolidation works should be made at every 20 to 30 m along channels to prevent slipping. The channel may be fixed with wooden stakes where the ground is poor. Hume pipe (centrifugal reinforced concrete pipe) or corrugated pipe may be recommended as draining channel, an example of which is shown in Figure 12-5 (a). When these pipes are not available, stone pitching channel shown in Figure 13-5 (b) or simple channel with asphalt lining can be used, as shown in Figure 13-5 (c).




(a) Draining Channel Using Hume Pipe




(b) Draining Channel Made of Stone Pitching




(c) Draining Channel Made of Stone Pitching

FIGURE 13-5 DRAINING CHANNEL

(2) Infiltration Prevention

This work is performed to prevent seepage of water into the ground. Since infiltration prevention work can not be made practicable to cover the whole ground surface of landslide, this work is applied only in the following areas with the suggested methods mentioned below.

Cracked portion which seepage water easily infiltrates

Cracks should be filled with clay or cement. Vinyl sheets are sometimes used as emergency measure to cover cracked portion of landslide.

Swamp or water route

This is actually ground water supply source because of large amount of surface water being impounded or collected.

In this situations, the bottom of the swamp or water route should be covered with impermeable materials such as asphalt and concrete, as shown in Figure 13-6.

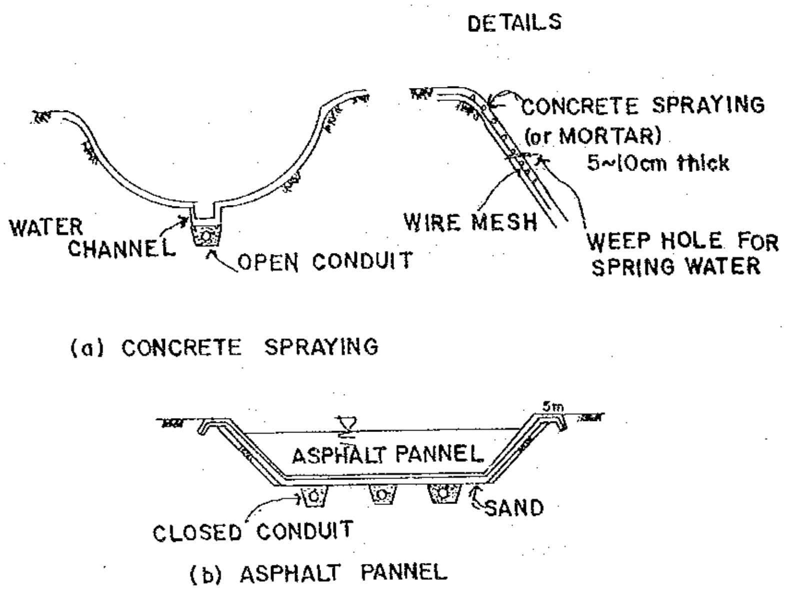



FIGURE 13-6 INFILTRATION PREVENTION

### 13.4.2 Subsurface Water Drainage

Subsurface water drainage should be carried out where groundwater affecting landslide is confirmed by survey.

This work is classified into two categories, namely:

Shallow Groundwater Drainage

Subsurface drains composed of closed conduit and drains conduit with open ditch

Deep, Groundwater Drainage

Horizontal drain hole, deep wall

(1) Subsurface Drainage

This is the most effective type to drain groundwater contained about 3 m. below the ground surface, particularly in cases where the groundwater between soil particles in soil layer have small coefficient of permeability.

Collecting Channel

As a collecting channel for groundwater, perforated concrete pipe or gabion is generally used.

In the construction of the channel, vinyl cloth or asphalt board is, at first, laid at the bottom of excavated ditch to prevent any leakage before the pipe is placed. Gravel or fascine is placed as filter around and above the pipe or the gabion to prevent clogging.

If the length of collecting channel is too long, water sedimentation may take place which may eventually result to clogging. Therefore, catch basins or manholes are usually installed at every 20 to 30 m. and collecting channel is connected to surface water channel or draining conduit. (Refer to Section 7; Design of Drainage)

Draining Conduit

This is made of non-perforated hume pipe or corrugated pipe and is connected to a drainage canal at the point of anchoring.

Closed Conduit with Open Ditch

This is effective to drain water where shallow groundwater exists together with surface water.

Large Closed Conduit

Where aquifer exists 3 to 5 m. below ground surface, large closed conduit is required. This kind of large-scale closed conduit can not only drain water in soil masses which is the cause of landslide, but also prevent shallow groundwater coming from outside of landslide area.

This type is, therefore, recommended to be constructed near the boundary at the upper portion of lanslide slope.

(2) Horizontal Drain Hole

Open-cut method for the construction of drainage structure such as large closed conduit to drain groundwater deeper than 5 m. is not practical because it requires a lot of excavation works which might be sometimes dangerous. In this case, horizontal drain hole is applied. For draining shallow groundwater, bore hole with 30 to 0 m. in length should be drilled with a 5° upward angle. While, for deep groundwater, the length should be about 80 to 100 m. enough to reach to bedrock through slide plane under slide scarp. See Figure 13-7.

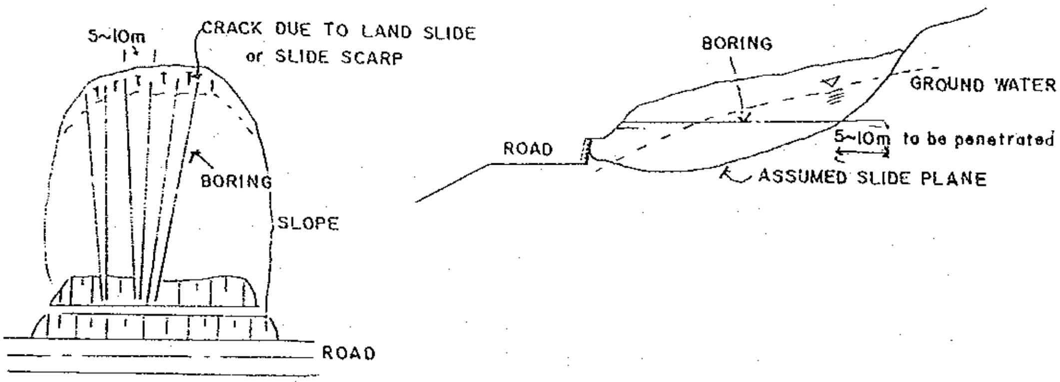



FIGURE 13- 7 HPRIZONTAL DRAIN HOLE

The diameter of bore hole should be 66 mm. After completing the drilling work, hard vinyl chloride pipe or gas pipe attached with a strainer should be inserted as hole-protecting and water-collecting/draining pipe to an aquifer. Double polyethylene net pipe is sometimes attached to a part of strainer to prevent the clogging of the strainer. End portion of the drain pipe should be protected by gabion or concrete wall. See Figure 13-8.

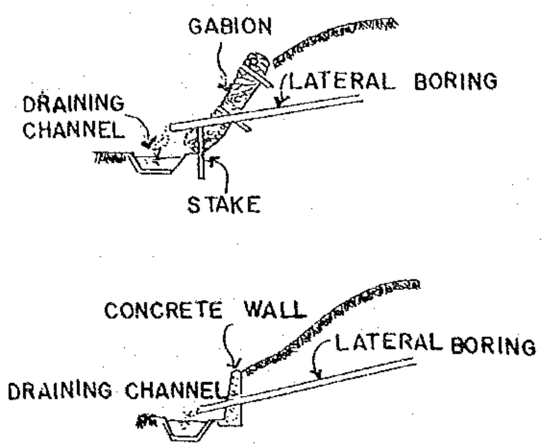
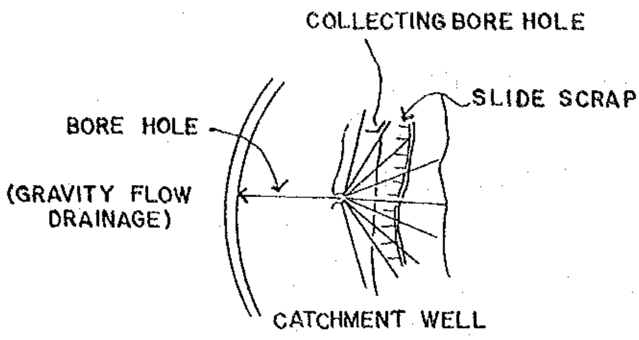


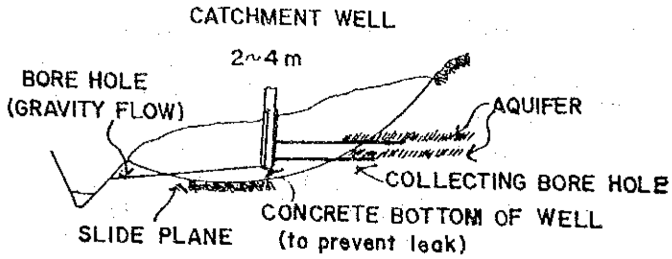

FIGURE 13-8 PROTECTION WORK FOR HORIZONTAL DRAIN HOLE

(3) Deep Well

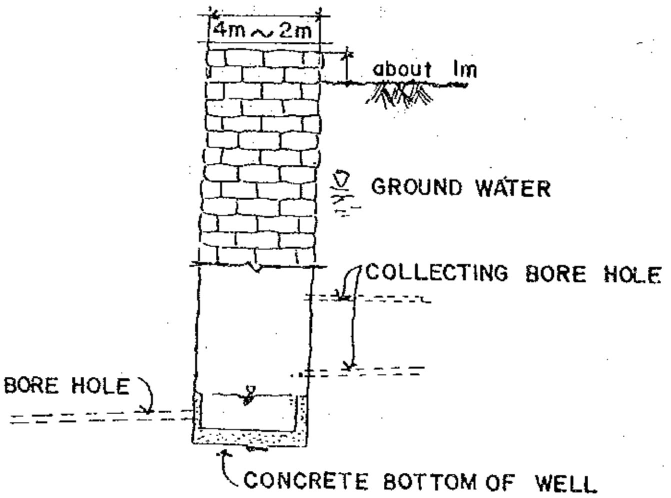
Deep well is used in the case where horizontal drain hole is too long or where the groundwater is concentrated near a bedrock. There are two types of catching method, one is through wall to well and the other is by lateral bore holes. For the former, the diameter of well is normally form 0.3 to 1.5 m. For the latter, a diameter of 2.5 to 4.0 m. is required because of the boring work within the well and the short rods about 1.0 to 1.5 m. long are usually used for the boring. Boring from the well is normally planned in several steps for each aquifer. The deep well is made of reinforced concrete or liner plates (rustproof plates). Gas-pipe with 3 to 4 inches in diameter is usually used as drain pipe. See Figure 13-9.




(a) GENERAL PLAN OF WORK




(b) LOCATION OF CATCHMENT WELL




(c) DETAIL OF CATCHMENT WELL

FIGURE 13-9 DEEP WELL

## 13.5 EARTH WORK

### 13.5.1 Earth Removal

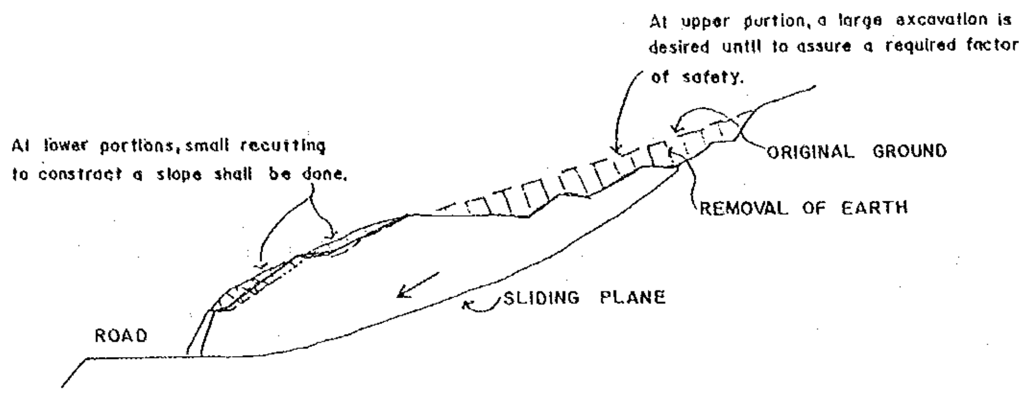
Earth removal aims to stabilize slope by removing a part or the whole earth of the sliding soil mass. Usually, only the head portion of the landslide mass is removed. This is one of the reliable methods found effective and therefore frequently used for medium or small size landslide. Stability analysis based on actual survey on scale and range of landslide and strength of soil should be made to assure a required factor of safety with this process.

(1) Method of Earth Removal

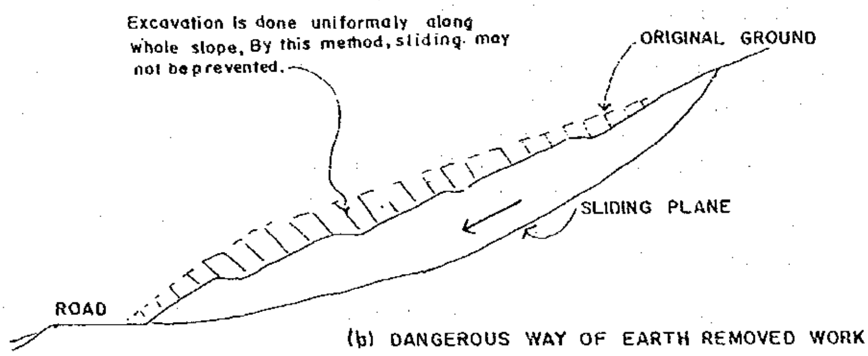
Area of soil to be removed

It is only an effective way for preventing a landslide to remove a head portion of landslide mass in the area. Earth at the lower portion should not be removed. When soil at the lower portion of the slope is required to be removed, excavation should be done at the head portion first progressing towards the bottom in order to maintain the stability of the landslide area.

See Figure 13-10 in which both effective and dangerous methods of earth removal are shown.




(a) EFFECTIVE WAY OF EARTH REMOVED WORK




(b) DANGEROUS WAY OF EARTH REMOVED WORK

FIGURE 13-10 METHOD OF EARTH REMOVAL

Where several landslide blocks are located continuously, earth removal at the intermediate or lower landslide blocks is not permitted since it may adversely affect the upper blocks. See Figure 13-11.

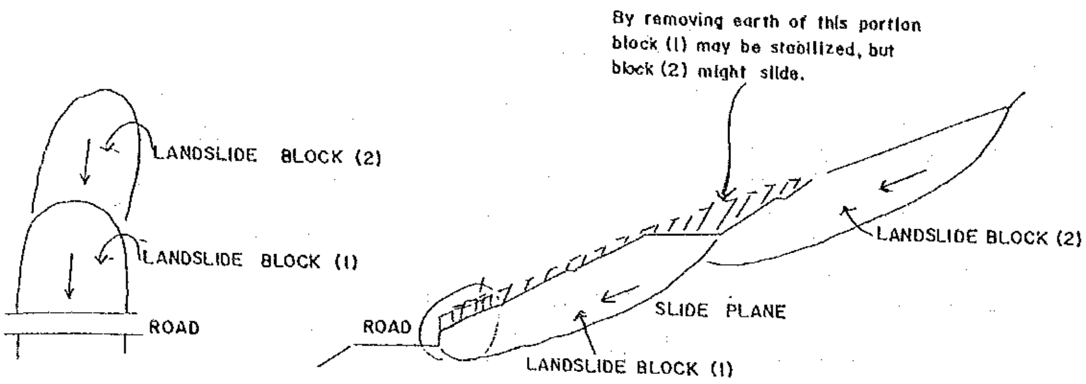



FIGURE 13-11 METHOD OF EARTH REMOVAL FOR SEVERAL LANDSLIDE BLOCKS

Earth removal can be made effective only in the case where the shape of the slide plane is almost an arch or the thickness of landslide mass at an upper portion is extremely larger than that at the lower portion.

Notes in the execution of work

Earth removal work should be performed from the upper to lower portions so as to maintain the stability of the slope. Work should be performed in dry season, and work during rainfall should be avoided.

(2) Gradient of slope after earth removal

Earth removal work is mainly performed at the head portion of landslide area with a gentle slope gradient of 2.0:1 to 4.0:1 at the head portion. Slopes near a slide scarp (boundary at the head portion of landslide area) and near the tail portion are usually steep which has almost the same gradient as the natural ground or a slightly gentler than 1.0:1 to 1.5:1.

(3) Slope protection after earth removal

A slope after removal of earth may be made up of soil with high permeability which may easily collapse due to rainfall. Therefore, a collecting and draining channel network together with vegetation work should be planned. Stone masonry or crib work may be required for bench-cut portions. When an exposed portion of bedrock has many cracks and is likely to be easily weathered, mortar or concrete spraying is recommended.

### 13.5.2 Counter Weight Fill

Counter weight fill aims to stabilize slope filling earth at the lower portion of landslide. Since soil at the tail portion of landslide is usually disturbed and poor quality, earth filling should be done after groundwater is completely discharged in order to avoid a collapse of foundation soil and an increase of pore water pressure due to obstructing of groundwater flow by the filling process.

Location and height of filling shall be carefully analyzed using the result of the actual survey and investigation such as size and range of landslide and strength of foundation soil.

Effective method of filling work is shown in Figure 13-12.

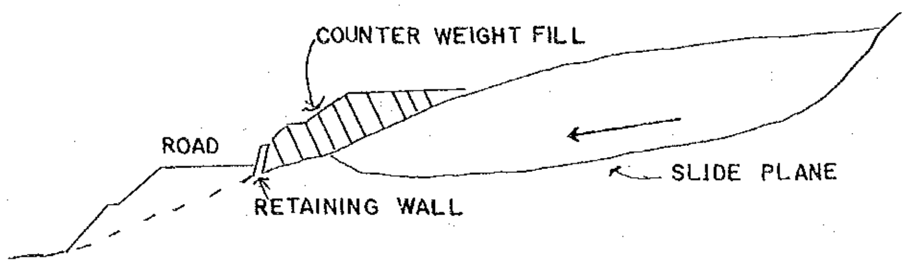



FIGURE 13-12 METHOD OF COUNTER WEIGHT FILL

A retaining wall is used to prevent small-scale landslide or secondary failure at the tail portion of a large scale landslide. Ordinary gabion and mat gabion are also used as a counter weight for the tail portion.

### 13.5.1 Structural Work

Piling aims to control a movement force of sliding mass by bending movement and shearing strength of pile. Anchoring is sometimes used with piling to increase the resisting force of pile against thrust of sliding mass.

Piling is usually applied at a place where the bedrock is strong so that pile can withstand a sliding mass. This type is also effective in cases where the sliding plane is deep. However, if the motion of a landslide is vigorous and exceeds 1 mm per day, piling may not be effective because each pile may act individually.

Piles widely used are pre-cast concrete, cast-in-place concrete and steel pile. As the special type are of cast-in-place concrete pile, Shinso type (Well type) is often adopted. A diameter of this pile is 1.5 m to 3 m. Well is first dug down to the bedrock with man-power and the concrete is poured in this well.

(1) Required Control Force of Pile

The control force of pile required per meter may be estimated with the following formula:

$$\frac{\Sigma\{C.\ell + (W \cos \theta - u\ell) \tan \phi\} + P}{\Sigma W \sin \theta}$$

Where;

$F_s$ : Design Safety Factor, $F_s = 1.1$

P ; Control Force per meter (t/m)

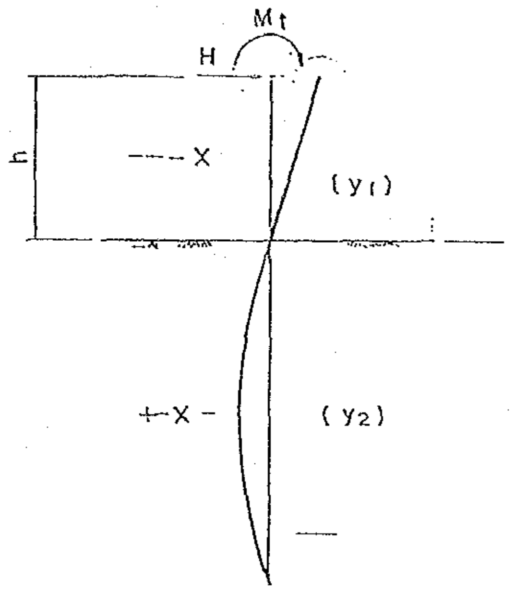
Refer to Section 6-3 and 13.1

(2) Design of Pile

Pile may be designed using Chang's Formula presented in Table 13-7. This formula can also be applied for the design of the pile used as the foundation of an abutment at pier in other similar structures.

TABLE 13-6 (a) DESIGN FORMULA ON PILE

## FUNDAMENTAL EQUATIONS (PILE ON GROUNDS)




DIFFERENTIAL EQUATION OF DEFLECTION CURVE

ABOVE GROUND: $EI \dfrac{d^4 y_1}{dx^4} = 0$

BELOW GROUND: $EI \dfrac{d^4 y_2}{dx^4} + P = 0$

$P = K \cdot D y_2$

where :

H = LATERAL FORCE ON TOP OF PILE (KG.)

Mt = MOMENT ON TOP OF PILE (kg. cm.)

D = DIAMETER OF PILE (cm.)

E = MODULUS OF ELASTICITY OF THE MATERIAL OF PILE (kg./$cm.^2$)

I = MOMENT OF INERTIA OF PILE ($cm.^4$)

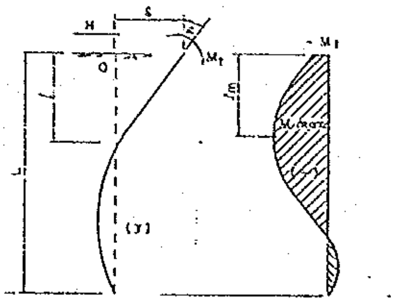
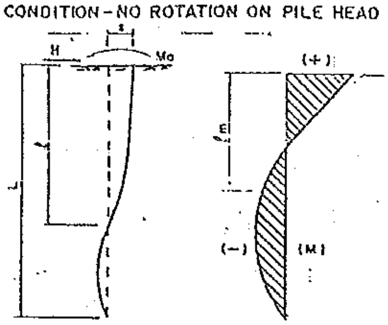
K = LATERAL ELASTICITY OF SOIL (kg./$cm.^3$)

h = HEIGHT ABOVE THE GROUND WHERE H AND Mt. ACT (cm.)

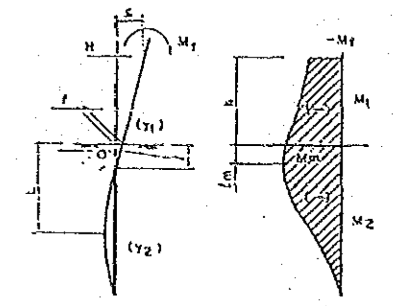
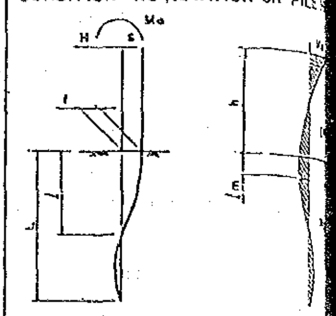
$\beta = \sqrt[4]{\dfrac{k.D}{4EI}}$ ······ ($cm.^{-1}$)

$ho = \dfrac{Mt.}{H}$ (cm.)

## TABLE 13-6.(b) DESIGN FORMULA OF PILE

| CASE I TOTAL LENGTH OF PILE FULLY EMBEDDED ON GROUND ($h = o$) | | |
|---|---|---|
| DEFLECTION DIAGRAM<br>BENDING MOMENT DIAGRAM | BASIC CONDITION<br><br>DEFLECTION CURVE DIAGRAM BENDING MOMENT DIAGRAM | CONDITION-NO ROTATION ON PILE HEAD<br><br>DEFLECTION CURVE DIAGRAM BENDING MOMENT DIAGRAM |
| a. DEFLECTION CURVE $y$ (cm.) | $y = \frac{H}{2EI\beta^3} e^{-\beta x} \{(1+\beta h_o) \cos\beta x - \beta h_o \sin\beta x\}$ | $y = \frac{H}{4EI\beta^3} e^{-\beta x} (\cos\beta x + \sin\beta x)$ |
| b. TOP OF PILE DISPLACEMENT $\delta$ (cm.) | $\delta = \frac{H}{2EI\beta^3} + \frac{M_t}{2EI\beta^2} = \frac{1+\beta h_o}{2EI\beta^3} H$ | $\delta = \frac{H}{4EI\beta^3} = \frac{\beta H}{kD}$ |
| c. DISPLACEMENT AT GROUND SURFACE $f$ (cm.) | $f = \delta$ | $f = \delta$ |
| d. TOP OF PILE ROTATION $\phi$ (RAD.) | $\phi = \frac{H}{2EI\beta^2} + \frac{M_t}{EI\beta} = \frac{1+2\beta h_o}{2EI\beta^2} H$ | $\phi = 0$ |
| e. BENDING MOMENT OF PILE $M$ (kg.cm.) | $M = -\frac{H}{\beta} e^{-\beta x} \{\beta h_o \cos\beta x + (1+\beta h_o) \sin\beta x\}$ | $M = -\frac{H}{2\beta} e^{-\beta x} (\sin\beta x - \cos\beta x)$ |
| f. SHEARING FORCE OF PILE $S$ (kg.) | $S = -He^{-\beta x} \{\cos\beta x - (1+2\beta h_o) \sin\beta x\}$ | $S = -He^{-\beta x} \cos\beta x$ |
| g. BENDING MOMENT AT TOP OF PILE $M_o$ (kg.cm.) | $M_o = -M_t = -Hh_o$ | $M_o = \frac{H}{2\beta}$ |
| h. BENDING MOMENT OF PILE AT $l_m$ $M_m$ (kg.cm.) | $M_m = \frac{-H}{2\beta} \sqrt{(1+2\beta h_o)^2 + 1}\ e^{-\beta l_m}$ | $M_m = -\frac{H}{2\beta} e^{-\frac{\pi}{2}} = -0.2079\ M_o$ |
| i. DEPTH OF MAX. BENDING MOMENT $l_m$ (cm.) | $l_m = \frac{1}{\beta} \tan^{-1} \frac{1}{1+2\beta h_o}$ | $l_m = \frac{\pi}{2\beta}$ |
| j. DEPTH OF DISPLACEMENT $l$ (cm.) | $l = \frac{1}{\beta} \tan^{-1} \frac{1+\beta h_o}{\beta h_o}$ | $l = \frac{3\pi}{4\beta}$ |
| k. DEPTH OF NO DEFLECTION ANGLE $L_o$ (cm.) | $L = \frac{1}{\beta} \tan^{-1} \{-(1+2\beta h_o)\}$ | $L = \frac{\pi}{\beta}$ |

# TABLE 13-6 (c) DESIGN FORMULA OF PILE

| CASE II PILE-LENGTH PARTIALLY EMBEDDED ON GROUND ( $h > 0$ ) | | |
|---|---|---|
| DEFLECTION DIAGRAM<br>BENDING MOMENT DIAGRAM | BASIC CONDITION<br><br>DEFLECTION CURVE DIAGRAM    BENDING MOMENT DIAGRAM | CONDITION - NO ROTATION ON PILE…<br><br>DEFLECTION CURVE DIAGRAM    BENDING MOMENT DIAGRAM |
| a. DEFLECTION CURVE $y$ (cm) | $y_1 = \frac{H}{6EI\beta^3}[\beta^3x^3 + 3\beta^3(h+h_0)x^2 - 3\{1+2\beta(h+h_0)\}\beta x + 3\{1+\beta(h+h_0)\}]$<br>$y_2 = \frac{H}{2EI\beta^3}e^{-\beta x}[\{1+\beta(h+h_0)\}\cos\beta x - \beta(h+h_0)\sin\beta x]$ | $y_1 = \frac{H}{12EI\beta^3}[2\beta^3x^3 - 3(1-\beta h)\beta^2x^2 - 6\beta^2hx + 3(1+\beta h)]$<br>$y_2 = \frac{H}{4EI\beta^3}e^{-\beta x}[(1+\beta h)\cos\beta x + (1-\beta h)\sin\ldots$ |
| b. TOP OF PILE DISPLACEMENT $\delta$ (cm) | $\delta = \frac{(1+\beta h)^3 + 1/2}{2EI\beta^3}H + \frac{(1+\beta h)^2}{EI\beta}M_T$ | $\delta = \frac{(1+\beta h)^3 + 2}{12EI\beta^3}H$ |
| c. DISPLACEMENT AT GROUND SURFACE $f$ (cm) | $f = \frac{1+\beta(h+h_0)}{2EI\beta^3}H$ | $f = \frac{1+\beta h}{4EI\beta^3}H$ |
| d. TOP OF PILE ROTATION $\varepsilon$ (RADIANS) | $\varepsilon = \frac{(1+\beta h)^2}{2EI\beta^3}H + \frac{1+\beta h}{EI\beta}M_t$ | $\varepsilon = 0$ |
| e. BENDING MOMENT OF PILE $M$ (kg. cm.) | $M_1 = -H(x+h) - M_t = -H(x+h+h_0)$<br>$M_2 = -\frac{H}{\beta}e^{-\beta x}[\beta(h+h_0)\cos\beta x + \{1+\beta(h+h_0)\}\sin\beta x]$ | $M_1 = \frac{H}{2\beta}[-2\beta x + (1-\beta h)]$<br>$M_2 = \frac{H}{2\beta}e^{-\beta x}[(1-\beta h)\cos\beta x - (1+\beta h)\sin\beta x]$ |
| f. SHEARING FORCE OF PILE $S$ (kg.) | $S_1 = -H$<br>$S_2 = -He^{-\beta x}[\cos\beta x - \{1+2\beta(h+h_0)\}\sin\beta x]$ | $S_1 = -H$<br>$S_2 = -He^{-\beta x}(\cos\beta x - \beta h\sin\beta x)$ |
| g. BENDING MOMENT AT TOP OF PILE $M_0$ (kg.cm.) | $M_0 = -M_t = -Hh_0$ | $M_0 = \frac{1+\beta h}{2\beta}H$ |
| h. BENDING MOMENT OF PILE AT $l_m$ $M_m$ (kg. cm.) | $M_m = \frac{-H}{2\beta}\sqrt{\{1+2\beta(h+h_0)\}^2+1}\cdot e^{-\beta l_m}$ | $M_m = -\frac{H}{2\beta}\sqrt{1+(\beta h)^2}\cdot \exp(-\beta l_m)$ |
| i. DEPTH OF MAX. BENDING MOMENT $l_m$ (cm.) | $l_m = \frac{1}{\beta}\tan^{-1}\frac{1}{1+2\beta(h+h_0)}$ | $l_m = \frac{1}{\beta}\tan^{-1}\frac{1}{\beta h}$ |
| j. DEPTH OF DISPLACEMENT $l$ (cm.) | $l = \frac{1}{\beta}\tan^{-1}\frac{1+\beta(h+h_0)}{\beta(h+h_0)}$ | $l = \frac{1}{\beta}\tan^{-1}\left(\frac{\beta h+1}{\beta h-1}\right)$ |
| k. DEPTH OF NO DEFLECTION ANGLE $L_0$ (cm.) | $L = \frac{1}{\beta}\tan^{-1}[-\{1+2\beta(h+h_0)\}]$ | $L = \frac{1}{\beta}\tan^{-1}(-\beta h)$ |

## CHAPTER 14 COUNTERMEASURES FOR DEBRIS FLOW

In general, the area of a water-shed is made up into two sections; the river channel area and hillside area, as shown in Figure 14-1.

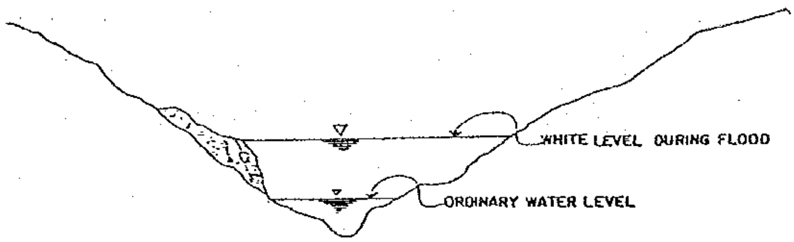



FIGURE 14-1 DIVISION OF WATER-SHED

Furthermore, the river channel area is sub-divided into what is called traction area and debris flow area. Traction is actually the sediment that is transported a little above or near the stream bed. The sediment moves in a sliding, rolling or jumping motion. On the other hand, the debris flow area is where large amount of sediment, stone and gravel flow down by their own gravitational weight and with the force of water.

In this chapter, countermeasures for debris flow mentioned above are discussed. However, countermeasures for scouring due to the flow of stream may be referred to in Chapter 11.

### 14.1 MECHANICS OF DEBRIS FLOW

Debris flow commonly results from unusually heavy precipitation. It occurs during torrential run-off following heavy downpours. This is influenced by the presence of soil on steep mountain slopes from which the vegetative cover has been removed, but the absence of vegetation is not a prerequisite. Once in motion, a small stream of water heavily laden with soil has transporting power that is disproportionate to its size, and, as more material from its banks are added to the stream, its size and power increases. Flow may extend many kilometers, until it drops its loads in a valley of lower gradient or at the based on a mountain front.

### 14.1.1 Occurrence of Debris Flow

Debris flow is likely to occur under the following cases and/or physical configurations:

a) Debris and/or earth deposited on a torrential bed suddenly begin to move due to the increased flow water caused by heavy precipitation.

b) Debris and/or earth at hillside removed by heavy precipitation begin to move and flow together with surface water with the speed at the failure.

c) A sliding mass during landslide of clayey soil becomes liquified and flows with the current.

### 14.1.2 Causes of Debris Flow

Factors and conditions influence the occurrence of debris flow are discussed below:

1) Geology and Geological Structure

Occurrence of debris flow is not necessarily concentrated at places with specified geology as in landslides. The following geological structures are where debris flow are likely to occur.

a) Granite

Granite is easily weathered, sometimes up to its deepest portion. Decomposed granite is highly permeable. Piping phenomenon is often observed at the boundary of its permeable layer and impermeable layer such as bedrock which eventually causes debris flow.

b) Volcanic Fracture Zone

Volcanic fracture zone consists of tuff, volcanic ash or volcanic sand is easily eroded and scoured. Therefore, sediment produced from the zone to precipitation scoured heaped up on stream bed and thus causes debris flow. Sometimes, during heavy precipitation, failure occurs in this zone which results to debris flow.

c) Tertiary Era Zone

Soft rock composed of sand stone, mudstone or tuff which sometimes accumulates clayey soil between the rock creates mud flow in the form of land slide which result to debris flow.

d) Mesozonic and Paleozonic Zone

Sandstone and slate are not easily subjected to failure, but the rock fractured by crustal movement sometimes induces large-scale failure resulting to debris flow.

2) Heavy Precipitation

Debris flow commonly results from unusual heavy precipitation. The discharge increases extensively to move sediments on stream bed and affects groundwater and seepage water which may cause failures. However, data necessary to discuss the relationship between precipitation and the occurrence of debris flow have not yet been formulated.

3) Gradient of Torrent Bed

Gradient of torrent bed has a direct influence on the occurrence of debris is flow. It is known that debris and sediment flow heaped up on the torrent bed in accordance with the gradient of torrent bed, $\theta$, as shown in Figure 14-2.

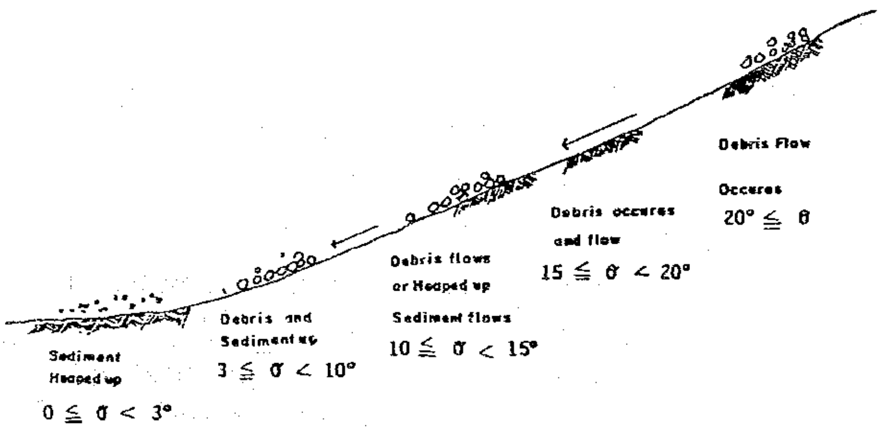



FIGURE 14-2 GRADIENT OF TORRENT BED AND DEBRIS FLOW

4) Other Factors

Others factors and/or conditions which influence the occurrence of debris flow are as follows:

. Condition of torrent bed rock.
. Unstable derbis and sediment deposited on torrent bed.

. Condition of vegetation at hillside.
. Occurrence of failure at hillside.
. Occurrence of landslide.
. Volcanic activity.

### 14.1.3 Characteristics of Debris Flow

In planning countermeasures for debris flow, the following characteristics shall be thoroughly taken into consideration.

1) Velocity

Velocity of debris flow varies with a wide range, generally from 0.5 m/sec to 17 m/sec.

2) Straight Flow

In many cases, debris flow goes straight on climbing over obstacles or sometimes showing them away. On the other hand, it immediately changes direction when it encounters rigid obstacles which can not be moved by the flow.

3) Density

It is observed from past experience that the density of debris flow ranges from 1400 kg/m$^3$ to 2500 kg/m$^3$.

4) Transport of Debris

Debris are transported like a mass transport type wherein the debris more by theirown Kinetic force. Bigger rock which has stronger kinetic force moves faster than smaller rocks, as shown Figure 14-3 (a). On the other hand, sand and stone tracted in bed load move as unit transport type, as shown in Figure 14-3 (b).

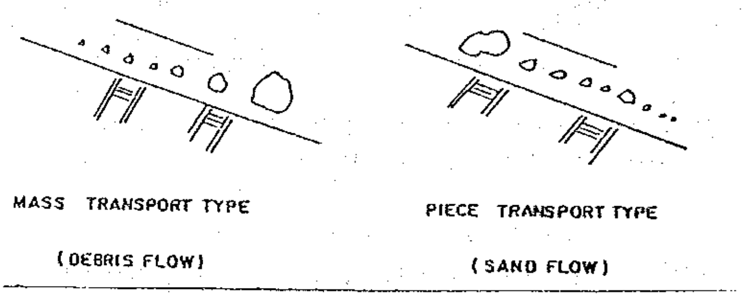



FIGURE 14-3 TRANSPORT TYPE

5) Breaking Force

Kinetic energy of breaking forces is observed as big as 0.3 ton to 6.0 ton in a past occurrences.

6) Shape of Debris Flow

From observations the shape of debris flow are shown in Figure 14-4.

b) CROSS SECTIONAL LONGITUDINAL SHAPE

FIGURE 14-4 SHAPE OF DEBRIS FLOW

## 14.2 TYPES OF COUNTERMEASURES

Countermeasures for debris flow are classified into the following types.

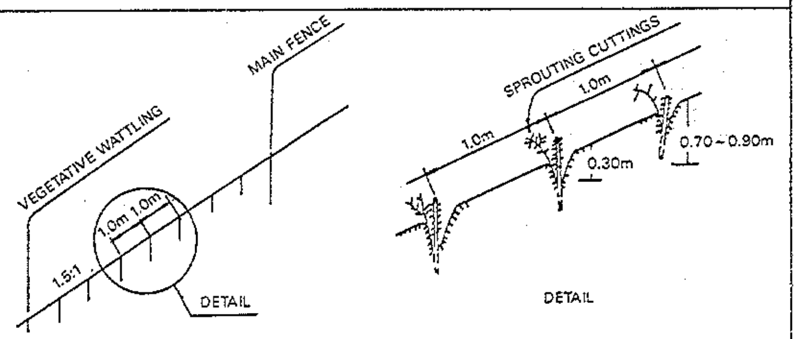
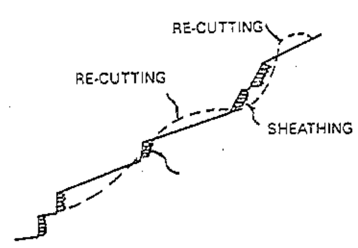
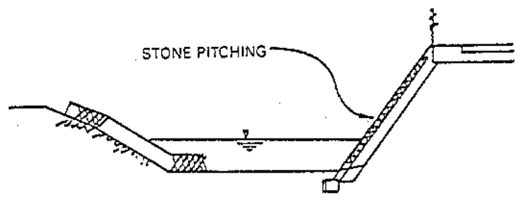
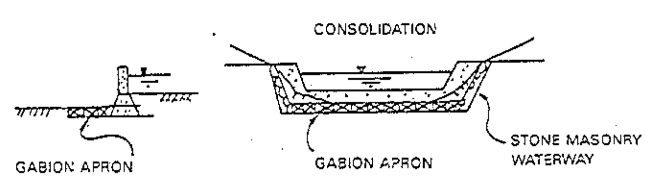
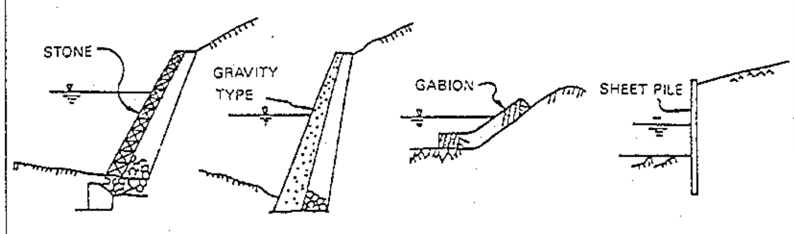
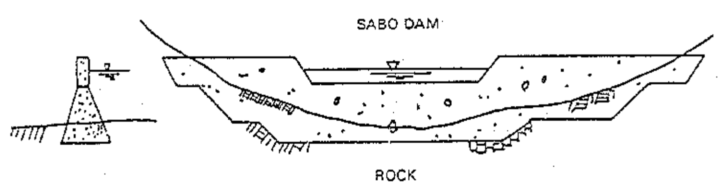
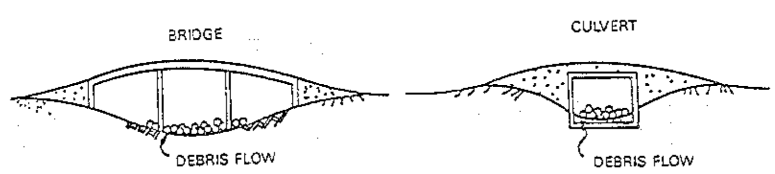
- Hillside work
- Torrent work
- Sabo work
- Avoiding problem work

Each of these is sub-classified into several types of works. The major types are listed in Table 14-C, which also indicates the purpose, application and typical illustrations.

The details of each type of works are discussed in Section, 14.4, 14.5 and 14.6.

The procedure in selecting countermeasures is briefly discussed in Section 14.3 and the application mentioned in Table 14-1 may be refered to for the selection.

## Table 14-1 COUNTERMEASURES FOR DEBRIS FLOW

| | Classification | Type of Work | Purpose | Application | Illustration |
|---|---|---|---|---|---|
| Hillside Work | Drainage | Water Channel | To collect surface water on hillside and thus prevent slope from erosion and scouring. | Applied to many cases. Used with other counter-measures. | Same as Countermeasures for Landslide |
| | | Subsurface | | | Same as Countermeasures for Cut Slope Failure. |
| | Vegetation | | To firmly bind materials of slope surface and thus prevent slope from erosion and scouring. | Vegetation is usually applied in combination with protection work such as terracing with stone, net muddling, etc. |  |
| | Afforestation | | To cover hillside with tree and shrub and thus prevent slope from erosion and scouring and sometimes to reduce velocity of surface water. | Applied to bare hillside. | |
| | Re-cutting | | To stabilize slope by cutting unstable portion of hillside and reforming irregularity of surface of slope. | Applied to hillside with irregularity Used with vegetation, sheathing and others. |  |
| | Sheathing | | To retain unstable earth with stone or concrete wall or wicker etc. | Applied to a little steep slop where earth shall be retained. Mainly used with other hillside work. | |
| Torrent Work | Water Way | Stone Pitching Water Way | To smoothly lead flow of water and thus control turbulent flow and prevent scouring of stream bed and bank. Also to prevent overflow of flood to adjacent area. | Applied to stream bank composed of erodable soil or to stream bed with steep gradient. Usually used together with consolidation or sabo dam. |  |
| | | Concrete Pitching Water Way | | | |
| | Consolidation | Stone Consolidation | To control flow of water providing head of water to make gradient of stream bed gentler and to prevent turbulent flow and thus prevent scouring of stream bed and bank. Sometimes only to protect stream bed. | Applied to swift stream, meeting point of flow or stream bed susceptible to scouring. Usually used together with revetment, water way and sabo dam. Concrete consolidation is widely used. |  |
| | | Concrete Consolidation | | | |
| | | Crib Consolidation | | | |
| | Revetment | Stone Masonry Revetment | To protect stream bank or hillside from waterclash due to curved flow of stream. | Applied to curved portion of stream. |  |
| | | Gravity Type Revetment | | | |
| | | Gabion Revetment | | | |
| | | Sheet Pile Revetment | | | |
| | Foot Protection | Concrete Foot Protection | To protect foots of revetment and water way from scouring. | Applied to foots of revetment and water way. | Same as Countermeasures for Embankment Slope Failure |
| | | Gabion Foot Protection | | | |
| Sabo Works | Sabo Dam | Stone Dam | To control flow of debris and to catch and collect debris and sand, providing space for deposited materials and making gradient stream bed gentler and thus avoid spread of damage and, at the same time, prevent scouring of stream bed and bank. | Mainly applied to large scale of debris flow. Constructed at portion such as narrow stream width, hard bedrock or after meeting of flow. |  |
| | | Concrete | | | |
| | | Concrete Dam | | | |
| | | Steel Dam | | | |
| Avoiding Problem Work | | Bridge | To avoid damage. Debris flows passes under bridge or inside of culvert. | Applied when other counter-measures are difficult and costly. |  |
| | | Culvert | | | |

* Structural details of revetment may be same as those of retaining wall.

## 14.3 SELECTION OF COUNTERMEASURES

The procedure in selecting countermeasures for debris flow is briefly discussed in this section.

1) Basically, there are two types or methods of countermeasures for debris flow. One is to directly prevent the occurrence of debris flow itself and the other is to avoid the problem when proper countermeasures for the prevention can not be applied. Avoiding the problem sometimes is more economical than other measures, especially for large size debris flow.

2) When reasonable countermeasures may be applied, the hillside should be examined. Whenever materials such as debris and earth exist on a hillside and those are susceptible to flow out due to run off, then hillside work should be executed.

3) Where there are large amount of deposits or sediments susceptible to debris flow in the stream, torrent work or sabo work should be adopted. In this method, concrete sabo dams are widely used. Generally, both methods are used.

## 14.4 HILLSIDE WORK

Hillside work as a countermeasure for debris flow includes the following:

- Drainage
- Vegetation
- Afforestration
- Re-cutting
- Sheathing

Drainage works are discussed in Chapter 7, while the other works are discussed.

1) Vegetation

The purpose and application of vegetation as a countermeasure is the same as discussed in Chapter 8.

There are many types of vegetation. The typical methods are;

- Seed Mud Spraying Refer to Chapter 8.2
- Vegetation with Wicker (Net Mudding) Refer to Chapter 8.8
- Vegetation by terracing With Stone See Fig. 14-5

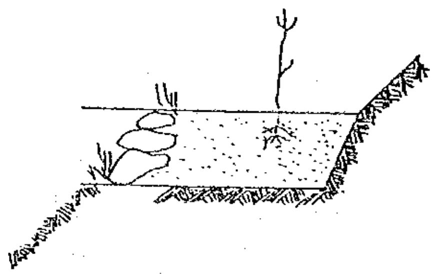


FIGURE 14-5 VEGETATION BY TERRACING WITH STONE

2) Afforestration

This type aims to cover hillside with tree and shrub to prevent slope from erosion and scouring. It sometimes contribute to the reduced in velocity of surface water.

It should be applied along bare hillside and wherever applicable, not only from the view point of slope protection but also from the environmental aspect.

3) Re-Cutting and Sheathing

This type aims to reshape the irregularity of the surface of a slope by re-cutting and by retaining unstable portion and thus to stabilize the slope.

There are many types of sheathing - For a small steep portion of a slope where earth pressure is not so large, wicker may be recommended (refer to Chapter 8.8). For a bit large earth pressure, stone masonry type retaining wall may be adopted, while for extensive earth pressures, concrete retaining wall is proposed. Refer to Chapter 9.4 and 9.5 for details of stone masonry and concrete retaining walls.

## 14.5 TORRENT WORK

Torrent work is used to rehabilitate and improve a water way by protecting the stream bed and river bank, and thus aims to prevent the occurrence of floods. This work is classified into the following types, taking into consideration as a countermeasure requirement for debris flow.

. Water Way
. Consolidation
. Revetment
. Foot Protection

The purpose and application of each type briefly mentioned with the illustration in Table 14-1.

### 14.5.1 Water Way

Refer to APPENDIX 2: STANDARD DRAINING NO. 20; STONE PITCHING MATERIALS AND FOOT PROTECTION.

1) Purpose

It aims to prevent turbulent flow by improving the water way so that, a flow of water can be controlled and thus scouring of stream bed and bank may be presented.

2) Implementing Timing

Water way should be implemented at a proper time, as follows:

i) The upstream area is devastated

Firstly, sabo work and hillside work at the upstream should be carried out and then water way can be planned.

ii) The upstream area is slightly devastated

Water way may be applied to the curved portion of stream and to the badly eroded portion.

3) Detail

The structural types of water way are stone pitching, concrete pitching, etc. The detail of these could be same as those discussed in Chapter 8.3 and 8.4 respectively.

As a rule, pitching should not be applied to the stream bed, except in the case when the critical velocity is smaller than a planned velocity.

Water way should be planned with the proper combination of sabo dam and consolidation.

### 14.5.2 Consolidation

1) Purpose

Consolidation aims to stabilize a stream bed to prevent it from scouring by making a gradient of the stream bed gentle and providing a head of water. Thus, movement of sediment on the stream bed can be controlled and at the same time the river bank is also protected. It is sometimes applied with the aim to protect the foundation of structures along the river bank.

2) Location

The location of a consolidation should be decided taking into consideration the following:

a) where stream bed may be scoured

b) a downstream just after a confluence (a meeting point of flow)

c) a downstream after a failure of river bank and a land slide

d) a downstream just after the curved portion of stream

e) Swift flow and turbulent flow

3) Details

a) Height of consolidation is usually less than 5 m. Even when an apron and a vertical wall is provided, a head of water should be less than 3.5 to 4.5 m.

b) When the height of consolidation is required to be more than 5 m. or when consolidation is required to be located in a long section, consolidation may be located in steeper arrangement.

### 14.5.3 Revetment

1) Purpose

Revetment aims to protect a stream bank and a toe of hillside from water clash due to the curved flow of a stream.

2) Location

Figure 14-6 shows the typical shape of stream where revetment may be recommended.

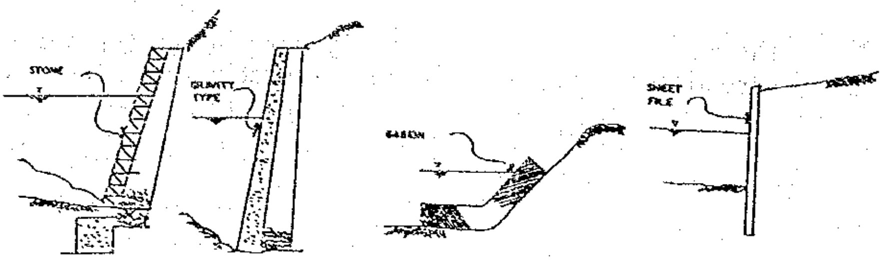


FIGURE 14-6 TYPE OF REVETMENT

3) Type of Revetment

The types of revetment are stone masonry, gravity type, gabion and sheet pile revetment, the typical of which are shown in Figure 14-7

The structural details of revetments may be same as those of a retaining wall. Refer to Chapter 11.

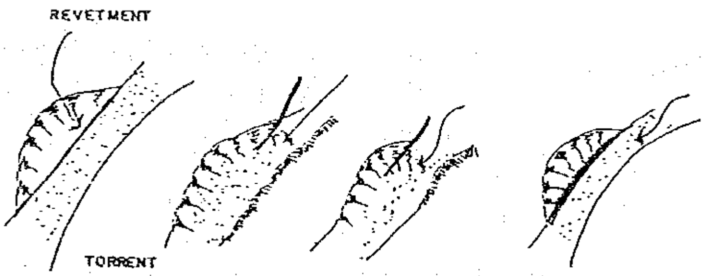



FIGURE 14-7 LOCATION OF REVETMENT

14.5.4 Foot Protection

Refer to STANDARD DRAINING NO. 20: STONE PITCHING WATERMAT AND FOOT PROTECTION

1) Purpose

This work aims to protect the foot of the retaining wall and other protection works from scouring by river stream.

2) Type

The materials which are widely used in gabion and concrete revetments. Typical sections are shown in Figure 14-8.

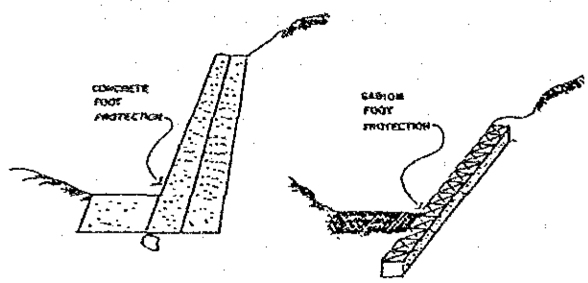


FIGURE 14-8 TYPE OF FOOT PROTECTION

## 14.6 SABO WORK

Refer to APPENDIX 2: STANDARD DRAINING, NO. 21; CONCRETE SABO DAM.

As a countermeasure for debris flow, a sabo dam is widely adopted. In this report, a concrete sabo is discussed.

1) Purpose of Sabo Dam

The purposes of sabo dam are as follows:

- To catch and collect debris and sediments
- To control flow of debris and sediments
- To make gradient of stream bed gentler to avoid the stream bed and bank from scouring.
- To control turbulent flow and thus prevent stream bank from scouring.

2) Kinds of Sabo Dam

Sabo Dam is classified into several types such as concrete, stone, steel, etc, depending on the material used, but only concrete dam is widely adopted.

Also, this work is classified in accordance with the purpose as follows:

- Debris Flow Prevention Dam is used to catch and collect debris and sediment.

- Control Dam to control flow of debris and sediment
- Scour Prevention Dam to prevent bed and bank from scouring
- Hillside Dam to protect stream bank and hillside from scouring

3) Location of Sabo Dam

The location of sabo dam should be carefully selected in order to serve its purpose. The following are general guidelines in considering the location of sabo dam:

a) Firm Bedrock is preferable to have a stable foundation. Where a foundation is gravel, a height of sabo dam should be less than 15 m.

b) Downstream just after the place where debris and sand are atored and/or deposited.

c) Upstream just before the width of torrent becomes wider

d) A curbed portion of torrent is not preferable.

e) Stepped arrangement.

In case the length of torrent is long or the volume of debris is estimated to be extensive, a series of sabo dams may be arranged in a step-like manner as shown in Figure 14-9.

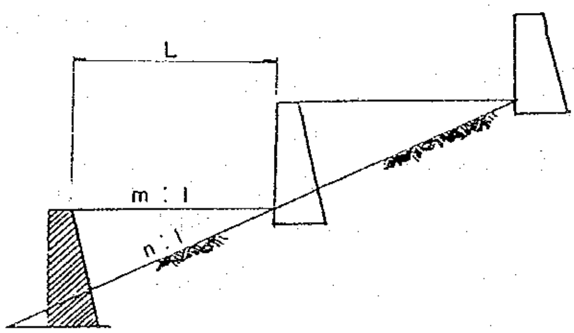



FIGURE 14-9 LOCATION OF SABO DAM

Distance of each dam L may be calculated using the following formula.

$$L = \frac{m - n}{m - n} \cdot h$$

Usually, m is recommended to be a half of n.

$$m = n/2$$

## 4) Design of Sabo Dam

### (1) General

Gravity type concrete sabo dam is designed using the same method applied to design of gravity type concrete retaining wall except external force acting on the sabo dam.

### (2) External Force

In design of sabo dam less than 15 m high, analysis for normal case may not be required. However, an analysis during floods may be made considering only its own weight and the hydrostatic pressure as an external force.

On the other hand, a sabo dam whose height is more than 15 m. uplift, silt pressure (pressure due to deposited silt), earthquake force should be taken into consideration aside from its own weight and hydrostatic pressure. For debris flow dam which may be directly attached by debris flow, impact force due to debris flow should be considered.

Hydrostatic pressure may be estimated using the following formula.

$$P = \frac{1}{2} \cdot Wo.Ho$$

Where,

P ; Hydrostatic pressure ($t/m^2$)

Wo ; Unit Weight of Water ($t/m^3$)

Ho ; Water Depth (m)

### (3) Volume of Deposited Debris

The volume of debris flowing with the current and sediments transported with bed load traction lane estimate for design purposes as follows:

a) Estimation by Actual Survey

The volume may be estimated by actual survey in the field investigating the depth of stream and scouring by a flood.

b) Estimation by Past Experience

For water-shed wider than 3 $km^2$ the following equation is proposed based on past experience:

$$V_s = H \times L \times B$$

$V_s$ ; A volume of debris and sediment ($m^3$)

H ; Average depth of stream bed scoured (m)
H=2 m is generally adopted as a scoured depth

L ; Length of torrent scoured (m)
$L = 3000 \times \sqrt{A_{10}}$

$A_{10}$ ; Catchment Area whose gradient is more than 10° ($km^2$)

B ; Average width of torrent scoured (m)
$B = 3 \sqrt{Op}$

Op ; $\frac{1}{3.6} \cdot f \cdot r \cdot A_{10}$

f ; Coefficient of run-off
f = 1.0 is generally adopted

r ; Average Rainfall Intensity within concentration time of flood (mm/hr)

(c) Water-shed less than 3 $km^2$

In the equation mentioned above, total catchment area may be used instead of $A_{10}$ to estimate the volume of debris and sediments.

(d) Estimation by Kyoto University's Formula

This assumption is given by the Disaster Prevention Institute, Kyoto University, Japan as follows:

$$D = \alpha (A.R24 - 1200)^2$$

D : Volume of debris flow for one flood time ($m^3$)

A : Catchment Area ($km^2$)

$R_{24}$ : Maximum Daily Rainfall

$I_{200}$: Gradient along the torrent between the deposited site and such a site as high as 200 m than the deposited site. (See Figure 14-4)

$\alpha$ : Coefficient ($\alpha = 7 \sim 10$)

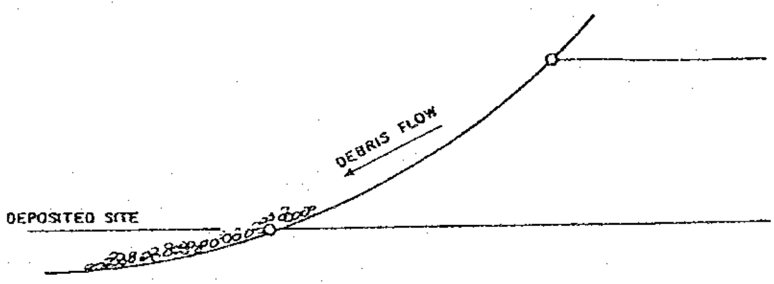



FIGURE 14-10 DEPOSITED SITE OF DEBRIS

## 14.7 AVOIDING PROBLEM WORK

In the same cases avoiding the debris flow thru relocation of road section or by combination of bridges and culverts may be more economical than the method to directly prevent occurrence of debris flow.

The comparative study in selecting measures is recommended. At the stage of design of road, especially, the comparative study including route location should be made.

## PART V ADMINISTRATION AND MAINTENANCE

# CHAPTER 15 ADMINISTRATION

## 15.1 GENERAL

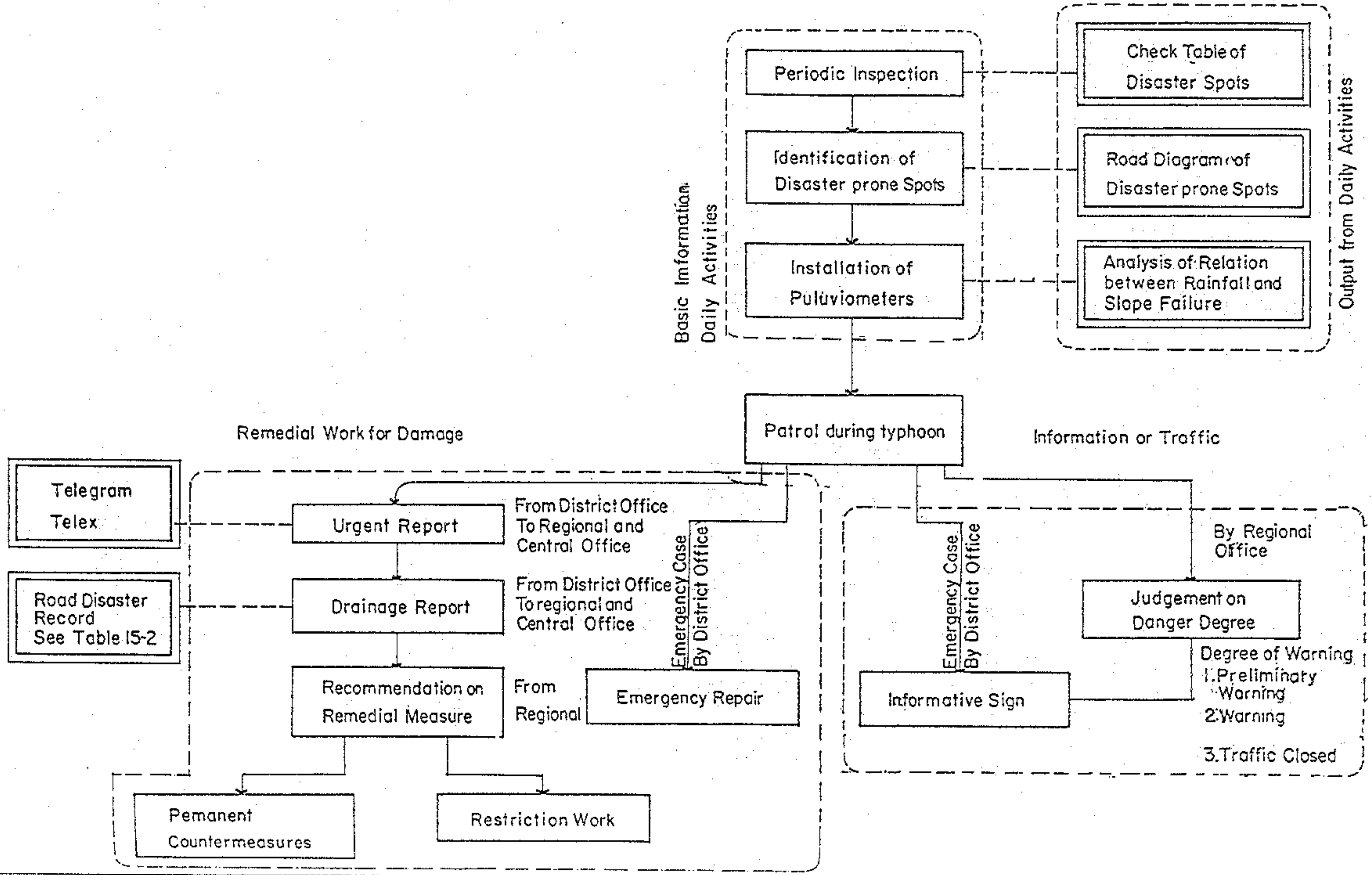
Traffic is very frequently disturbed by the damages caused by calamities such as typhoons and heavy rains. More specifically, traffic disturbance is largely due to the failures of slopes. Main cause of such failure is presence of water. In this chapter, therefore, the administrative strategy in managing road disaster is discussed giving emphasis to typhoons.

Strategies to be taken in relation to road disasters should be planned to be two phases, those which occurs before typhoons or road disaster will occur, and those during or after the occurrence.

Actions prior to the occurrence (Daily Activities) include the periodic inspection of slope, the identification of disaster-prone spots and installation of puluviometers.

Actions during and after the occurrence, on the other hand, involve traffic control and information system and the remedial works for damages. It should be emphasized that both can be properly carried out only when patrols to inspect any sign of slope failure during typhoons are carefuly executed. Table 15-1 shows the flow of actions to be taken in relation to road disasters.

TABLE 15-1 FLOW CHART ON STRATEGY TO BE TAKEN IN RELATION TO ROAD DISASTER



## 15.2 BASIC INFORMATION IN RELATION TO ROAD DISASTERS

In managing road disasters and protecting people and roads from danger and damages, the most important factor is daily activities, only which can furnish the basic information on road disasters.

(1) The periodic inspection on slopes should be performed.

In order to check the condition of slopes, the items to be inspected for natural slopes and for slopes with countermeasure are explained in Para. 16.2.2 and 16.2.3 respectively. Check Table prepared for each type of road disaster can be used so that the condition of slope for each spot can be summarized in a table Refer to Chapter 3.

This check table should be the bases for managing road disasters on slopes.

(2) Identification of Disaster-Prone Spots

Based on the information on slopes given in Check Table, disaster-prone spots can be identified and their disaster potential and impact to traffic may be evaluated.

Spots identified and evaluated as those with high disaster potential and severe impact to traffic should be clearly and systematically presented in a table format. An example is shown in Table 15-2 titled as ROAD DIAGRAM FOR DISASTER-PRONE SPOTS.

Information to be covered in this table should be kilometrager of spots identified type of failure, cause, name of typhoon affected, topography, geology.

Among others. In table 15-2, the history of slope failure can also be seen within three years, 1984, 1985 and 1986. This history of slope failures may furnish interesting and useful data, especially in predicting the occurrence of slope failures.

(3) Installation of Pulviometer

Pulviometers are strongly recommended to be installed, at least at the spots identified as one with high disaster potential.

As mentioned earlier, the main cause of slope failure is water. The relation between slope failure and rainfall intensity should, therefore, be analyzed. With these analysis and data, the causes of slope failure can be further studied so that the occurrence of slope failure may be predicted.

| | GOOD | FAIR | BAD |
|---|---|---|---|
| CONCRETE | G | F | B |
| ASPHALT | G | F | B |
| GRAVEL | G | F | B |

TABLE-15-2 ROAD DIAGRAM FOR DISASTER PRONE SPOTS

| REGION | | ROAD | | | SHEET NO. | |
|---|---|---|---|---|---|---|
| DISTRICT | | CAMARINE SUR | NAGA CITY | | CAMARINES SUR | |
| KM. POST | | 415, 420 | 425, 430, 435 | | 440, 445, 450 | |
| PAVEMENT CONDITION | | G | G | | | |
| BRIDGE | | 423 CAMARINES Br. | | | | |
| TOPOGRAPHY | | ROLLING | FLAT | | MOUNTAINOUS | |
| GEOLOGY | | GRANITE | TUFF | | ANDESITE | |
| SLOPE | RIGHT | MOUNTAIN | EMBANKMENT WITH LOW HEIGHT | | MOUNTAIN | |
| SLOPE | LEFT | RIVER | SAME | | RIVER | |
| HISTORY OF SLOPE FAILURE | SPOT NO. | (36) 405.300 | | | | |
| | DEGREE OF DANGER | HEAVY | | | | |
| RIGHT SIDE | 1984 | EMBANKMENT FAILURE (TYPHOON, DAY) | | | 448 FALL (TYPHOON, DAY) | |
| RIGHT SIDE | 1985 | | | | | |
| RIGHT SIDE | 1986 | | | | | |
| LEFT SIDE | 1984 | | | | | |
| LEFT SIDE | 1985 | | | | | |
| LEFT SIDE | 1986 | | | | | |

The analysis and data obtained can also be utilized in selecting the appropriate countermeasures for slope failure, and in their design and construction.

Pulviometers are also essential for traffic control and information system during typhoon.

## 15.3 TRAFFIC CONTROL AND INFORMATION SYSTEM

Recently, electronic instruments are sometimes used to perceive an occurrence of slope failure and raise the alarm, But because, these require facilities such as wire net, fence, sensor, etc, a basic and simple traffic control and information system is described.

(1) Designation of Spots with high disaster potential

Spots with high disaster potential where traffic control during typhoon may be required should be designated. Spots are recommended to be ranked; for example, Class 1 (Most Dangerous), Class II (Highly Dangerous) and Class III (Dangerous) in accordance with the disaster potential and the impact to traffic when slope failure occurred.

(2) Establishment of Regulation on Traffic Control

Regulation on traffic control during typhoon should be established. Regulation is desired to be establised based on the ranking of spots and 24 kms rainfall. For this purpose, pulviometers are recommended to be installed at the proper spots.

For this purpose, pulviometers are recommended to be installed at the proper spots.

The kind of regulation may be three, A) Road closed to traffic, B) Warning and C) Preliminary warning.

(3) Patrol and Information

During typhoons and heavy rains, patrol should be conducted in order to observe any sign of abnormal condition of slope.

As soon as any abnormality of the slope is found, the office concerned should be informed to decide which kind of regulation should be taken. The judgement may be done based on 24-hours rainfall measured by pulviometers.

For an emergency case, the patrol man should be authorized to enforce the regulation without consulting with the higher authorities.

## 15.4 ROAD DISASTER RECORD

The Ministry of Public Works and Highways issued the Ministy Order on the guidelines on actions to be taken in case of damages caused by calamities on national highways and public facilities and structures, on August 5, 1982. In compliance with this Ministry Order, an example of Road Disaster Record, Form I and Form II, are prepared as shown in Table 15-3 and 15-4, respectively.

Information to be covered by the Record, Form 2, should be on failures of slope, typhoons, damages, impact to traffic, conditions of slope and torrent, among others. This Form I aims to fill up the engineering information on slope failures. This information should, therefore, be listed in the Table 15-2, ROAD DIAGRAM FOR DISASTER-PRONE SPOTS.

On the other hand, the Record, Form 2, intends to summarize the information on the administrative matters. The contents of Form 2 should, therefore, be reviewed by the Government. The pictures and sketches to show the situation of slope failure is recommended to be attached.

TABLE 15-3 ROAD DISASTER RECORD (FORM 1)

SHEET NO.

NAME OF TYPHOON : ____________

DATE OCCURED : ____________

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | REPORTER | | DATE | |
| LOCATION | REGION | | DISTRICT | | | |
| | ROAD | | KM. POST | | | |
| FAILURE | TYPE | CUT SLOPE FAILURE, EMBANKMENT SLOPE FAILURE, FALL, LANDSLIDE, DEBRIS FLOWS AND OTHERS. | | | | |
| | PROBABLE CAUSE | | | | | |
| | SIZE | LENGTH M, WIDTH M, VOLUME $M^3$ | | | | |
| | DEGREE | | | | | |
| | OUTLINE OF DAMAGE | | | | | |
| TYPHOON | RAIN CONTINUOUS | FROM TO NO. OF DAYS | | | | |
| | AREA COVERED | | | | | |
| | RAINFALL | INTENSITY /DAY | | | | |
| ANY DAMAGE | | | | | | |
| ROAD CONDITION | | NUMBER OF LANES WIDTH SHOULDER | | | | |
| TRAFFIC VOLUME | | | | | | |
| IMPACT TO TRAFFIC | | WARNING ONLY FROM TO NO. OF DAYS | | | | |
| | | PARTIALLY CLOSED FROM TO NO. OF DAYS | | | | |
| | | ENTIRELY CLOSED FROM TO NO. OF DAYS | | | | |
| SLOPE | CONDITION | EROSION, SCOURING, WEATHERING, VEGETATION, REGULARITY AND PLANT. | | | | |
| | TOPOGRAPHY | HEIGHT M, GRADIENT | | | | |
| | GEOLOGY | | | | | |
| | WATER | CONCENTRATION OF SURFACE WATER, GROUNDWATER AND OTHERS. | | | | |
| RIVER OR CURRENT | TOPOGRAPHY | WIDTH M, GRADIENT | | | | |
| | BASIN | AREA | | | | |
| | DEPOSIT | KIND THICKNESS M, WIDTH M, | | | | |

TABLE 15-4 ROAD DISASTER RECORD (FORM 2)

| SHEET NO. | |
|---|---|

NAME OF TYPHOON ____________

DATE OCCURED ____________

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | | REPORTER | | DATE | |
| LOCATION | REGION | | | DISTRICT | | | |
| | ROAD | | | KM. POST | | | |
| PROPOSED REMEDIAL OR RESTRATION WORK | TYPE | | | | | | |
| | COST | | | | | | |
| | REASON | | | | | | |
| | CONSTRUCTION PERIOD PROPOSED | | | | | | |
| | PROPOSED B | | | CONCURRED BY | | | |
| PROPOSED PERMANENT COUNTERMEASURES | TYPE | | | | | | |
| | COST | | | | | | |
| | REASON | | | | | | |
| | CONSTRUCTION PERIOD PROPOSED | | | | | | |
| | PROPOSED BY | | | CONCURRED BY | | | |
| SKETCH | | | | | | | |
| DATE OF SURVEY | | | | SURVEYOR | | | |

# CHAPTER 16 MAINTENANCE OF SLOPES

## 16.1 GENERAL

The maintenance of slopes should be discussed on both of the maintenance of natural slopes and of slopes with countermeasures against slope failure.

Fundamentally, the former involves the judgement on whether any remedial measures or countermeasures are required and if any sign of deterioration or failure is observed. The periodic inspection should be performed in detail enough to give information on these judgements. When judged that a measure is required, countermeasure should be applied. The appropriate countermeasures may be found in this report in accordance with causes, types and characteristics of failures and other informations.

The maintenance of slopes with countermeasures, on the other hand, may cover i) the work to inspect conditions of countermeasures (periodic Inspection) ii) the work to keep the function of countermeasure (route maintenance) and iii) the work to execute remedial measures in case of emergency (emergency measure)

This section, therefore deals with the following:

i) Inspection on Natural Slopes and Slopes with Countermeasure)

ii) Routine maintenance for Countermeasures

iii) Emergency measures for road disasters

## 16.2 INSPECTION

### 16.2.1 Inspection on Natural Slopes

The methods and items to be inspected can be the same as mentioned in Chapter 3; IDENTIFICATION OF ROAD DISASTERS. Check Tables and Rating Method of Disaster Potential can also be utilized.

(1) Inspection Items

Items to be investigated are summarized as follows:

- Cut Slopes

  . Evidence of Failure (kind and size of failure, etc.)

  . Existing Condition of Slope including sketch of slope

. Geological condition of Slope (Weathering, crack, etc.)
. Water condition (Influence of Water)
. Other

- Embankment Slopes
  . Evidence of Failure (Kind of Slope, rainfall intensity etc.)
  . Existing condition of Slope including sketch of slope
  . Others

- Slopes Plane Fall
  . Evidence of Failure (type of fall, fallen rock size, etc.)
  . Existing condition of slope including sketch
  . Geological condition of slope (Material, Gully, Weathering, etc.)

- Slopes Plane to Landslide
  . Evidence of landslide (kind and size of landslide, etc.)
  . Topographic and Geological condition including sketch
  . Other condition (saturation, slide plane, etc.)
  . Others

- Slopes Prone to Debris Flow
  . Evidence of Debris Flow (depositional toe, size, etc.)
  . Existing Stream Condition (gradient, deposit, etc.)
  . Others

(2) Rating Items

Items to be considered in evaluating disaster potential are as follows:

- Cut Slopes Embankment Slopes and Slopes Prone to Fall
  . Topography
  . Geology
  . Slope Surface
  . Water
  . Symptom of Failure

- Slope Prone to Landslide
  - . Location
  - . Topography
  - . Geology
  - . Water
  - . Evidence of Landslide
- Slope Prone to Debris Flow
  - . Stream Gradient
  - . Deposits on River Bed
  - . Basin
  - . Plant and Vegetation
  - . Hillside

### 16.2.2 Inspection on Slopes with Countermeasures

Items to be inspected for each type of countermeasures are summarized as follows:

(1) Drainage (For surface water drainage)

Drainage condition immediately after rainfall

Deposition of sediment and drift woods inside drainage facilities

Conditions of erosion of slope surface

Conditions of slant and displacement of drainage facilities

Breaks of drainage facilities

Concaves at both sides of ditch

(Seepage Water Drainage)

Wet conditions of the slope surface immediately after rainfall

Change in the conditions of spring water from slope surface

Change in run-off from drain holes

Conditions of clogging in drain hole

Cracks and breaks at the bottom of drainage facilities

Spring water from joints of slope protection works

(2) Stone pitching, block pitching

Partial fall of cobblestones or crushed stones

Looseness of stone pitching due to weathering of stones

Outflow of backfilled earth, sinking of protection works

Slip, settlement, warping and cracking of protection works due to slope failure (such as circular sliding)

Conditions and disposal of spring water or seepage water

Conditions of drainage especially weep holes

Scouring of foundation

(3) Concrete Pitching

Cracks and slips

Conditions and disposal of spring water and seepage water

Conditions of drainage especially weep holes

Scouring of foundation

(4) Concrete block crib

Looseness and sinking of materials filled in crib

Outflow of sediment behind crib

Cracking and warping of crib

Conditions of drainage especially weep holes

Scouring of foundation

(5) Cast-in-place concrete crib

Looseness and sinking of material filled in crib

Cracking in crib

Conditions of drainage especially weep holes

Scouring of foundation

(6) Mortar and concrete spraying

Cracks

Conditions and disposal of spring water and seepage water

Warping and slipping-down

Presence of voids or gaps between the spraying and the ground

Conditions of drainage

7) Wicker

Conditions of slipping-down due to weight of deposited sediment and of floating due to erosion

Slipping-down due to inflow of rainwater and rot of stakes and wicker

8) Slope gabion

Conditions of clogging due to sediment and slipping-down

Rust of wire cylinder rust, and looseness of filled stones

9) Wire nets

Cut net and rope

Deposition of fallen rocks and sediment

Loose anchors

Loose ground behind nets, change of shape, development of weathering

10) Catch Fence

Broken or bent posts of fences, conditions of rot

Deposition of fallen rocks and sediment

Weathering and failures of foundation

Looseness of upper slope, change of shape, development of weathering

## 16.3 ROUTINE MAINTENANCE FOR COUNTERMEASURE

### 16.3.1 Drainage

Since water is the main cause of slope failure, the extra precaution should be taken for the drainage facilities. Top slope ditch; berm ditch and vertical ditch should be always inspected. Whenever fallen earth, fallen rocks and muds are observed preventing water flow, those should be removed as soon as possible. Moreover, top slope ditch of cut slope and embankment slope and berm ditch on high embankment slope greatly affect the stability of slope.

The drainage facilities sometimes cause more severe failures of slope than failures without facilities, if they are not properly functioning.

### 16.3.2 Vegetation

Vegetation becomes effective only after the growth of the plants, and their effects can be continued for many years and only if they are properly maintained. Plants are living things and must therefore be properly maintained.

The maintenance works for vegetation are summarized in Table 16-1, dividing into those until the slope will be completely covered and those for vegetation will be stabilized, in accordance with soil type.

TABLE 16-1 MAINTENANCE FOR VEGETATION

| Type of Soil | | Maintenance Until Completely Covered | Maintenance Until Stabilized |
|---|---|---|---|
| Embankment and cut of soft soil | Sandy Soil | Be cautious of poor germination. Surface must be covered as soon as possible. Erosion prevention agents to be used if vegetation is not ready to meet the heavy rainy season. | Any broken cover is dangerous. Additional fertilizer is needed quickly if any naked portions of land are observed. |
| | Clayey Soil | Slow growth. | Maintenance is almost unnecessary. Additional fertilizer is required according to the conditions of growth. |
| Cut of Hard Soil | | Shortage of water immediately after work or lack of fertilizer occurs quickly. Sufficient water spraying and additional fertilizers are needed. | A long time is required until the stabilization of vegetation. Additional fertilizer is to be continued for several years. |

Generally, lawn grasses grow poorly at the top of slopes and the top of slope should therefore be maintained.

Sandy soils are generally more suited to the growth of plants than clayey soils, but the sandy soils tend to cause defective germination due to shortage of water and delay the formation of cover, resulting in considerable damage by erosion after heavy rains. It is therefore required to spray effective curing materials during work, to cover the plants with covering material such as asphalt emulsion, to perform water spraying and curing in summer, and to give additional fertilizer as quickly as possible in order to accelerate the covering of the whole surface if the growth is very slow.

Even after the slope is not completely covered with vegetation, additional fertilizer should be applied once a year until the humid layer develops fully and is able to supply nourishment by itself. Particularly, in the case of seed spraying and seed-mud spraying, the additional fertilizer is necessary for 2 to 3 years after spraying, and the application of additional fertilizer will be necessary for more years for hard cut slopes.

## 16.4 EMERGENCY MEASURES FOR ROAD DISASTER

### 16.4.1 Cut Slopes with Vegetation

When any sign of failure is found or a failure has occurred, the scale and range of the failure should be thoroughly examined.

If the failure has partly occurred, large-scale failure may not be immediately broken out. In this case, a wicker is recommended for emergency measures.

If the scale of the failure is large, the fundamental stability method such as re-cutting should be applied. As an emergency measure at the occurrence of a failure, the cracked portion of the slope should be covered with sheets in order to prevent the infiltration of rain water and to prevent further increase of damages. An example of countermeasures for the failure that the cracks occured at the top of a slope is shown in Figure 16-1.

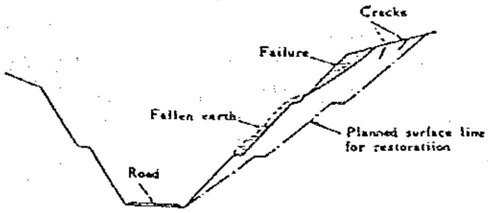
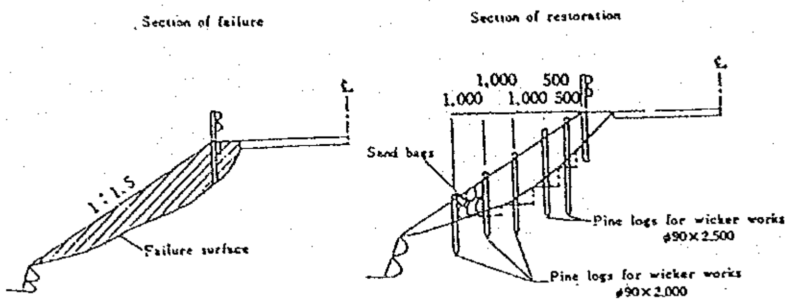



FIGURE 16-1 EMERGENCY MEASURE FOR CUT SLOPE WITH CRACKS

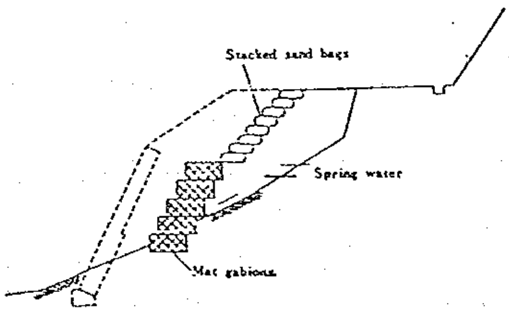
### 16.4.2 Embankment Slope with Vegetation

A slope failure tends to occur when ditches are filled up with rain water due to improper maintenance or heavy rain. In this case, the place of failure should be inspected and restored by placing and fully compacting good soil.

As emergency countermeasures, wicker and gabion works are recommended. See Figure 16-2.




(a) Wicker




(b) Gabion

FIGURE 16-2 EMERGENCY MEASURE FOR EMBANKMENT SLOPE

### 16.4.3 Emergency Measures for Slope Protection Work with Structures

Typical examples of emergency measures for slopes protected by mortar or concrete spraying, block masonry and crib are discussed.

(1) Mortar of Concrete Spray

When sprayed mortar or concrete is partially chipped off or separated from a slope due to weathering of the sprayed mortar or concrete, emergency measure using the wire net should be taken as shown in Figure 16-3. Spraying should be re-performed if damage progresses further and a more basic measure. If the ground itself has been weathered and is required to come off or if the stability of ground was lost and earth pressure acts to the concrete or mortar, concrete pitching or concrete cribwork is recommended.

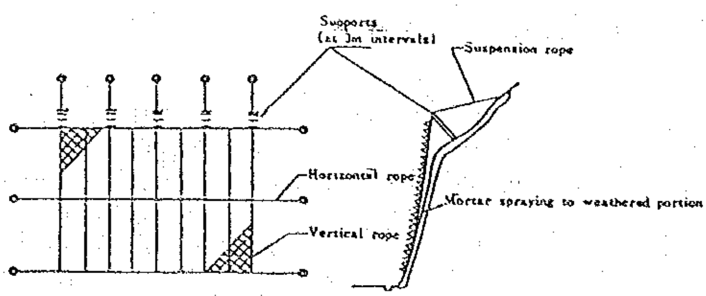



FIGURE 16-3 WIRE NET AS EMERGENCY MEASURE

(2) Block Masonry

The abnormal conditions in the concrete block masonry are observed in the form of cracks or wraping resulted from the settlement of foundation or from the action of a high earth pressure. In this case, a crib with anchor or cast-in-place crib is recommended. See Figure 16-4.

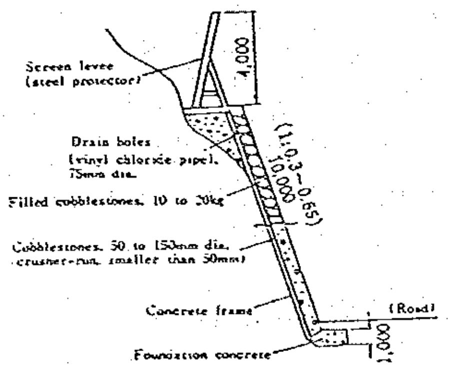



FIGURE 16-4 CAST-IN-PLACE CRIB AS EMERGENCY MEASURES

(3) Crib

Abnormal conditions of cribwork are frequently observed in the form of floated and fallen cobblestones which were originally filled into the cribwork. In this case, concrete should be filled cribwork after properly disposing spring water.

If there is sandy soil behind the cribs and spring water exists, the rear of cribs may be scoured, resulting in sinking of cribs and outflow of the filled sediment. In this case, the spring water at the rear should be properly disposed of, and the re-installation of cribs or consolidation by concrete may be recommended.

### 16.4.4 Emergency Measures for Landslide

#### (1) Prediction of Occurrence of Landslide

When cracks or depression are observed on the road surface, or the upper or lower portion of a slope and these are still developing, it may be a sign of landslide and therefore, the probable time of landslide occurrence should be predicted.

The rate of expansion of cracks is related to the scale of landslide and soil type. For example, clayey soil slips very slowly even if the strain velocity is relatively high, while sandy soil and weathered rock tend to slip within a short time. If the plasticity of a soil mass increases, the soil mass tends to slip more slowly even though the ground has been considerably deformed. The time from the start of cracks to the start of slip becomes shorter and acceleration of the slip becomes larger in the order of rock, weathered rock, sand, sediment and clay. Clayey slopes are relatively stable except during rainfall even though the speed of movement is about 1 mm/day. However, on slopes containing bedrock-like soil masses, slip progresses very quickly due to local severe rain or the like.

With respect to the relation with topography, slips occurs easily if the tail portion of landslide is exposed on the slope and cliff failure or the like have occured in nearby area. On the other hand, slips do not occur easily if an upheaval has already occured at the tail portion of the landslide area. In the former case, the failure at the tail portion due to cliff failure will lower the factor of safety of the whole of landslide area, so that a landslide in the whole area may be triggered, thereby creating a very dangerous state. Thus, full precautions must be taken if the landslide surface has been exposed after cutting or if the cut slope has subsequently collapsed.

#### (2) Survey for Landslide

The following survey should be conducted in order to clarify the causes and features of landslides and to take proper emergency countermeasures:

- To determine the history of landslides of the slope under consideration, and the distribution and characteristics of landslides in the surrounding areas.

- To determine the location and scale of cracks in detail, the presence of tension cracks and compression cracks, places of spring water, and the transition point of of the gradient after performing investigation of the ground surface.

- To determine the scale of the landslide and its generating mechanism and to predict the future activities of landslide after surveying the geological structure of landslide area, the ground surface fluctuation, the distribution of groundwater, and the sliding surface.

(3) Emergency restoration

If a landslide occurs while the road is in service, emergency road restoration work must be carried out immediately. In this case, the following minimum precautions should be taken to prevent further damage due to the re-occurrence of landslide.

(a) Roads should be detoured away from the landslide area, and emergency restoration should be performed.

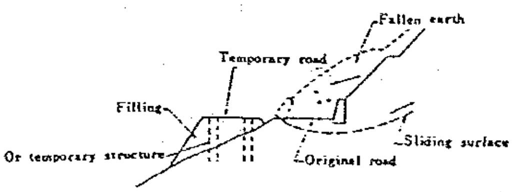



FIGURE 16-5 DETOUR METHOD AS EMERGENCY RESTORATION FOR LANDSLIDE

(b) If the detour is not possible, emergency restoration may be carried out on the collapsed earth without removing it though this may increase the longitudinal gradient of detour.

To remove collapsed earth at the toe of landslide is not advisable because it acts as a counterweight against the landslide. See Figure 16-6.

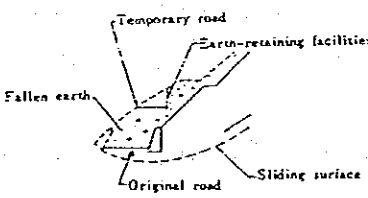



FIGURE 16-6 DETOUR ON COLLAPSED EARTH WITH EARTH RETAINING WALL

(c) If it is unavoidable to perform emergency restoration after the removal of collapsed earth from the road, earth retaining facilities should be installed at the mountain side so as to minimize the amount of earth removal to a minimum. See Figure 16-6.

(4) Emergency Measures

Emergency measure work is taken to maintain the damage to a minimum by reducing the speed of the movementof landslide and by stabilizing the slope, but the methods of work must be simple ones that can be done easily at low cost. Also, in the determination of emergency measures, the future permanent measures should be taken into account at the same time. The typical methods of emergency measures are described below.

(a) Drainage for Surface Water

Open-cuts are desirable to drain water in the pond of swamp which exists in the upper portion of slope. Cracks should be covered with vinyl sheets to prevent the increase of seepage water, and also spring water and water in the channel or swamp should be drained with vinyl pipe to prevent infiltration.

(b) Drainage for groundwater

If the landslide motion is still active, drainage by the lateral boring should be performed. Several bore holes should be drilled across the cracks and about 10 to 20 m beyond the cracks at 5 to 10 m intervals in the direction of cracks. Also, water near the outlet of each bore hole should be very carefully drained. See Figure 16-17.

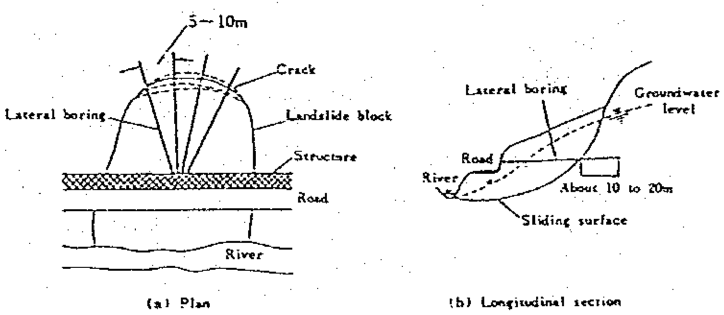



FIGURE 16-7 DRAINAGE FOR GROUNDWATER AS EMERGENCY MEASURE

(c) Earth retaining works

If the tail portion of landslide area is likely to collapse or if a failure is likely to enlarge, earth retaining works should be performed with wire cylinders or mat gabions at the tail portion.

(d) Earth removal

It is very effective in many cases to horizontally cut the soil mass by several meters at the head of the landslide area. See Figure 16-8.

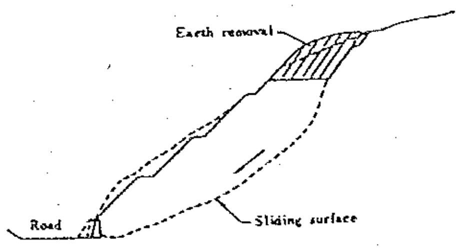



FIGURE 16-8 EARTH REMOVAL AS EMERGENCY MEASURE

However, this horizontal cut method should not be used if the head portion of the cut may become unstable or if it is located at the tail of the secondary landslide area.