CHAPTER 4

COUNTERMEASURES AGAINST ROCK SLOPE COLLAPSE

4.1 General

Rock slope collapse is a rapid movement of rock blocks or rock mass on a steep rock face, ranging in size from individual rock fall to small-scale rock mass failure. Because of its high speed, the rock slope collapse can cause considerable damage to vehicles, death or injury to drivers and passengers, and economic loss due to road closures.

For this reason, a large number of road sections have required countermeasures against rock slope collapse in mountainous zones, especially along long, large slopes and steep cliffs. Since rock slope collapses along the national highway are mainly in the form of rock falls, this chapter focuses considerations on planning and design countermeasure works against rock falls.

Moreover, Chapter 5 of this Guide III, “Countermeasures against Landslides” may be applied for the stabilization of rock slopes and large-scale rock slope collapses. Reference is made to Chapter 3 of this Guide III for the design of retaining walls.

4.2 Calculation of Impact Force of Falling Rocks

Countermeasures against rock falls shall be designed with the assumption that the external forces are to be safely borne by each countermeasure and by using these as design external forces.

4.2.1 Motion Mechanism of Rock Falls

The motion of falling rocks on a steep slope is divided into three types, namely, sliding, rolling and bouncing motions, as illustrated in Figure 4.1. These motion patterns change into other forms, as shown in Figure 4.2.

In designing countermeasures for rock falls, the weight, speed, direction and position of the falling rocks is determined on the basis of the survey and/or history of rock falls in the specific area.

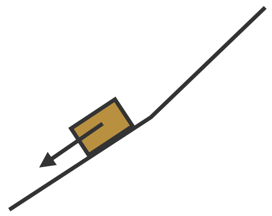
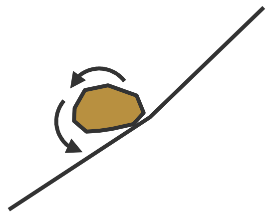
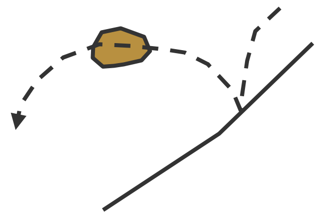
Motion pattern	Sliding	Rolling	Bouncing
Diagram			
Characteristics	Slides down slopes	Rolls down a slope	Bounces in the air and moves downwards
Falling speed	Slow	Average	Fast
Bounce height	Zero	Small	Great

Figure 4.1 Illustration of Motion Mechanism of Falling Rocks

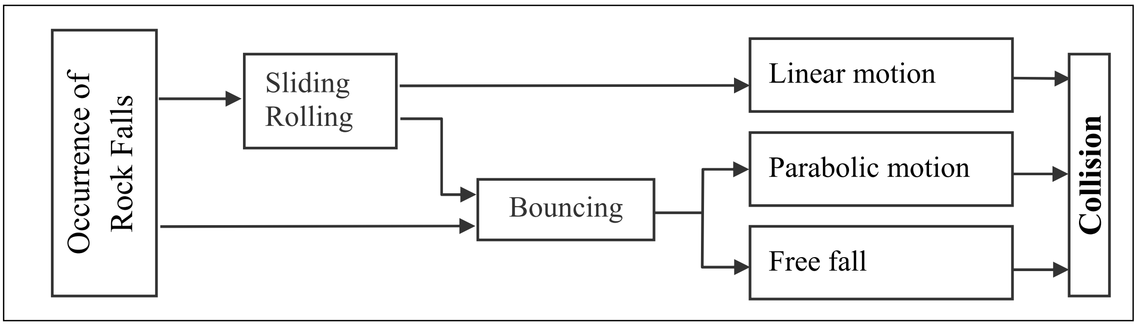


Figure 4.2 Motion Pattern of Falling Rocks

Source: Modification from reference No. 4 MANUAL FOR COUNTERMEASURES AGAINST ROCK FALL, Published by Japan Road Association, June 2000.

4.2.2 Velocity of Falling Rocks

Among the three motion patterns, the velocity of falling rocks moving down a slope is highest during the bouncing motion. The velocity of a falling and bouncing rock block along a slope is less than that of the freely falling rock in the air from the same height.

Empirically, the following relationship is used to calculate the velocity of a falling and bouncing stone.

$$V = \alpha \times \sqrt{2gh} \quad \cdots\cdots (4.1)$$

$$\alpha = \sqrt{1 - \frac{\mu}{\tan\theta}} \quad \cdots\cdots (4.2)$$

Where,

V= Velocity of a falling and bouncing stone (m/s)

$\sqrt{2gh}$ = Velocity of a freely falling rock in the air (m/s)

α= Coefficient of velocity reduction

g= Gravity acceleration (m/s^2)

H= Falling height (m)

μ= Equivalent coefficient of friction of the slope

θ= Gradient of the slope (degrees)

Table 4.1 gives the recommended coefficient of friction based on experiments for different kinds of slopes.

Table 4.1 Kinds of Slopes and Values of the Equivalent Coefficient of Friction

Class	Characteristics of Rock Falls and Slopes	Value of μ Used for Design	Range of μ Obtained from Experiments
A	1) Hard rocks, round shapes, 2) Small concave and convex rocks, no standing trees.	0.05	0.0 ～ 0.1
B	1) Soft rocks, square to round shapes, 2) Medium to large concave and convex rocks, no standing trees.	0.15	0.11 ～ 0.20
C	1) Sediment, talus, round to square shapes, 2) Small to medium concave and convex rocks, no standing trees.	0.25	0.21 ～ 0.30
D	1) Talus, talus with boulders, square shapes, 2) Medium to large concave and convex rocks, with or without standing trees.	0.35	0.31 or more

Source: Modification from
Reference No. 4 MANUAL FOR COUNTERMEASURES AGAINST ROCK FALL, Published by Japan Road Association, June 2000.
Reference No. 5 DESIGN GUIDE －EARTHWORKS, Published by Japan Highway Public Corporation, May 1998.

4.2.3 Kinetic Energy of Falling Rocks

When designing countermeasures for rock falls, it is necessary to calculate the kinetic energy of the falling rocks by means of energy calculations.

Kinetic energy of falling rocks is expressed by the sum of the linear velocity energy and rolling energy, as follows:

$$E = E_v + E_r \quad \cdots\cdots (4.3)$$

$$E = (1+\beta)\times(1-\frac{\mu}{\tan\theta})\times m \times g \times H \quad \cdots\cdots (4.4)$$

Where,

E= Kinetic energy of falling rocks (t/s^2)

E_v= Linear velocity energy of falling rocks (=1/2mV^2)

E_r= Rolling energy of falling rocks

m= Mass unit of falling rocks (t)

β= Rolling energy ratio (=E_r/E_v) and $(1+\beta)\times(1-\frac{\mu}{\tan\theta})\leq 1.0$

In the above equation, the value of β is generally in the range of 0.1 to 0.4, and 0.1 shall be used most frequently for design calculations.

From the results of experiments conducted, the height of the bounce of the falling rocks increases as the height of freefall becomes larger, but does not exceed 2 meters in most cases. Therefore, a bounce height of 2 meters is frequently used as the acting position of the design external force for countermeasure design.

4.2.4 Impact Force of Falling Rocks

Rock fall protection works shall be designed by converting the impact force of falling rock to a static force and by using the allowable stress method instead of the energy calculation method.

Since the impact force of falling rocks is considerably large, it is advantageous to use shock-absorbing materials to economically design these countermeasures, such as sand mats.

If the shock absorbing material is assumed to be an elastic body with a semi-infinite thickness and the specific gravity of the falling rock is assumed to be 2.6, then the maximum impact force P_{max} of the falling rock can be expressed by the following equation:

$$P_{\max} = 2.108\times(m\times g)^{2/3}\times\lambda^{2/5}\times H^{3/5} \quad \cdots\cdots (4.5)$$

Where,

Pmax= The maximum impact force (kN)

λ= Lame's constant (kN/m2) (referring to Table 4.2)

H= Height of freefall of rocks (m)

Table 4.2 Lame's Constant of Shock Absorbing Materials

Material conditions	Constant (kN/m^2)	Remarks
1. Very soft	1,000	
2. Soft	3,00 to 5,000	
3. Hard	10,000	

Note): 1 t/m^2 = 10 kN/m^2.

Source: Modification from
Reference No. 4 MANUAL FOR COUNTERMEASURES AGAINST ROCK FALL, Published by Japan Road Association, June 2000.

4.3 Selection of Countermeasures

4.3.1 Classification of Countermeasures

Countermeasures for rock falls are classified into rock fall prevention works and rock fall protection works. Rock fall prevention works involve the rock fall source, such as removal of the rocks and crib work, while rock fall protection works aim at protecting the relevant objects from the damage of rock fall. Table 4.3 includes the most common countermeasures divided into these two categories.

Table 4.3 Classification of Countermeasures for Rock Falls

CLASSIFICATION			TYPE OF WORK
ROCK FALL PREVENTION WORK	1. EARTH WORK	Earth Work	Removal
			Cutting
	2. DRAINAGE	Surface Drainage	Drainage ditches
	3. SLOPE WORK	Pitching Work	Stone pitching
			Block pitching
			Concrete pitching
		Shotcrete	Mortar spraying
			Concrete spraying
		Cribs	Concrete block cribs (precast)
			Cast-in-place concrete cribs
			Shotcrete cribs
		Anchoring	Ground Anchors
			Rock bolt
ROCK FALL PROTECTION WORK	4. WALLS AND OTHER STRUCTURES	Catch Work	Catch fill and ditches
			Catch walls (concrete and gabion)
			Catch fences
			Catch nets
	5. PROTECTION WORK	Shed	Rock sheds
	6. OTHERS	Avoiding Problematic Works	Route relocation
			Bridges, tunnels

4.3.2 Criteria for Selection of Countermeasures

Adequate and effective measures for preventing rock fall are selected in consideration of topographical and geological conditions, vegetation, rock fall history, and effects of the countermeasure by predicting the size and height of the rock fall. Figure 4.3 gives a selection of countermeasures for rock falls.

The following criteria are used for the selection of countermeasures.

a) If there is a danger of rock fall, in principle, the rock fall source should be removed. When these methods are difficult to implement, other methods should be adopted.

b) In selecting countermeasures, it is essential to consider not only the conditions of slope and rock fall, but also the road structure, traffic conditions and ground conditions.

c) It is necessary to combine various kinds of works together because the function of the various types of countermeasures for rock falls is limited, as shown in Figure 4.4.

d) Countermeasures for rock falls are designed by assuming the external forces to be safely borne by each work and by using this as design external forces.

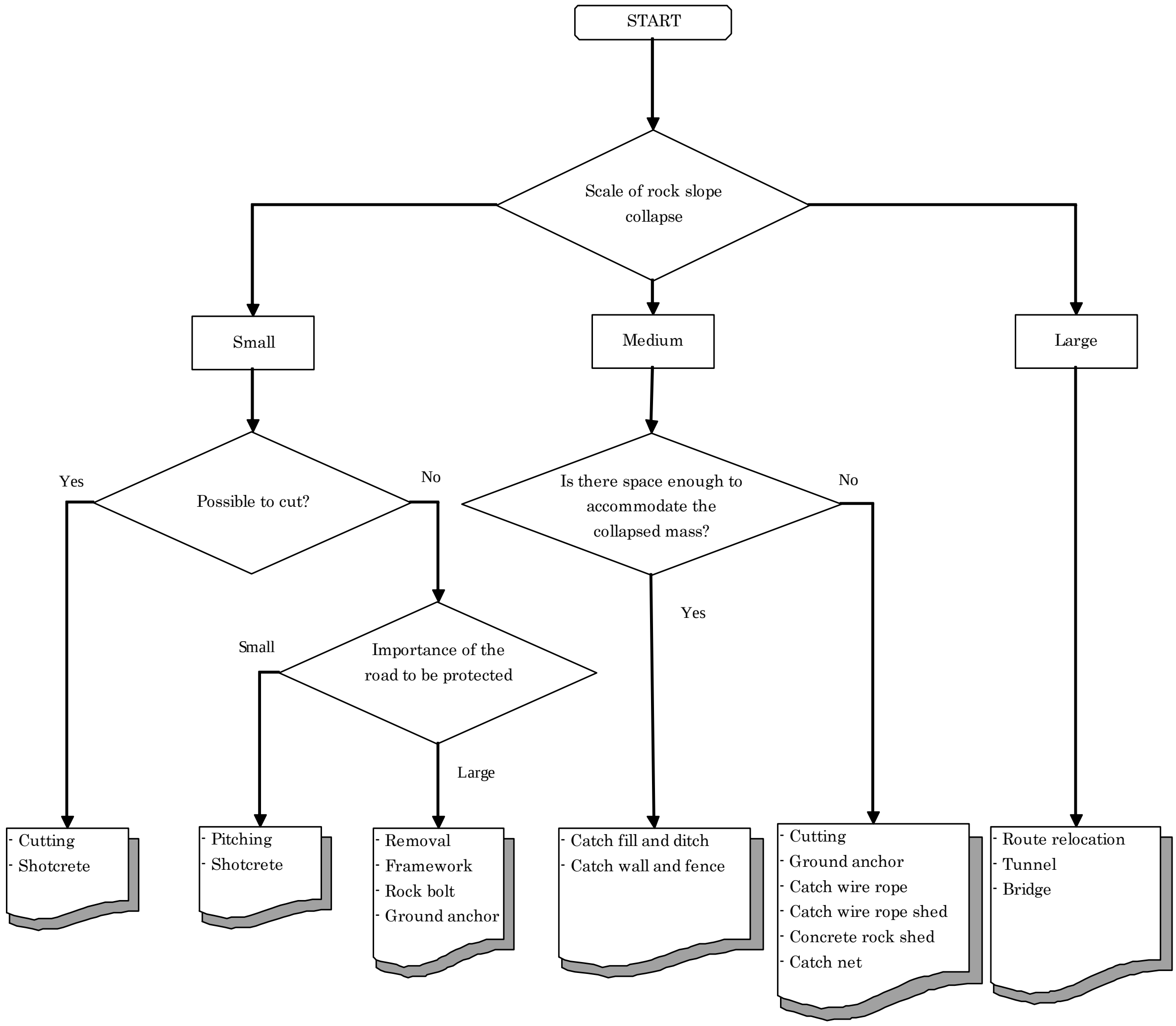


Figure 4.3 Selection Flowchart of Countermeasures for Rock Falls

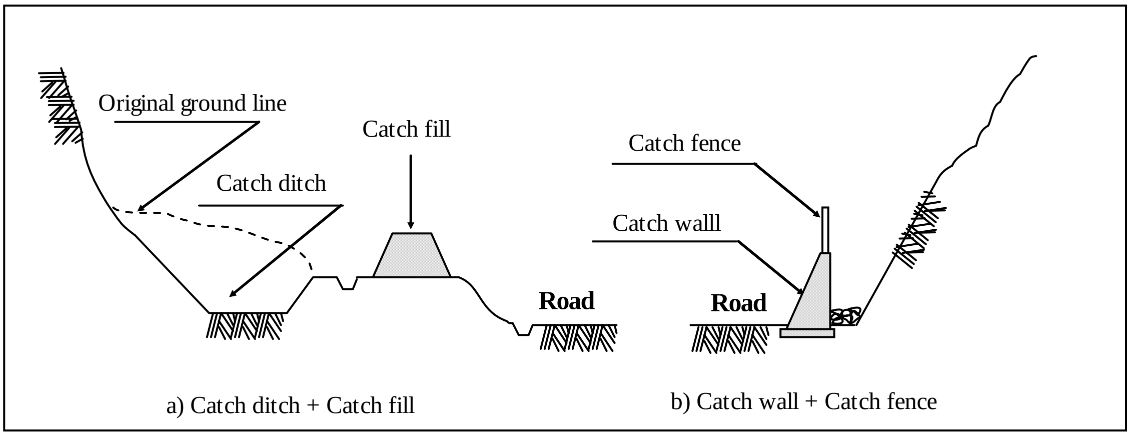


Figure 4.4 Combinations of Countermeasures

For designing rock fall protection works, the following objectives must be considered: 1) effectiveness in absorbing the energy of falling rocks, 2) effectiveness in changing the direction of falling rocks to direct them to fall in areas where they will inflict no or minimal damage, and 3) effectiveness in reducing the impact force and to halt the motion of the rocks. In selecting the proper countermeasures, their effectiveness and capability to resist the energy of falling rocks is to be carefully considered. In general, the effectiveness of the protection works in absorbing the energy of falling rocks is in the following order from least to greatest: rock fall catch nets, rock fall catch fences, rock fall catch walls and rock sheds.

On the other hand, in selecting rock fall prevention works, care must be taken to ensure an appropriate combination of protection works. Effective combinations of countermeasures against rock falls are often determined by the function, durability, construction ease, construction cost and maintenance requirements of each type of countermeasure, as well as the conditions of the roads and slopes.

Table 4.4 summarizes the application of these countermeasures.

Table 4.4 Application of Countermeasures for Rock Falls

	Types of Work	Durability	Maintenance	Construction Ease	Construction Cost	Degree of Safety
ROCK FALL PREVENTION WORK	Removal	◎	◎	△	○	◎
	Cutting	○	○	○	○	○
	Seed spraying	○	○	◎	◎	△
	Seed mud spraying	○	○	◎	◎	△
	Turfing (Sodding)	○	○	◎	◎	△
	Drainage ditches	○	○	○	◎	○
	Stone pitching	◎	◎	○	◎	○
	Block pitching	◎	◎	○	◎	○
	Concrete pitching	◎	◎	○	◎	○
	Mortar spraying	○	○	◎	◎	○
	Concrete spraying	◎	◎	○	◎	○
	Concrete block cribs	◎	○	○	◎	○
	Cast-in-place concrete cribs	◎	◎	○	○	◎
	Shotcrete cribs	◎	○	○	◎	○
	Ground Anchors	◎	◎	△	△	◎
	Rock bolts	◎	◎	△	△	◎
ROCK FALL PROTECTION WORK	Catch fill and ditches	◎	○	◎	○	○
	Catch walls	◎	○	◎	◎	○
	Catch fences	○	○	◎	◎	○
	Catch nets	○	○	◎	◎	○
	Rock sheds	◎	◎	△	△	◎

Note): (1) This table is based on the Japanese experience modified by reviewing Philippine road conditions.
(2) ◎ = Very good or very easy, ○ = Good or easy, △ = Good or easy in some cases.

Source: Modification from
Reference No. 4 MANUAL FOR COUNTERMEASURES AGAINST ROCK FALL, Published by Japan Road Association, June 2000.

4.4 Design of Main Countermeasures

4.4.1 Removing and Cutting

This method involves 1) removal of small-scale potentially unstable rock masses, 2) removal of rock overhangs by trimming/blasting and 3) removal of loose individual rock debris by hand scaling. This method is preferred, because it eliminates the hazard and no future maintenance is required.

(1) Purposes

The method is used to directly remove the potentially unstable rock, thereby eliminating the hazard.

(2) Design considerations

In planning the removal of unstable rock masses, it is important to consider the rock character. For example, when rocks are highly degradable and strongly susceptible to weathering and jointing, such as shale, the removal of loose rock from the surface will only start a new cycle of weathering and instability.

Moreover, similar to cut work in soil slopes, the work should not undermine other potentially loose rock blocks or unstable rock masses. Figure 4.5 gives some examples of the removal works.

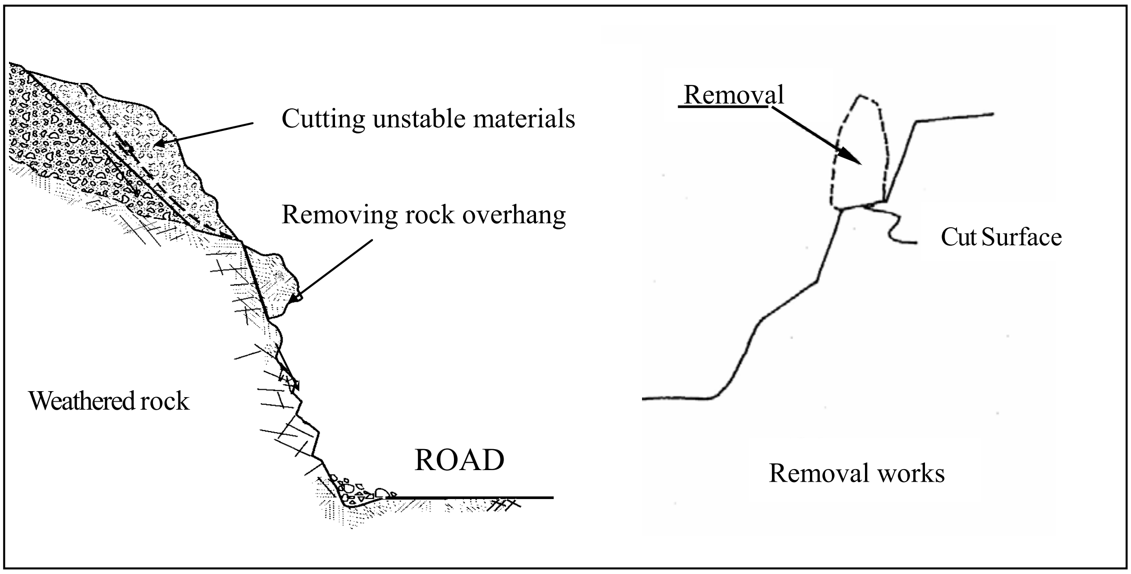


Figure 4.5 Examples of Rock Removal

4.4.2 Rock Fall Catch Nets

Rock fall catch nets consist of nets and wire rope and include two major types: cover type and pocket type. The cover type rock fall catch net is able to restrain loose rocks by means of the net tension and friction between the rocks and the ground. The pocket type rock fall catch net is installed with the upper end of the net separate from the surface of the slope. Falling rocks from the upper slope are caught in the gap between the net and slope.

(1) Purpose

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

(2) Design considerations

Figure 4.6 shows the design procedure. Figure 4.7 gives an example of pocket type rock fall catch nets. When designing the pocket type rock fall catch net, the assumed point of collision of the falling rocks is at the center of the two posts and at the center between the top and second horizontal ropes.

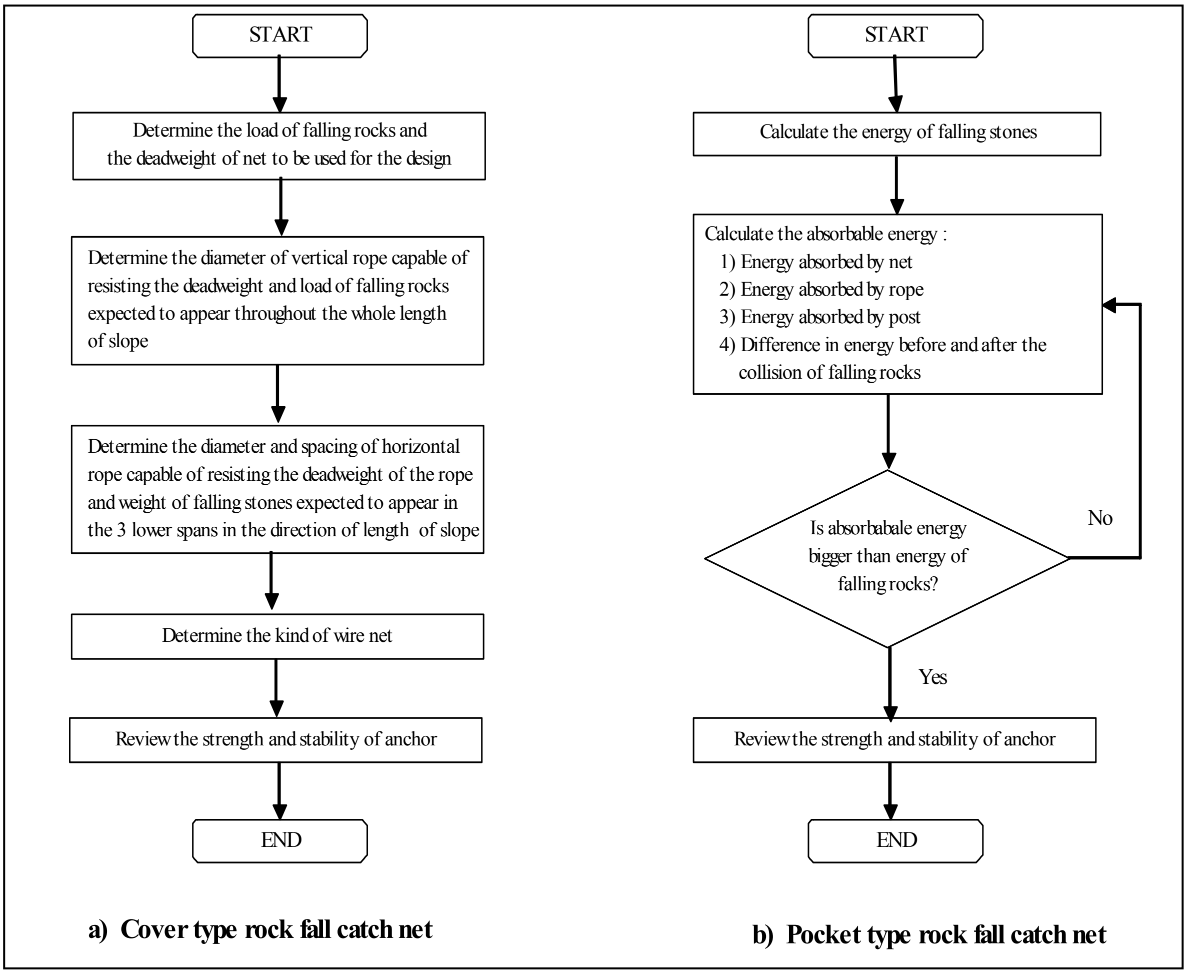


Figure 4.6 Design of Catch Nets

Source: Modification from
Reference No. 4 MANUAL FOR COUNTERMEASURES AGAINST ROCK FALL, Published by Japan Road Association, June 2000.

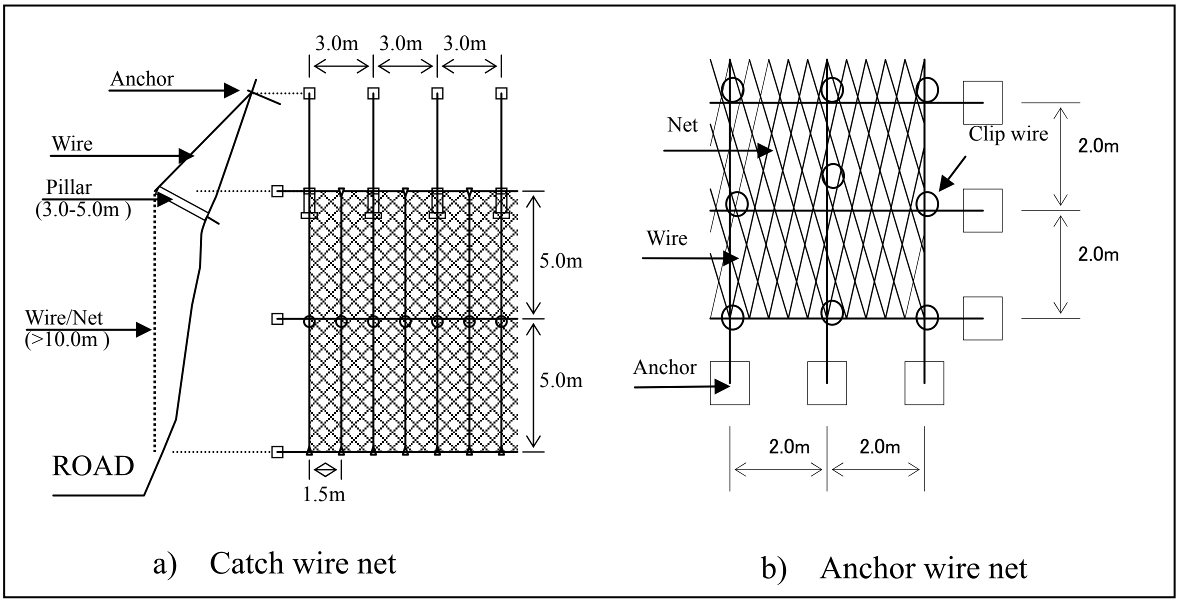


Figure 4.7 Example of Pocket Type Rock Fall Catch Net

4.4.3 Rock Fall Catch Fences

Rock fall catch fences consist of fences made of net and wire rope attached to steel pipes or H-section posts. This type of fence has the capacity to absorb the energy of falling rocks.

(1) Purpose

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

(2) Design considerations

Figure 4.8 gives the design flowchart for rock fall catch fences. The design of a rock fall catch fence involves consideration of the energy of the falling rock and the energy absorbable by the fence, as given in Equation (4.6) and involves the following steps.

$$E_T = E_R + E_P + E_N \quad \cdots\cdots (4.6)$$

Where,

E_T= Energy that can be absorbed by the rock fall catch fence

E_R= Energy absorbed by the wire rope

E_P= Energy absorbed by the posts

E_N= Energy absorbed by the nets

a) Determine the yield tension $\boldsymbol{T_y}$ corresponding to the diameter of the wire ropes.

b) Find the force $\boldsymbol{R}$ acting on the posts from $\boldsymbol{T_y}$ of the wire ropes. The two wire ropes are assumed to be capable of resisting the force of the falling rocks.

c) Find the force $\boldsymbol{F_y}$ required to form a plastic hinge at the bottom of the intermediate post.

d) Compare forces $\boldsymbol{R}$ and $\boldsymbol{F_y}$ and calculate the energy that can be absorbed by the fence.

The height of the point of impact is generally considered to be two-thirds of the height of the fence, and falling rocks are assumed to collide with the wire ropes between posts for the design.

In designing the foundation (retaining wall or direct foundation) for the fence, loads due to falling rocks should be considered in addition to the earth pressure and dead load.

START

Conditions of falling rocks

Determine the falling rocks to be used for design:
1) Weight of falling rocks (W)
2) Falling height of fall rocks (H)

Calculate the energy of falling rocks (Er):
1) $Ei=(1+\beta)(1-\mu/\tan\theta)m \cdot g \cdot H$

Conditions of slopes

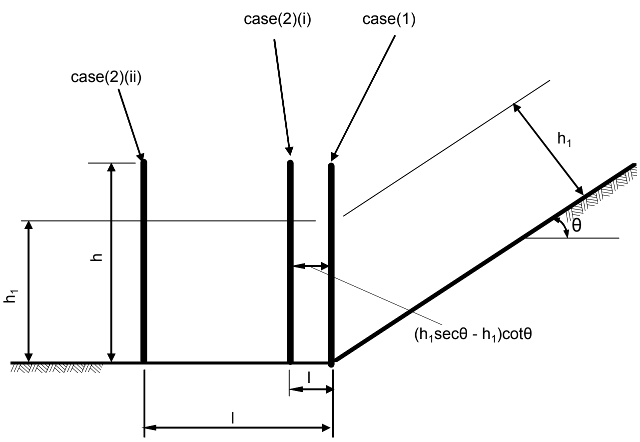
Determine the height of rock fall catch fence:
1) With flat area (Case 1)
$h>h1\sec\theta$
2) With small flat area of l in width (Case 2)
i) When $0<l<(h_1\sec\theta-h_1)\cot\theta$, $h>(h_1\sec\theta-l\tan\theta)$
ii) When $l>(h_1\sec\theta-h1)\cot\theta$, $h>h_1$

Determine the section of post, and number and number of ropesso as to satisfy the following condition:
$E_T > E_i$

When $E_T \leqq E_i$, consider seperately

Determine the shape and size of the foundation, so as to prevent the foundation from being broken even after plastic deformation of the posts.

END



E_i= Energy of falling rocks for design

m= Unit mass of falling rocks

H= Free fall height

θ= Gradient of a slope (degrees)

μ= Equivalent coefficient of friction of the slope

β - Rotational energy ratio

h_1- Bounce height of falling rocks

l: Width of flat area

E_T: Absorbable energy by fence

g: Gravity acceleration

Figure 4.8 Design Flowchart for Rock Fall Catch Fences

Source: Modification from
Reference No. 4 MANUAL FOR COUNTERMEASURES AGAINST ROCK FALL, Published by Japan Road Association, June 2000.

Table 4.5 Standard Specifications for Rock Fall Catch Fences

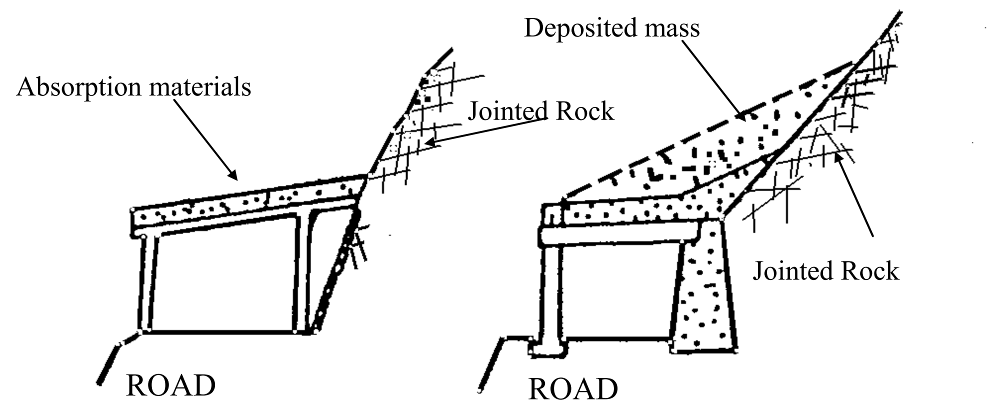
Height of Fence (m)	Post			Wire Rope	Wire Net
	Size and Type	Sectional Coefficient (cm^3)	Interval (m)		
1.5	H-200×100×5.5×8	181	3.0	3×7G/0, ϕ 18 Sectional area: $A = 129\ mm^2$ Elastic coefficient $E_w = 10^5\ N/mm^2$ Fracture strength $T_b = 157\ kN$ Yield strength $T_y = 118\ kN$	diamond shape ϕ 3.2×50×50
2.0					
2.5					
3.0					
3.5					
4.0	H-200×100×8×12	472			
4.5					
5.0					
5.5					
6.0					

Source: Modification from
Reference No. 4 MANUAL FOR COUNTERMEASURES AGAINST ROCK FALL, Published by Japan Road Association, June 2000.

4.4.4 Rock Sheds

Rock sheds are reinforced concrete or steel structures covering a road and can be subdivided into four types from the structural viewpoint; portal (gate) type, retaining wall type, arch type and pocket type (Figure 4.9).

This method is very costly and would only be planned and designed in areas of extreme rock fall hazard.



a) Portal Type b) Retaining Wall Type

Figure 4.9 Types of Rock Sheds

(1) Purpose

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

(2) Design considerations

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

The design procedure generally involves the following steps shown in Figure 4.10. The kinds and combination of loads to be considered in the design of the rock shed are shown in Table 4.6.

START

↓

Step 1: Destermine Conditions of rock falls and slopes

1) Conditions of rock falls
   a) Scale of rock fall, b) falling height, c) Size of falling rocks, d) Others
2) Conditions of slopes
   a) Geology, b) Gradient of slope, c) Vegetation of slope, d) Height of slope, e) Others

↓

Step 2: Calculate loads to be considered in the design

1) Kinds of loads
   a) Dead load, b) Earth and water pressures, c) Weight of deposited materials, d) Impact load of falling rocks, e) Earthquake skock
2) Combination of loads
   a) In normal case, b) In seismic case, c) At occurrence of rock falls, d) Others (when being impacted by car) if necessary

↓

Step 3: Calculate and design the strucutes

1) Study on alternative structures
   a) Upper structures, b) Lower structures at mountain side, c) Lower structure at valley side
2) Structural calculations
   a) Check the stability of foundation, b) Check the allowable strength of each kind of materials to be used

↓

END

Figure 4.10 Design Procedure for Rock Sheds

Furthermore, in the conventional design method, the dispersion of loads on the roof slab of the rock shed is simplified, as shown in Figure 4.11.

Table 4.6 Combinations of Loads for Design of Rock Sheds

	Dead load	Earth pressure	Water pressure	Weight of Deposited material	Rock fall	Earthquake	Impact by car	Coefficient of increase in allowable unit stress
1) In normal case	○	○	△	△				1.00
2) At occurrence of rock fall	○	○	△		○			1.50
3) In seismic case	○	○	△	△		○		1.50
4) At impact by car	○	○	△	△			○	1.50

Note: 1) Three cases, namely normal, seismic and rock fall cases must be combined in the design.
2) ○ = Loads expected must be considered in any case, △ = Loads should be considered according to site conditions.

Source: Modification from
Reference No. 4 MANUAL FOR COUNTERMEASURES AGAINST ROCK FALL, Published by Japan Road Association, June 2000.

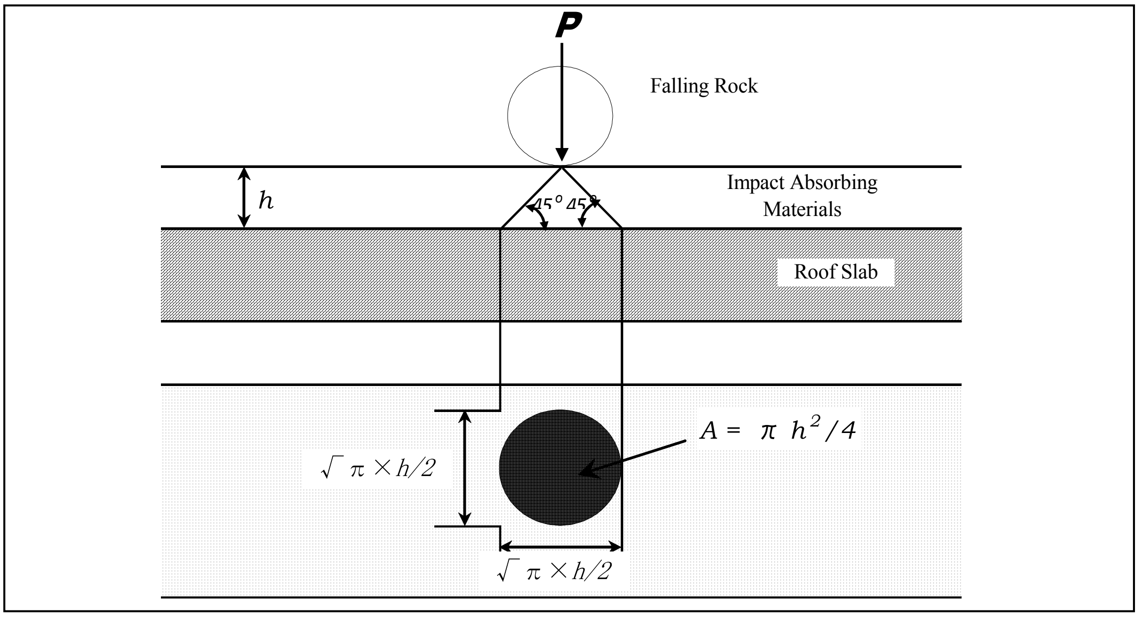


Figure 4.11 Loading Method for Impact Load

Source: Modification from
Reference No. 4 MANUAL FOR COUNTERMEASURES AGAINST ROCK FALL, Published by Japan Road Association, June 2000.

4.4.5 Catch Fill and Ditches

This method is commonly used and is cost-effective when a large-scale rock fall is expected. However, there must be sufficient space between the unstable slope and the road to receive the full volume of the potential rock fall. Figure 4.12 shows the conceptual arrangement of a catch fill and ditch.

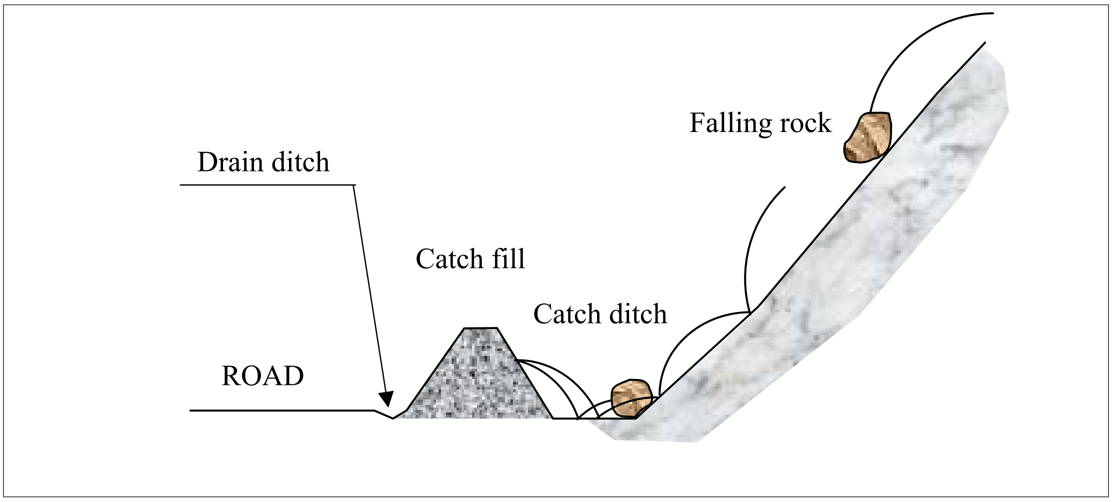


Figure 4.12 Diagrammatic Layout of Catch Fill and Ditch

(1) Purpose

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

(2) Design considerations

Apart from embankment stability analysis, design considerations are concerned with the shape and dimensions of the catch fill and ditch in terms of their capacity for catching and accommodating falling rocks.

In order to ensure the capacity of the catch fill and ditch, a drainage ditch is installed along side.

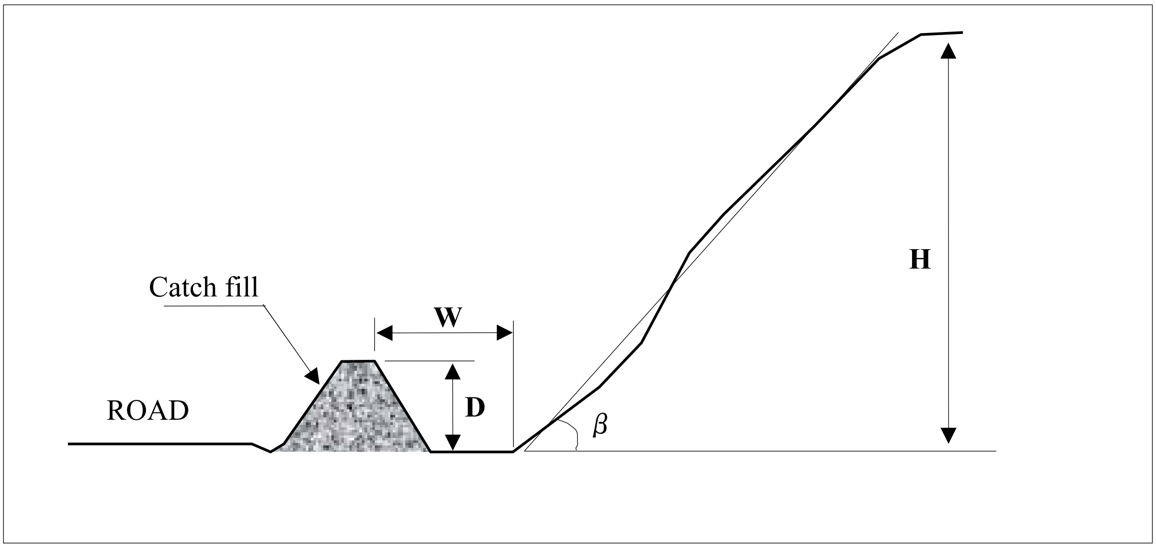
Table 4.7 lists the recommended shapes and dimensions of these structures in relation to the slope gradient.

Table 4.7 Recommended Shapes and Dimensions of Catch Ditches (Modified from Reference No. 4)

Gradient of slope β (Vertical to Horizontal)	Height of slope H (m)	Width of ditch W (m)	Depth of ditch D (m)
Nearly vertical (90°)	5 to 10	4	1.0
	10 to 20	5	1.5
	Over 20	6	1.5
1:0.25 to 1:0.3 (76°～73°)	5 to 10	4	1.0
	10 to 20	5	1.5
	20to 30	6	2.0
	Over 30	8	2.0
1:0.5 (63°)	5 to 10	4	1.5
	10 to 20	5	2.0
	20 to 30	6	2.0
	Over 30	8	2.5
1:0.75 (53°)	0 to 10	4	1.0
	10 to 20	5	1.5
	Over 20	5	2.0
1:1.0 (45°)	0 to 10	4	1.0
	10 to 20	4	1.5
	Over 20	5	2.0

Note: The symbols in the above table are the same as those in the figure below.

Source: Modification from
Reference No. 4 MANUAL FOR COUNTERMEASURES AGAINST ROCK FALL, Published by Japan Road Association, June 2000.



CHAPTER 5

COUNTERMEASURES AGAINST LANDSLIDES

5.1 General

Landslides involve large-scale areas with different movement blocks. Stabilization plans relevant to landslides should be drawn up for countermeasures for each movement block, as well as overall plans for increasing the safety of the area as a whole.

For this reason, this chapter provides key points for reconnaissance for formulating the landslide countermeasure plan and general guidelines on the stability analysis of the slopes. It focuses on design considerations for the main countermeasures for landslides.

Furthermore, the general guideline for surface drainage works and design of standard slopes presented in Chapter 3 is also applicable to landslides. Reference is made to Chapter 6 for guideline on the design considerations for reinforced earth walls. Reference is also made to Chapters 8 and 9 for guidelines on protection of the toe of a potential landslide, especially when a landslide may be triggered by river or coastal erosion.

5.2 Key Points of Reconnaissance for Formulating Landslide Countermeasure Plans

Reconnaissance is implemented at the potential landslide sites for estimating and referring the following items:

a) Estimation of extent of potential landslide;

b) Division of movement blocks;

c) Drafting of further survey plans; and

d) Investigations regarding urgent measures

(1) Estimation of extent of potential landslide;

The extent of the area subject to landslide activity includes the area where landslide activity may be expected in the future, together with the area subject to damage from landslide activities. These areas are estimated from various indications occurring in the landslide area (cracks, steps, settlements, bulges, deformation of structures), as well as the microtopographical conditions (distribution of depressions, lakes, spring water, etc., and geological conditions (outcrop of base rock and sliding surface).

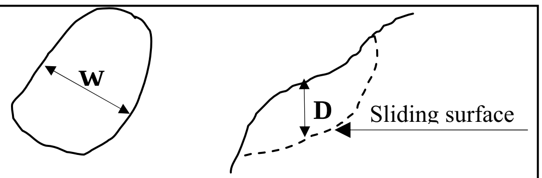
The boundaries (width and length) of potential landslide areas can be estimated from the distribution of cracks, and the depth of the sliding surface is estimated based on the following empirical relationships:

D = W×1/7～1/10 ·· (5.1)

Where,

D= Depth of sliding surface,

W= Width of landslide area.



(a) Plan (b) Section

(2) Division of landslide blocks

The landslide area as a whole is subdivided into a number of movement blocks. The division is based on observation of the distribution of landslide heads and cracking conditions. The distribution and location of cracks provides clues to identifying the activity, shape of sliding surfaces, direction of movement, and tension or compression zones.

(3) Drafting of further survey plans

When the reconnaissance results are not sufficient for the formulation of the landslide countermeasure plan, further surveys such as geological surveys and ground condition surveys should be conducted. The survey plan is formulated on the basis of the above estimated results.

(4) Investigations regarding urgent measures

Once inferences have been made on the movement mechanism and movement blocks, emphasis shall be given to the movement blocks for planning urgent measures.

5.3 Stability Analysis of Slopes

5.3.1 Stability Analysis

Stability analysis should be conducted to determine the scale and quantity of landslide countermeasure works required to maintain the stability of the landslide slope and so ensure the target safety factor. The Swedish slice method (also called ordinary slice method) is used for stability analysis of a landslide slope, as follows:

$$Fs = \frac{(\Sigma N - \Sigma U) \times \tan\phi + C \times \Sigma L}{\Sigma T} \quad \cdots\cdots \quad (5.2)$$

Where,

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

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

α (°) = Angle of the base of the slice to the horizontal

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

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

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

φ (°) = Internal friction angle of sliding surface

Equation 5.2 is used for the calculation of the quantity of works required, for example:

(1) Piling works

The additional shear strength required to satisfy the proposed safety factor for piling works is calculated from Equation 5.3 and schematically shown in Figure 5.1.

$$P_R = PFs \times \sum T - \sum(N-U)\tan\phi - C \times \sum L \quad \cdots\cdots (5.3)$$

Where,

P_R(kN/m)= Required preventive force to be provided by the pile

PFs= Proposed factor of safety

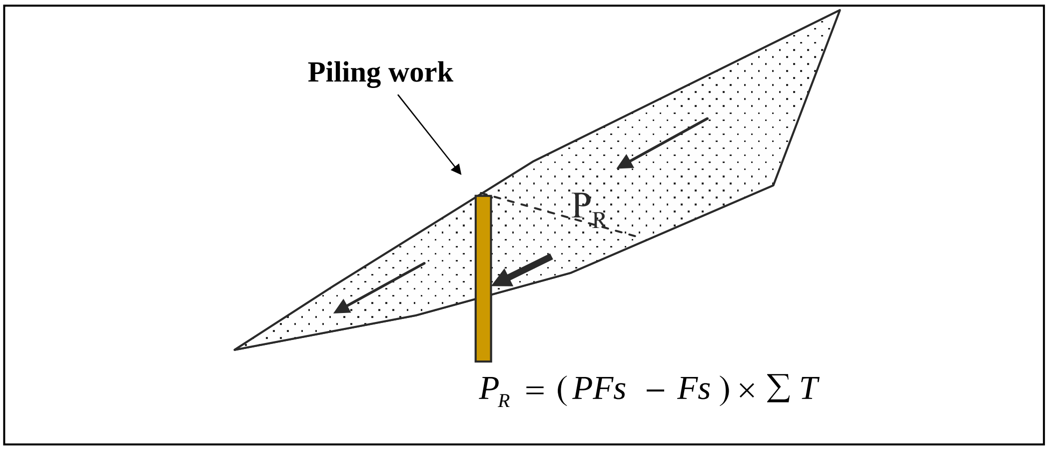


Figure 5.1 Schematic Diagram of Effectiveness of Piling Works

(2) Anchors

Anchors have two kinds of mechanical effects: a clamping effect (P1) - To increase the resistance against shear force by applying a force normal to the sliding surface; and a straining effect (P2) - To decrease the sliding force of a landslide by using steel members as shear pins. The required preventive power of the anchors shall be obtained from Equation (5.4), as schematically shown in Figure 5.2.

$$P = \frac{(PF_s - F_s) \times \sum T}{\cos(\alpha + \theta) + \sin(\alpha + \theta) \times \tan\phi} \quad \cdots\cdots (5.4)$$

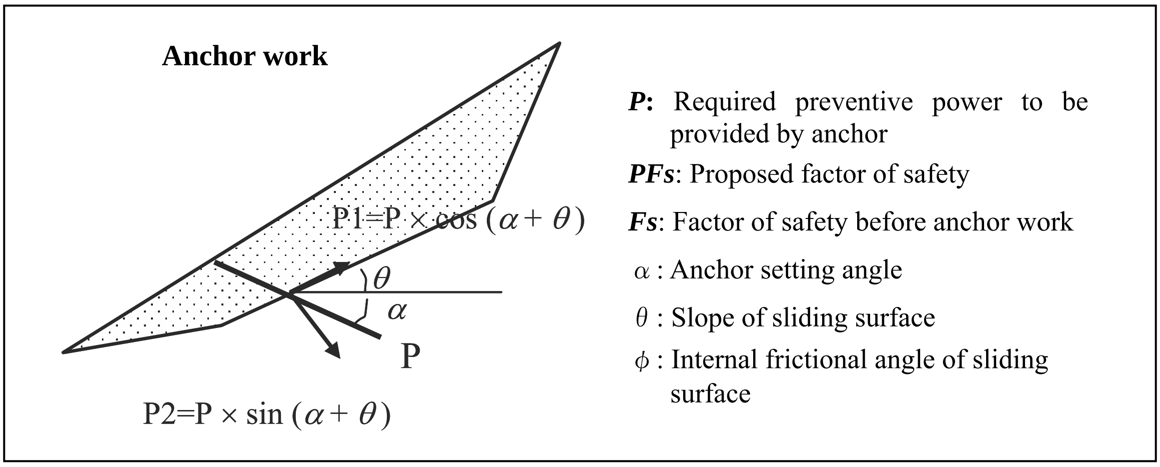


Figure 5.2 Schematic Diagram of Effectiveness of Anchor Works

(3) Drainage works

The amount of reduction in the pore water pressure that must be achieved through the construction of drainage works in order to satisfy the proposed safety factor is obtained using Equation (5.5), as schematically shown in Figure 5.3.

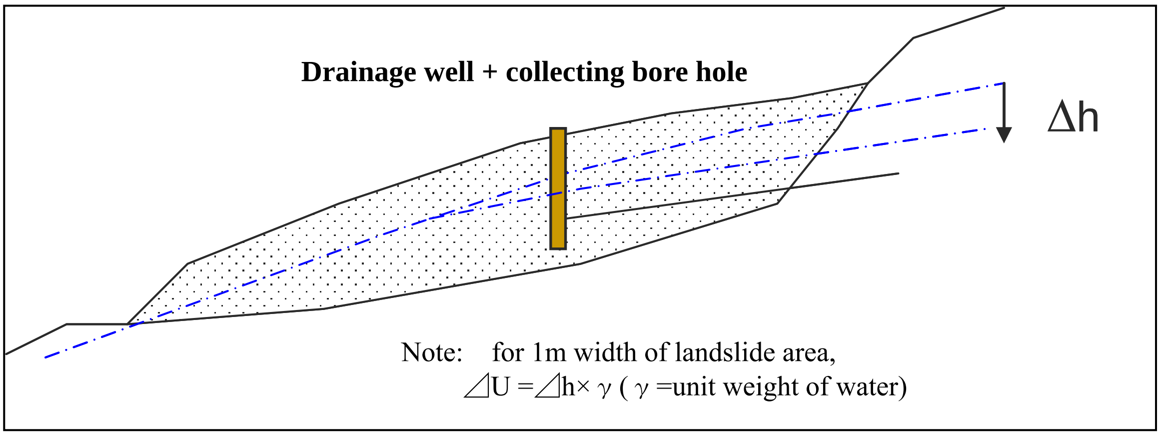


Figure 5.3 Schematic Diagram of Effectiveness of Drainage Works

$$\Delta U = \frac{1}{\tan\phi}(PF_s \times \sum T - \sum(N-U)\tan\phi - C \times \sum L) \quad \cdots\cdots (5.5)$$

Where,

$\triangle U$(kN/m) = Required reduction in pore water pressure

(4) Earthworks

The improved factor of safety due to earthworks (filling work and cutting work) is calculated by using Equation 5.6, as schematically shown in Figure 5.4.

$$F_s' = \frac{\sum(N' - U')\tan\phi - C \times \sum L}{\sum T'} \quad \cdots\cdots (5.6)$$

In the above equation, ∑T will decrease and ∑N will increase after earthworks, consequently the factor of safety is improved.

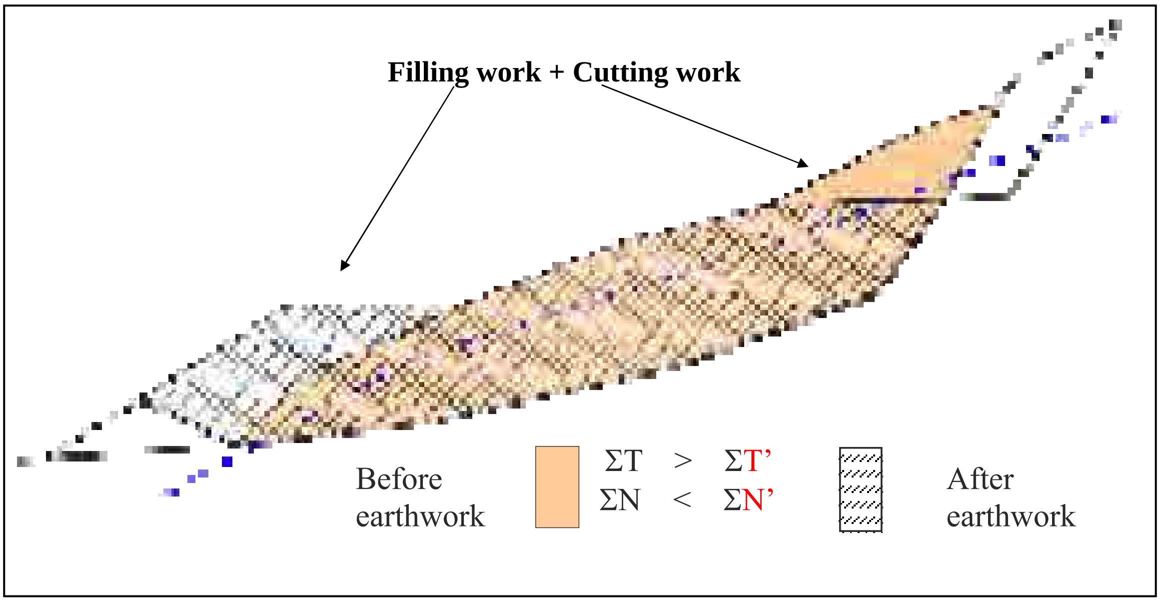


Figure 5.4 Schematic Diagram of Effectiveness of Earthworks

5.3.2 Parameters of Shear Strength of Sliding Surface

In general, cohesion, C, shall be determined from the thickness of the sliding mass (the depth of sliding surface), as shown in Table 5.1. The internal friction angle shall be determined from Equation 5.2 by using the assumed initial safety factor. Moreover, a unit weight of sliding mass, γ_t=18 kN/m^3 is usually used.

Table 5.1 Vertical Thickness of Sliding Mass and Cohesion

Vertical Thickness of Sliding Mass (m)	Cohesion C (kN/m^2)
Less than 5	5
Between 5 and 10	10
Between 10 and 15	15
Between 15 and 20	20
Over 25	25

Source: Modification from reference No. 6 MANUAL FOR RIVER WORKS IN JAPAN, Published by River Bureau, Ministry of Construction, November 1997.

5.3.3 Determination of Initial Factor of Safety

The initial factor of safety is estimated on the basis of the movement conditions, as given in Table 5.2.

Table 5.2 Determination of Initial Factor of Safety (Modified from Reference No. 6)

Initial Factor of Safety	Movement Conditions
Fs = 0.95	- A large number of obvious potential landslide topography such as scarps, bulges, stepped land, ponds and swamps; and - Many visible ongoing and active movements of cracks, subsidence, upheaval, toe erosion, or small toe collapse as well as springs.
Fs = 0.98	- Obvious potential landslide topography such as bulges, stepped land, ponds and swamps, but - Few or small ongoing movements of cracks, subsidence, upheaval, or small toe collapse.
Fs = 1.00	- Potential landslide area is at rest, - Cracks, subsidence, upheaval, or small toe collapse are visible, but not progressing.

Source: Modification from reference No. 6 MANUAL FOR RIVER WORKS IN JAPAN, Published by River Bureau, Ministry of Construction, November 1997.

5.3.4 Determination of Proposed Factor of Safety

The proposed factor of safety (PFs) is the target value for enhancing the degree of safety of the slope and achieving the conservation of the slope by means of landslide countermeasure works. Considerations in determining the proposed factor of safety include the landslide phenomena and its scale, the degree of importance of the object to be protected, and the degree of damage that is likely to occur as a result of the landslide.

Table 5.3 Determination of Proposed Factor of Safety

Proposed factor of safety	Condition
PFs = 1.10 to 1.20	- Potential exists for sudden and severe movement; and - Landslide liable to cause significant damage to, houses, main roads or rivers or other public facilities or loss of human lives.
PFs = 1.05 to 1.10	- A large landslide would have little effect on houses or public facilities; or - The proposed prevention works are temporary countermeasures.

Source: Modification from reference No. 6 MANUAL FOR RIVER WORKS IN JAPAN, Published by River Bureau, Ministry of Construction, November 1997.

It is noted that the proposed factor of safety mentioned indicates the degree of increase in the safety factor after completion of landslide prevention works on the assumption that the initial factor of safety before landslide is Fs=1.0.

5.3.5 Sliding Surface

The sliding surface is the most important factor affecting the accuracy of stability analysis and special care is needed in determining it. In determining the sliding surface (the shape of the sliding surface), the following factors are considered:

a) Geological conditions;
b) Distribution and direction of cracks at the ground surface;
c) Upheavals and settlements;
d) Sliding surface observation results if available; and
e) The relationship between depth and width of the landslide.

5.4 Selection of Countermeasures

5.4.1 Classification of Countermeasures

Table 5.4 shows the classification of countermeasures for landslides.

Table 5.4 Classification of Countermeasures for Landslides

Classification		Type of Work
1. EARTH WORK	Earth Work	Cutting (Earth Removal)
		Filling (Embankment Work)
2. VEGETATION	Vegetation	Vegetation
3. WATER DRAINAGE	Surface Drainage	Drainage Ditches and Cascade
		Subsoil Drainage Holes
	Subsurface Drainage	Horizontal Drain Holes
		Drainage Wells
		Drainage Tunnels
4.SLOPE WORK	Crib Work	Crib Work
5. ANCHORING	Anchoring	Rock Bolts
		Ground Anchors
6. WALLS AND RESISTING STRUCTURES	Retaining Wall	Gabion Walls
		Retaining Walls
7. PILING WORK	Piling Work	Steel Pipe Piles
		Shaft Work
8. Others	Alternate Solutions	Diversion or Route Relocation
		Bridges, Tunnels

5.4.2 Criteria for Selection of Countermeasures

Figure 5.5 shows the flowchart for selection of countermeasures against landslides.

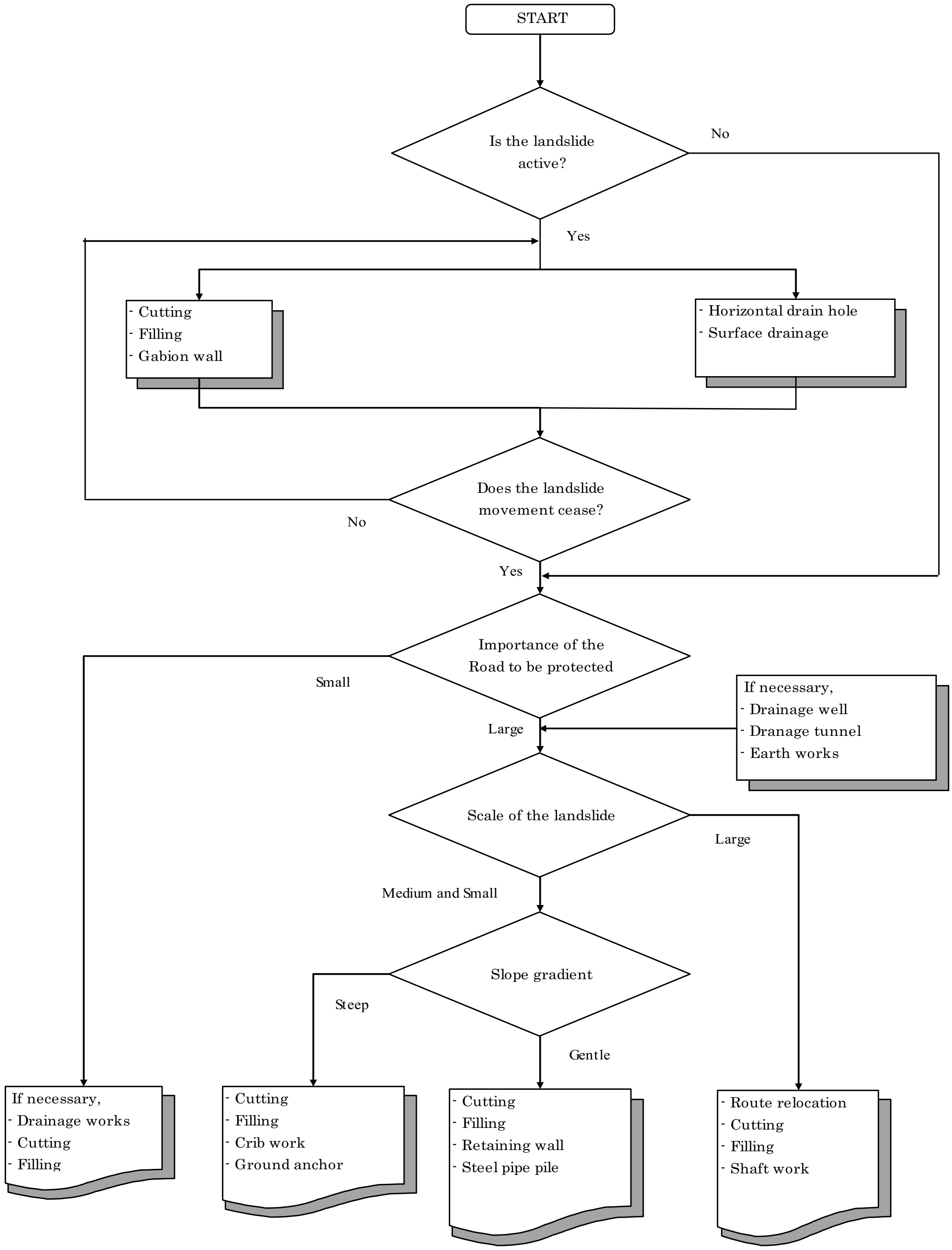


Figure 5.5 Selection Flowchart of Countermeasures against Landslides

Generally, an adequate combination of various works is cost-effective and should be selected in consideration of the following points:

a) The works selected should address the mechanism(s) of the landslide, the relationship between precipitation, groundwater and landslide movement, geological, topographical and soil properties, the scale and type of landslide and its likely movement velocity.

b) Drainage and earth works should be regarded as the main methods of landslide control, while anchoring and piling works should be adopted for the stabilization of small landslides to protect public facilities, houses, etc.

c) Where landslide movement is closely related to rainfall, surface drainage work should be performed immediately to minimize the infiltration of rainwater.

d) When a landslide is moving, drainage and earth works should be performed first; anchoring works, piling works and other structures can then be done after drainage and earth works halt the movement of the landslide .

5.5 Design of Main Countermeasures

5.5.1 Cutting work

(1) Purpose

Cutting (earth removal) work is applied to remove unstable landslide mass and to reduce the load, and hence driving force, at the head of a landslide area.

(2) Design considerations

In planning cutting work, special care is given to the following items:

a) The work is implemented only at the head of landslide area, never at the toe;

b) The work is not applicable if the landslide is continuous;

c) The most important consideration for the work is the stability of the adjoining slope behind the target area;

d) The stability of the cut slope should be considered, and vegetation covering and surface drainage should be installed on the cut slope after earth removal;

e) A combination of cutting and filling works, as described below, is more cost-effective.

The effect of the work is evaluated as a result of the reduction of the values of term N and term T in the equation of stability analysis of a slope, as follows:

$$PFs = \frac{\Sigma S - \Sigma \Delta N \times \tan\phi}{\Sigma T - \sum \Delta T} \quad \cdots\cdots (5.7)$$

Where,

PFs : Proposed safety factor

$\sum S$ (kN/m)= Sum of shear strength before implementation

$\sum T$ (kN/m)= Sum of shear stress before implementation

$\sum \Delta N$ (kN/m)= Sum of reduced normal stress after implementation

$\sum \Delta T$ (kN/m)= Sum of reduced shear stress after implementation

Moreover, the work is suitable as an urgent measure because its effect is reliable and immediate. However, the work is not applicable in the stabilization of a large-scale landslide because of the amount of the earth mass that would need to be moved. Topographical conditions usually restrict the use of the work.

Figure 5.6 gives the schematic diagram for cutting work for landslides.

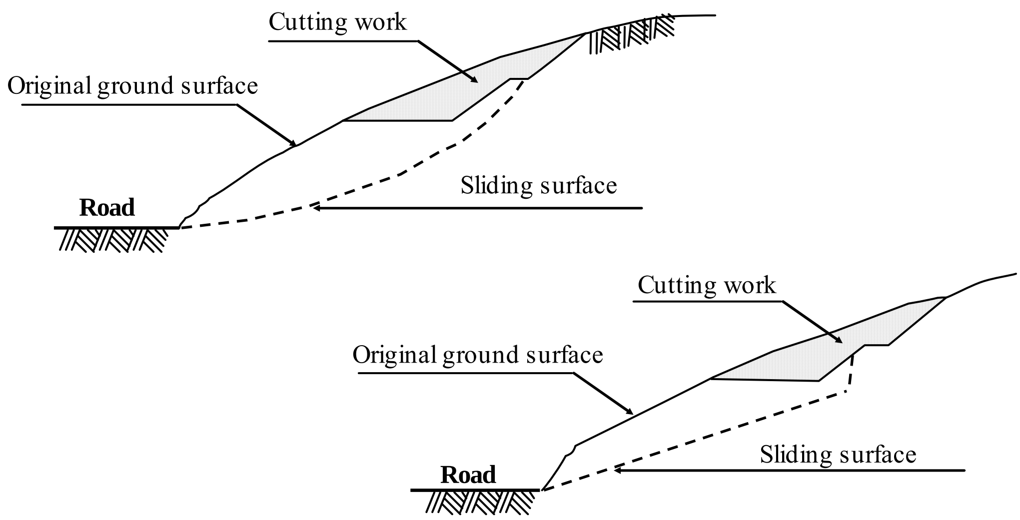


Figure 5.6 Conceptual Illustration of Cutting Work

5.5.2 Filling Work

(1) Purpose

Filling work is used at the toe of a landslide area to balance the driving force with additional loading.

(2) Design considerations

In planning filling work, special care is given to the following items:

a) The work shall be implemented only at the toe of landslide area, never at the head;

b) The toe of a landslide is often disturbed and weak, and therefore, the capacity of the base ground at the banking point should be carefully considered;

c) The probability of the filling work causing a subsequent landslide of the adjoining slope in front of (below) the target area should be estimated;

d) The work may cause increased pore water pressure in the landslide slope through the blockage of spring water flow, and therefore drainage inside filling should be carefully considered; and

e) The stability of the fill slope should be checked, and a standard fill slope should be considered first if topography allows (Table 5.5).

Table 5.5 Recommended Standard Fill Slopes

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

Note: Height of fill is the vertical height from the toe to the top of the fill.

Source: Modification from reference No. 6 MANUAL FOR RIVER WORKS IN JAPAN, Published by River Bureau, Ministry of Construction, November 1997.

The effect of the work is an increase in the values of term N and term T in the equation of stability analysis of a slope, as follows:

$$PFs = \frac{\Sigma S - \Sigma \Delta N \times \tan\phi}{\Sigma T + \sum \Delta T} \quad \cdots\cdots (5.8)$$

The symbols in the above equation are the same as those in Equation 5.7.

Figure 5.7 gives a schematic diagram of filling works for the stabilization of a landslide.

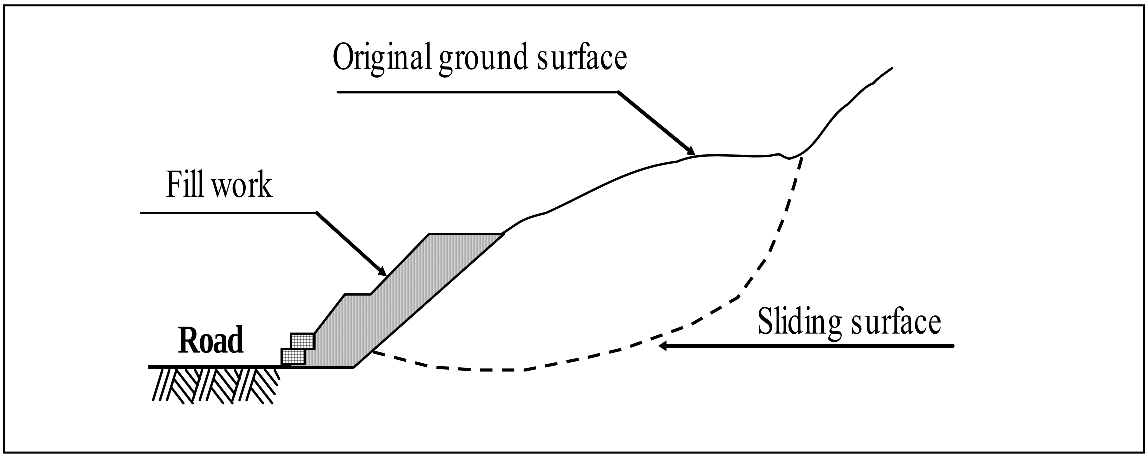


Figure 5.7 Conceptual Illustration of Filling Work

5.5.3 Surface Drainage

Surface drainage is classified into catch drains, berm drains and toe drains. In most cases, surface water is prevented from infiltrating into the landslide area to avoid any hydraulic thrusts. Especially where landslides are closely related to short-term rainfall, the work should be immediately performed regardless of the results of the stability analyses. U-shaped gutters, reinforced concrete or corrugated metal pipe may be used to construct the drainage ditches, as shown in Figure 5.8.

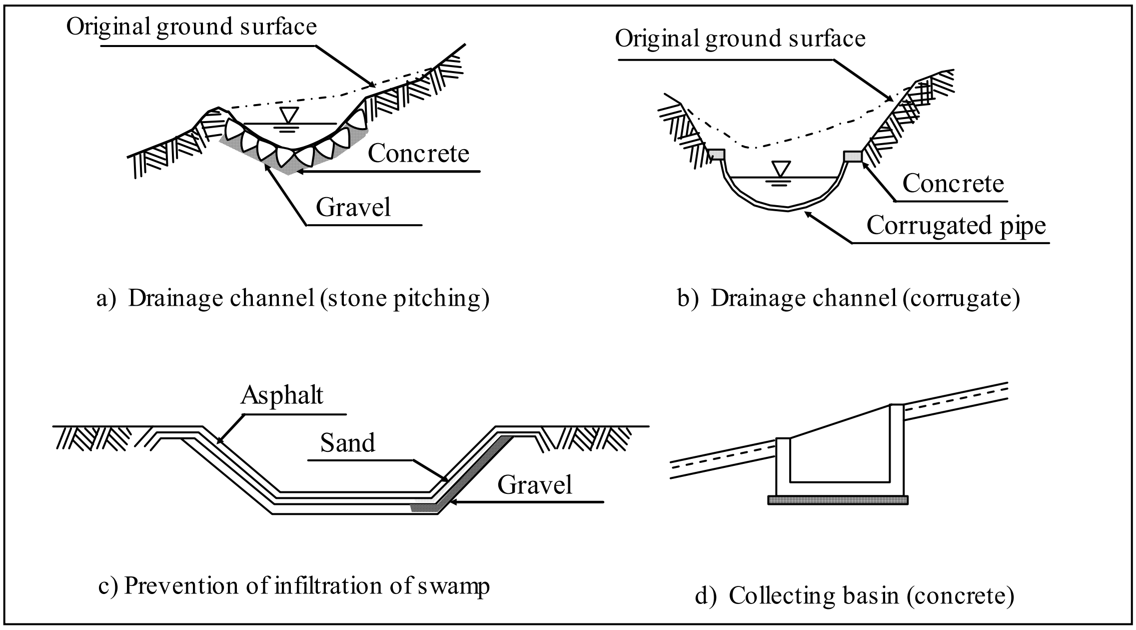


Figure 5.8 Drainage Channels and Collecting Basins

(1) Purpose

Surface drainage works are designed to prevent the occurrence of landslides that are by infiltration of precipitation or re-permeation of water from springs, swamps, etc.

(2) Design Considerations

The design calculations and considerations given in Section 3.4 of this Manual can be applied to the design of surface drainage works for landslides. In addition, the following items should be carefully considered in planning surface drainage work:

a) Drainage collection works are designed to collect surface flow by installing corrugated half pipes or lined U-ditches along the slopes, which are then connected to a drainage channel. The drainage channel works are designed to remove the collected water out of the landslide zone as quickly as possible, and are constructed from the same materials as the drainage collection works. The surface drainage works are often combined with subsurface drainage works.

b) The drainage ditch beds should, in principle, be covered. Collecting basins should be installed at the confluence with tributaries, curves and points of change in gradient.

c) When constructed in an area of active landslides, drainage ditches should have the required strength and be easy to repair. Bed consolidation must be planned every 20 to 30 m to prevent the drainage ditch from sliding.

d) The shoulders and cut slope faces of the ditches must be protected with vegetation, boulder covers, and so on.

5.5.4 Horizontal Drain Hole

Groundwater is generally divided into two types, shallow and deep. Shallow groundwater, 0 to 5 meters below the ground surface, is due mainly to rainfall accumulated in the short-term. Shallow groundwater frequently causes a shallow failure or the toe failure of a large-scale landslide. In such cases, culverts and horizontal drain holes are effective.

(1) Purpose

Horizontal drain holes are used to drain both shallow and deep groundwater to stabilize the landslide by decreasing the pore water pressure that is responsible for activating the sliding surface. The work is useful as a temporary countermeasure to decrease the progress of an active landslide.

(2) Design Considerations

Horizontal drain holes are constructed for the drainage of shallow groundwater and deep groundwater. If topography prevents the groundwater from being drained on a gentle gradient, then drainage wells or tunnels with horizontal drain holes shall be used to achieve drainage.

In designing horizontal drain holes, the following items should be carefully considered:

a) Horizontal drain holes are designed to traverse aquifers or penetrate into the sliding surface if it is deeper than 5 meters.

b) “Horizontal” drain holes, usually 20 to 50 meters in length, should be excavated at a gradient of 5 to 10 degrees

c) Hard polyvinyl chloride pipes or gas pipes with an internal diameter of 50 to 100 mm are used as casing pipes. Either the parts of the casing pipes traversing the aquifer or the whole length of the pipe is perforated to collect the underground water.

d) Outlet protection for horizontal drain holes is undertaken using gabions or concrete.

A typical layout of horizontal drain holes is shown in Figure 5.9.

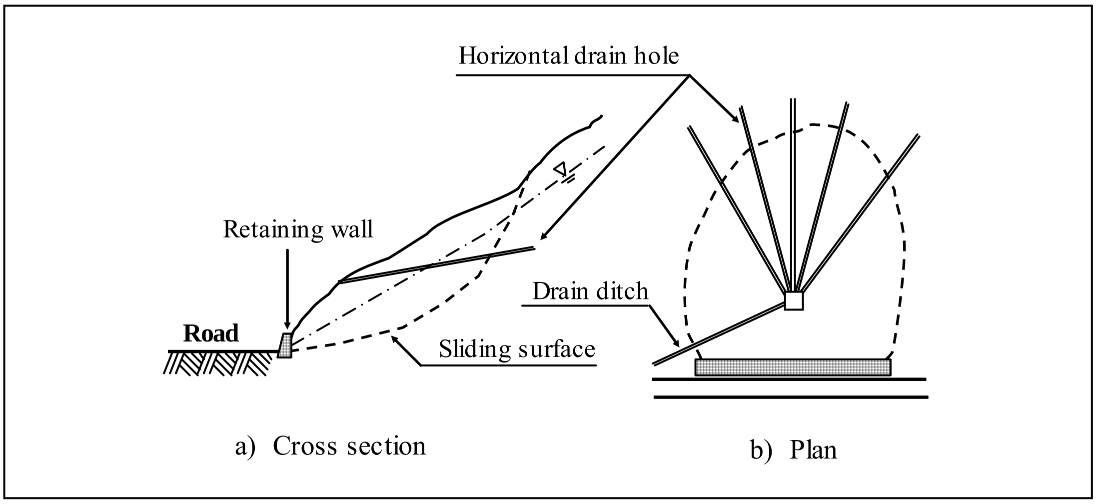


Figure 5.9 Typical Layout of Horizontal Drain Holes

In the case of the standard-scale landslide with a landslide depth of 20 m, the reduction in the groundwater level by installation of horizontal drain holes may be expected to be 1 to 3 meters.

5.5.5 Drainage Wells

Drainage wells consist of three parts: a) catchment well - collecting water through the wall of the well, b) collecting bore holes - collecting water in the same way as horizontal drain holes, and c) draining bore holes - draining the collected water from the catchment well.

(1) Purpose

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

(2) Design considerations

This work is used when horizontal drains or culverts cannot achieve efficient drainage because of the large scale of the landslide or the gradient of the slope surface.

In designing drainage wells, the following items are to be carefully considered:

a) The location of catchment wells shall be determined on the basis of the distribution of groundwater and in consideration of the well's safety. In principle, wells should be located in stable ground within an area from which it is possible to effectively collect groundwater.

b) Wells are usually between 2 to 4 meters in diameter and 10 to 30 meters in depth. Liner plates, reinforced concrete segments, and other materials generally support the sidewalls of the wells.

c) Collecting bore holes are similar to horizontal drain holes in terms of design considerations.

d) The diameter of draining bore holes is determined on the basis of the amount of groundwater collected.

Figure 5.10 shows the details of a drainage well. A typical drainage well layout is shown in Figure 5.11. The safety of the catchment wells shall be evaluated by checking the earth pressure of the surrounding area, as shown in the following equations:

$$P_h = K_a \times \gamma \times h \quad (h < 15m) \cdots (5.9)$$

$$P_h = K_a \times \gamma \times 15 \quad (h \geqq 15m) \cdots (5.10)$$

Where,

P_h (kN/m^2)=Active earth pressure at depth h (m)
γ (kN/m^3)=Unit weight of soils

K_a =Coefficient of active earth pressure

a) Sandy soil= $K_a = \tan^2(45^o - \frac{\phi}{2})$

b) Clayey soil= $K_a = \tan^2(45^o - \frac{\phi}{2}) - \frac{2C}{h\gamma}\tan(45^o - \frac{\phi}{2})$

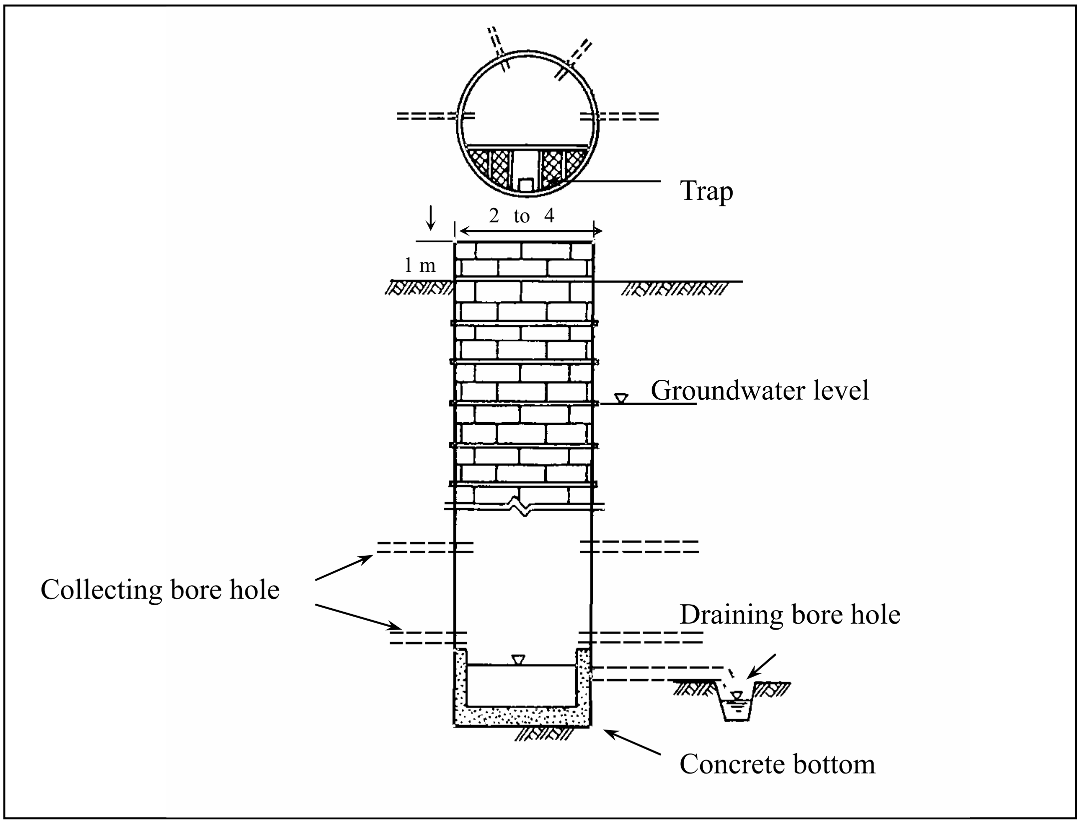


Figure 5.10 Structural Details of Drainage Well

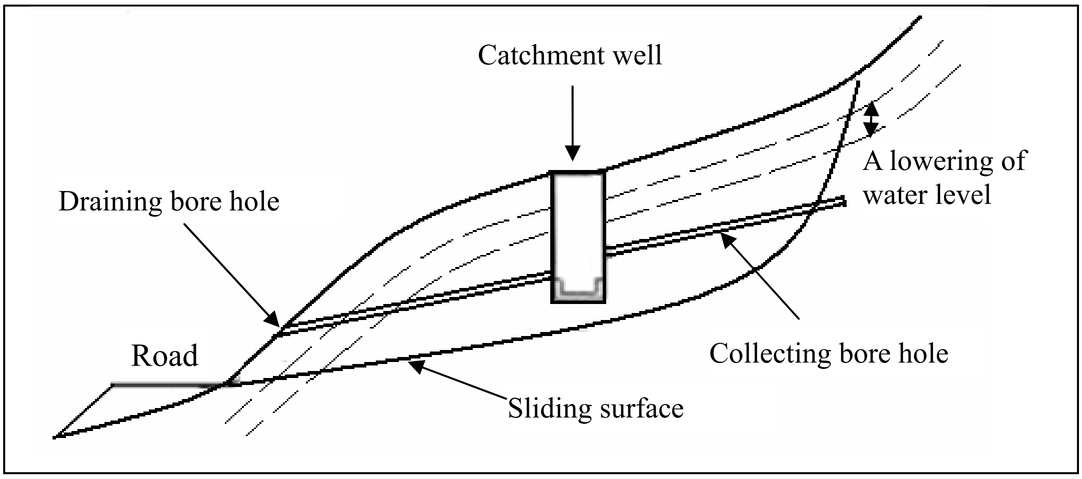


Figure 5.11 Typical Layout of Drainage Well

In the case of the standard-scale landslide with a landslide depth of 20 m, the reduction in the groundwater level by installation of horizontal drain holes may be expected to be 3 to 5 meters.

5.5.6 Ground Anchors

Ground anchors are reliable, but costly compared with other countermeasures. This method has been applied increasingly to artificial landslides to cut off the toe of the landslide. Compared with rock bolts and soil nailing, ground anchors have a relatively large resistance to sliding force and are therefore used to stabilize relatively large-scale slope failures.

(1) Purpose

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

(2) Design Considerations

When the slope of a landslide area or sliding surface is relatively steep, ground anchors are more effective. Figure 5.12 gives a conceptual diagram of a ground anchor installation.

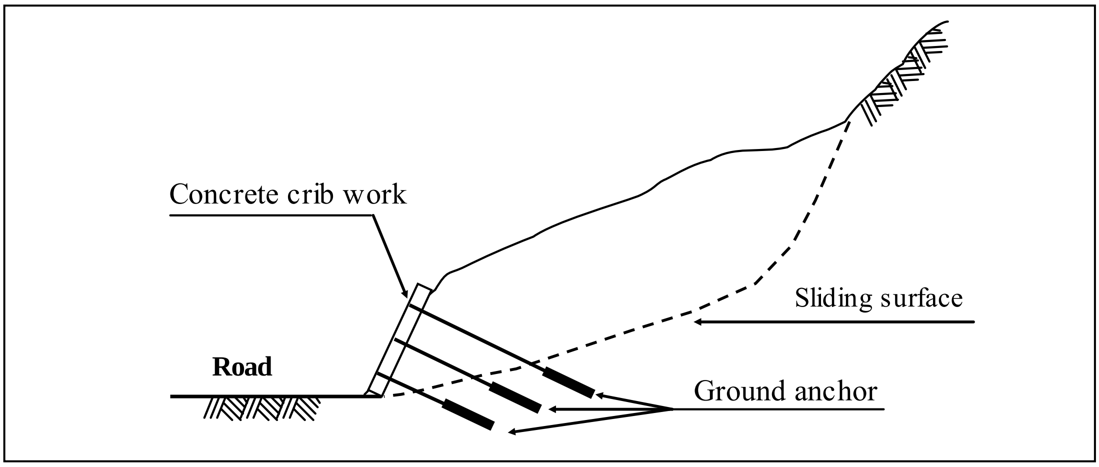


Figure 5.12 Landslide Stabilized with Ground Anchors

(a) Design procedure

Figure 5.13 shows the design flowchart for ground anchors. Important considerations for ground anchors are the bearing capacity of the ground under the bearing plate and the bond strength between the anchor grout and rock at the attachment point. In planning ground anchors, a bond strength test at the attachment is to be carried out.

Further, in planning and designing ground anchors, at least the following site tests should be performed at intervals of 20 to 30 m.

a) Bond strength test at fixation part (extraction test)

b) Bearing capacity test of soil mass under the bearing plate

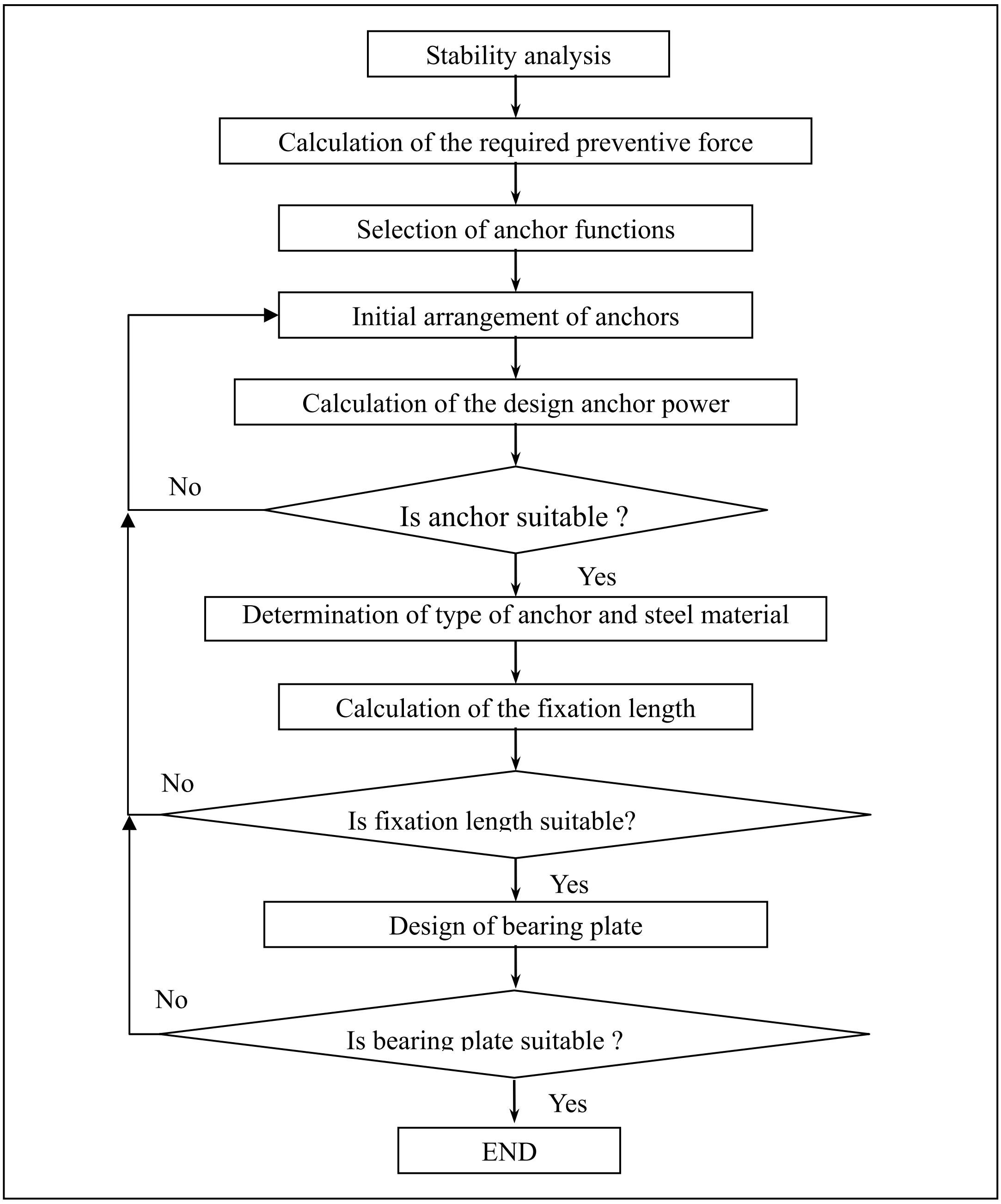


Figure 5.13 Design Flowchart for Ground Anchors

(b) Anchor functions

Anchors are installed to achieve two objectives (Figure 5.14):

a) Increase the resisting power against shear force by applying stress normal to the sliding surface (clamping effect), and

b) Decrease the sliding force of a landslide by using steel members as anchors (straining effect).

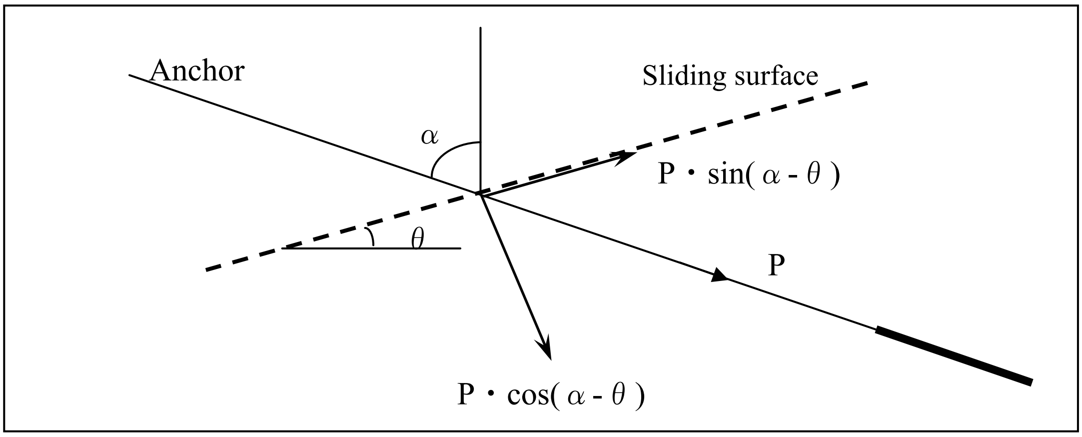


Figure 5.14 Functional Description of an Anchor

(c) Arrangement of anchors

The position, direction and intervals of anchor installation shall be determined during the initial stage of design.

a) Ground anchors shall be installed at a spacing of at least 2 meters in 2 or more rows.

b) The inclination of the anchors in a range from + 10˚ to -10˚ from horizontal. must be avoided for the reasons related to anchor installation, such as residual slime, bleeding of grout, etc.

c) The direction of anchoring is parallel to the direction of movement of the landslide.

d) Anchor interval is determined based on the interaction between anchors, which can be verified by reviewing anchor power, diameter of anchors, depth and ground properties.

(d) Calculation of the design anchor power

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

$$Td = \frac{P}{\sin(\alpha + \beta) \cdot \tan\phi + \cos(\alpha + \beta)} \cdot \frac{B}{N} \quad \cdots\cdots (5.11)$$

Where,

P (kN/m^2)= Required preventive power

α(degree)= Anchor setting angle (the angle to a perpendicular axis)

β (degrees)= Angle of slope of the sliding surface

φ(degrees)= Internal frictional angle of sliding surface

B (m)= Interval between anchors in horizontal direction

N= Number of anchors set in vertical direction

(e) Determination of type of anchor and steel material

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

(f) Determination of fixation length

Fixation length should be 3 to 10 meters, and the free length should be more than 4 meters. Figure 5.15 gives the structural description.

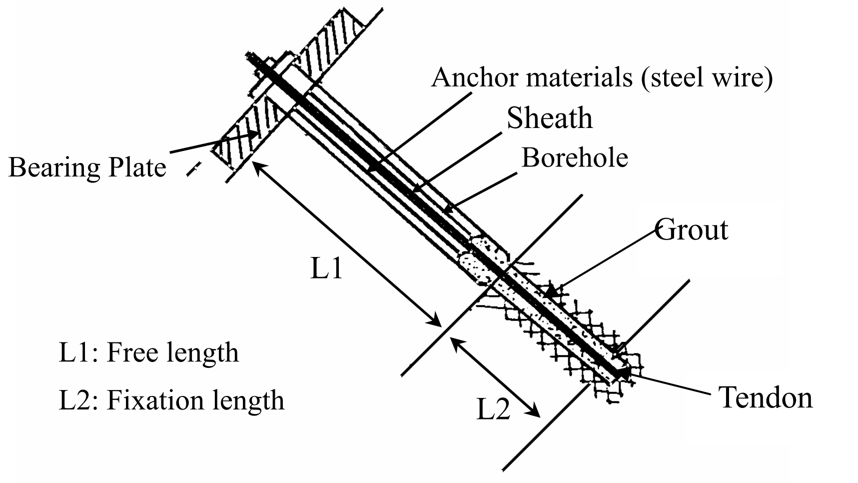


Figure 5.15 Outline of Anchor Structure

To allow the design anchor power to meet the allowable anchor extraction force, the length of contact between the ground and the grout must be compared with that between a tendon and grout. Whichever is longer should be defined as the fixation length.

$$l_{sa} = \frac{T_d}{3.14 \times D_s \times \tau_{ab}} \quad \cdots\cdots (5.12)$$

$$la = \frac{f \times T_d}{3.14 \times D_a \times \tau_{ag}} \quad \cdots\cdots (5.13)$$

Where,

lsa (m)= Required length between the tendon and the grout

la (m)= Required length of contact between the soil and the grout

Td (N/piece)= Design anchor power

D_S (m)= Diameter of a tendon

τab (N/m^2) = Allowable adhesive stress between the tendon and the grout (Table 5.6)

f = Safety factor (generally be defined as 2.5)

D_A (m)= Diameter of the anchor

τag (N/m^2)= Skin frictional resistance (Table 5.7)

Table 5.6 Recommended Allowable Adhesive Stresses

Standard Ground Design Strength (unit: N/cm^2)		240	300	400
Type of tendon	1. Prestressing steel wire	80	90	100
	2. Prestressing steel bar			
	3. Standard prestressing steel wire			
	4. Multi-standard prestressing steel wire			
	5. Deformed prestressing steel bar	160	180	200

Notes: (1) 1 kgf/cm^2 = 10 N/cm^2, (2) unit: N/cm^2.
Source: Modification from reference No. 1 Highway Earthwork Series, MANUAL FOR SLOPE PROTECTION, Published by Japan Road Association, March 1999.

Table 5.7 Recommended Skin Frictional Resistance of Anchors

Type of Ground			Frictional Resistance (N/cm^2)
Bedrock	Hard rock		150 to 250
	Soft rock		100 to 150
	Weathered rock		60 to 100
	Mudstone		60 to 120
Sand and gravel	N value	10	10 to 20
		20	17 to 25
		30	25 to 35
		40	35 to 45
		50	45 to 70
Sand	N value	10	10 to 14
		20	18 to 22
		30	23 to 27
		40	29 to 35
		50	30 to 40
Cohesive soil	Representative Cohesion C		10C

Note: 1 kgf/cm^2 = 10 N/cm^2

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

(g) Design of bearing plates

Cribs, plates or cross-shaped blocks set on the surface of the ground are used as pressure bearing plates. The most appropriate pressure bearing plate is selected in consideration of specifications, operational efficiency, cost-effectiveness, maintenance, landscape, etc.

Figure 5.16 shows a typical example of a landslide stabilized with ground anchors.

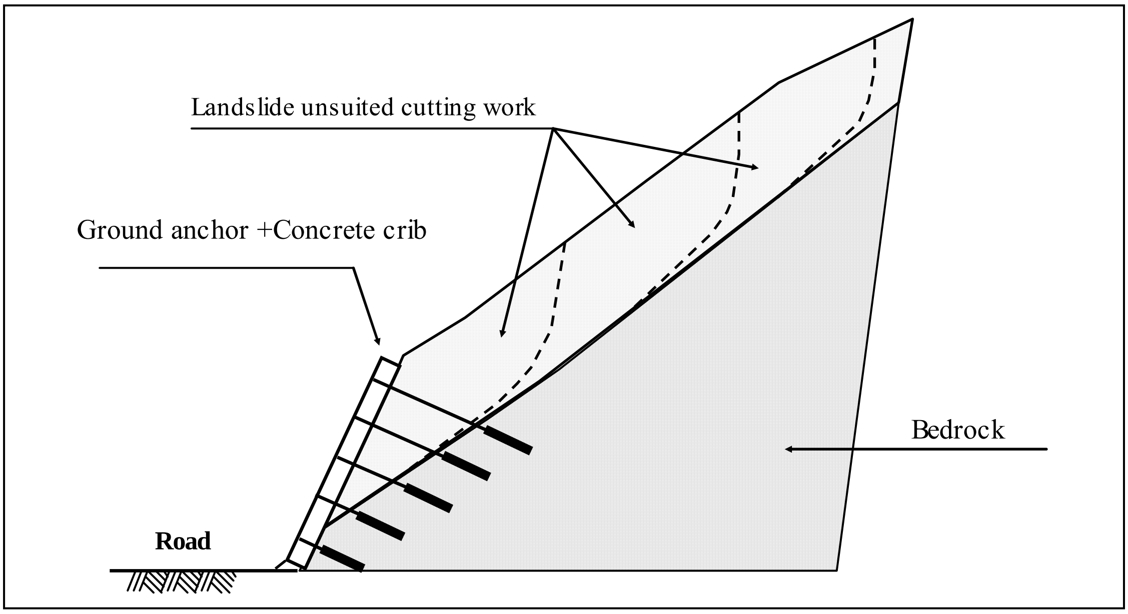


Figure 5.16 Typical Example of a Landslide Stabilized by Ground Anchors

5.5.7 Steel Pipe Piles

Similar to ground anchors, steel pipe piles are costly but reliable. The work is especially recommended when the ground below the sliding surface is firm and has sufficient resistance against landslide mass. Moreover, steel pipe piles are generally used when the slope of a landslide area or sliding surface is relatively gentle or a landslide has a large scale.

Steel pipe pile systems are classified, in terms of its effect, into shearing piles — by using the shearing strength of the piles, and bending piles — by using the bending and shearing effect of piles. Steel pipe piles generally have smaller bending strengths than shearing strengths and should therefore be installed in positions subject to small bending forces.

Moreover, bending piles can be conveniently subdivided into cantilever piles and cotter piles based on the positions of the piles in relationship to the landslide block. The former is constructed in the tensile zones of a landslide block and the subgrade reaction force of the sliding mass behind the pile is ignored; therefore the pile is considered to be a cantilever beam. Whereas the latter is constructed in the compressive zones of a landslide block with a large subgrade reaction behind the pile and and it functions as cotter pin to keep the sliding mass and the stable ground below the sliding surface together, as shown in Figure 5.17.

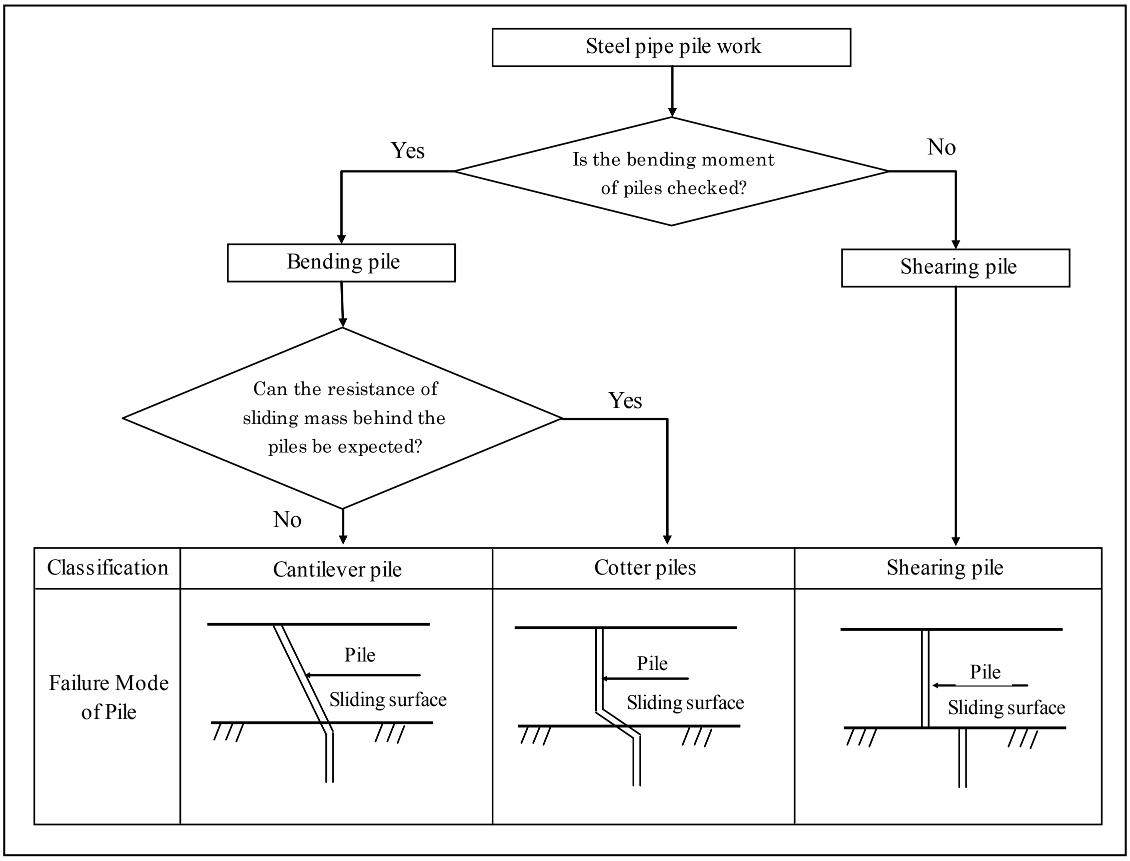


Figure 5.17 Classification of Steel Pipe Piles

(1) Purpose

Steel pipe piles are intended to prevent landslides with a doweling effect between the landslide mass and stable ground by applying the shear strength and bending resistance of the steel piles.

(2) Design Considerations

(a) Items to be examined

In designing pile systems, the items to be examined are summarized in Table 5.8.

Table 5.8 Items to be Examined (Modified from Reference No. 11)

Pile Type	Items				
	Shear force	Moment	Deflection	Passive failure	Horizontal resistance
Bending piles	○	○	△	○	○
Shearing piles	○	×	×	○	×

Notes: ○ = Must be evaluated, × = No need to be evaluated, △ = be evaluated only where the displacement of the pile head has an effect on the facilities surrounding the pile.

Source: Modification from reference No. 11 GUIDELINE FOR STEEL PIPE PILE DESIGN FOR LANDSLIDE CONTROL, Committee for the Survey of Design and Execution of Landslide Steel Pipe Pile, 1990.

Moreover, the piles must be placed close enough together to prevent segments of the soil from sliding in the space between the piles.

(b) Design procedure

Figure 5.18 shows the design flowchart for steel pipe piles. Important considerations for the work include 1) design method, 2) the preventive force of a pile, 3) pile intervals, 4) pile material and 5) pile length. It should be noted that piles are installed at the lower portion of a landslide area in an appropriate position so that passive earth breakdown will not induce a landslide at the top end of a sliding surface.

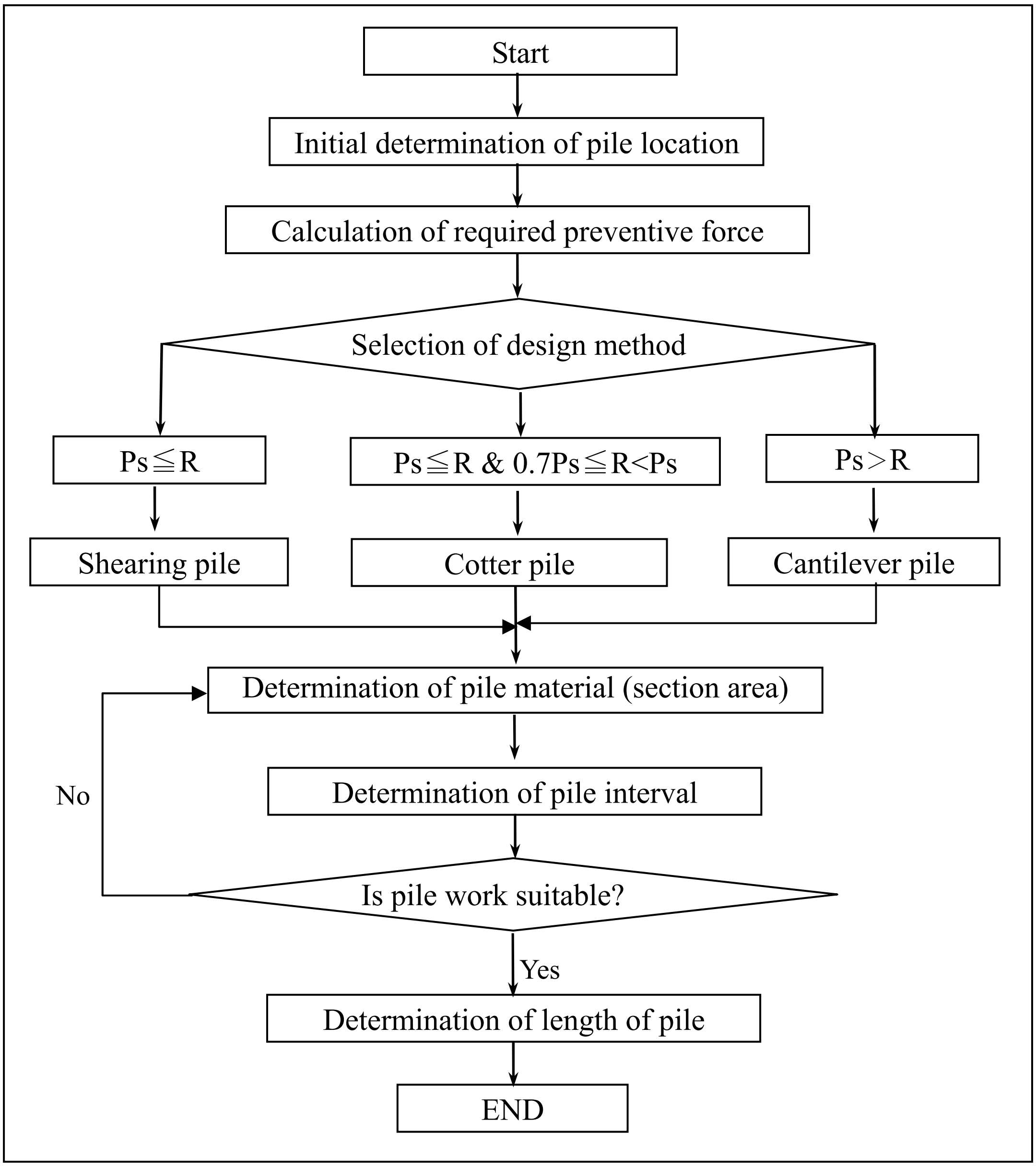


Figure 5.18 Design Flowchart for Piles

(c) Selection of design method

The design method for piles is based on the distribution of inner horizontal resistance behind the piles and the location of pile installation, as shown in Table 5.9. Shearing piles are installed in a position where there is sufficient subgrade reaction at the back of piles. Empirically, when piles are installed in a position defined by $P_S > R$, the bending piles will be considered as cantilever piles, otherwise, as cotter piles.

Table 5.9 Design Conditions for Piles (Modified from Reference No.11)

Pile Type	Design Criteria	Conditions
Cantilever pile	$R < P_S$	- Taking no account of horizontal resistance behind the pile
Cotter pile	$P_R \leqq R$	- Taking account of horizontal resistance behind the pile
	$0.7P_S \leqq R < P_S$	- Taking account of horizontal resistance behind the pile - Considering the decrease in the deformation coefficient of the sliding mass
Shearing pile	$P_S \leqq R$	Just checking the shear force of piles

Note: P_S = Sliding force, R = Inner horizontal resistant force of sliding mass.

Source: Modification from reference No. 11 GUIDELINE FOR STEEL PIPE PILE DESIGN FOR LANDSLIDE CONTROL, Committee for the Survey of Design and Execution of Landslide Steel Pipe Pile, 1990.

(d) Calculation of design pile power

The required preventive force of piles (P_R) is calculated by using Equation 5.3 (see Section 5.3.1), and then the design pile power is calculated as follows:

For shearing piles: $H = P_R$ ··························(5.14)

For bending piles: $H = P_R \cos\theta$ ··························(5.15)

Where,

P_R (kN/m)= Required preventive force of piles per unit width

H (kN/m)= Design pile power per unit width

θ (degrees)= Angle of slope of sliding surface

(e) Calculation of β value of piles

The β value of a pile is calculated by using Equation 5.16, as follows:

$$\beta = \sqrt[4]{\frac{K_h \times d}{4 \times EI}} \quad \cdots\cdots (5.16)$$

Where,

K_h (N/cm^3)= Coefficient of horizontal subgrade reaction of the ground

d (mm)= pile diameter

EI (Ncm^2)= Rigidity of steel pile to bending

(f) Determination of pile intervals

The distance, D, between the centers of the piles is determined in consideration of bending moment and the shear force of the piles by using the following equations:

$$\sigma = \frac{N_f}{A} \pm \frac{M}{Z} \leq \sigma_a \quad \cdots\cdots (5.17)$$

$$D \leq \frac{\sigma_a - \frac{N_{f1}}{A}}{\frac{N_{f2}}{A} + \frac{M_{\max}}{Z}} \quad \cdots\cdots (5.18)$$

$$\tau_{\max} = a_0 \frac{S}{A} \leq \tau_a \quad \cdots\cdots (5.19)$$

$$D \leq \frac{1}{a_0} \times \frac{\tau_a \times A}{S_{\max}} \quad \cdots\cdots (5.20)$$

Where,

σ (kN/m^2)= Bending stress on pile

σ_a (kN/m^2)=Allowable bending stress intensity of the steel pile

N_f (kN)= Axial force on piles

N_{f1} (kN)= Axial force on a pile

N_{f2} (kN)= Axial force on pile per unit width

A (m^2)= Cross-sectional area of steel material in pile

M (kN・m)= Bending moment on pile

Z (m^3)= Section modulus of steel material in pile

D (m)= Distance between centers of piles

τ (kN/m^2)= Shear stress on pile

τ_a (kN/m^2)= Allowable shear stress intensity of steel pile

S (kN)= Shear force on pile

S_{max} (kN)= Maximum shear force on pile

a_0 = Coefficient, generally a_0 =2

Furthermore, some design manuals in Japan provide a general guideline for the interval between piles as follows:

a) Reference No. 1

Set generally at less than 2.0 m.

b) Reference No. 6

Set in principle at 1.5 m to 4.0 m.

c) Reference No. 11

Table 5.10 Standard Interval between Piles

Vertical Thickness of Sliding Mass (m)	Interval Between Piles (m)
Less than 10	2.0 or less
Between 10 and 20	3.0 or less
20 m or thicker	4.0 or less

In most cases in Japan, the interval between piles is set at about 2.0 m. The standard interval between piles is set at 2.0 m in principle based on the above-mentioned manuals.

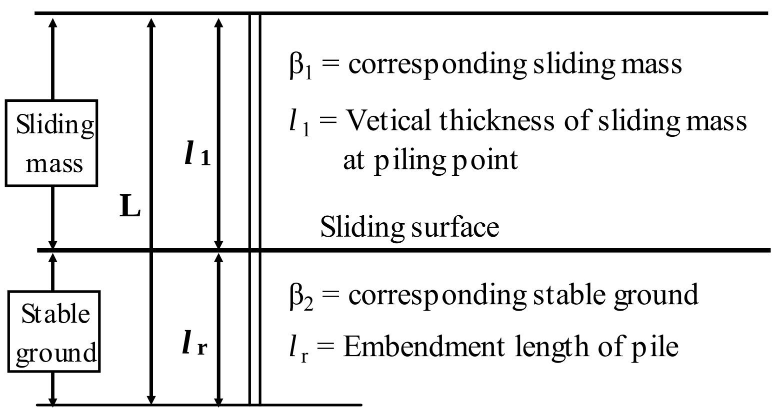
(g) Determination of pile length

The embedment length, l_r, of piles to be driven into the ground below the sliding surface is obtained according to the following table.

Table 5.11 Embedment Length of Piles

Pile Type	l_r (m)	Remarks
Cantilever pile	π / β_2	Generally, (1～1.5) π / β_2
Cotter pile	π / β_1	Generally, (1～1.5) π / β_1
Shearing pile	L/3	Ground below sliding surface is soft rock.
	L/4	Ground below sliding surface is hard rock.

Note: Symbols in the above table are the same as those shown in the following figure.



CHAPTER 6

COUNTERMEASURES AGAINST ROAD SLIPS

6.1 General

Road slips include all types of road shoulder collapses, such as soil slope collapse, embankment erosion, and settlement of road surfaces.

The road shoulder is the part of the roadway between the edge of the traffic lane and the edge of the side slope. Road capacity decreases and the potential for road accidents increases if the road shoulder narrows due to road slips.

For this reason, a stable road shoulder must be designed and road slips be restored quickly. This chapter provides the procedures for the selection and design considerations for the countermeasures for road slips.

Moreover, the basic principles and procedures given in Chapter 3 of this Guide III, Countermeasures against Soil Slope Collapse are also applicable to the design for the restoration of road slips.

6.2 General Policy for Design of Stable Road Shoulders

As with other types of road slope disasters, road slips occur during the rainy seasons. They are triggered mostly by rainwater flow and subsequent erosion as a result of inappropriate drainage treatment. Topographically, road slips are concentrated in two different kinds of road sections. One is the section lying in a saddle with a deep narrow valley, where rainwater is collected from higher ridges on both sides and flows through the deep narrow valley. The other is the section parallel to a larger river, where some small tributary streams or canals run into the larger river, contributing to water erosion and consequently triggering road slips.

Therefore, the general policy for the design of a road shoulder, which should consider long-term stability and maintenance cost, is to provide appropriate surface drainage:

Two conditions are evaluated as follows:

a) Surface water flowing across the surface of the slope, and

b) Surface water seeping into or infiltrating the slopes.

In order to mitigate road slips resulting from water flow and erosion, the following technical policies are recommended:

a) A proper drainage system should be designed and installed to prevent surface water from flowing into the disaster-prone areas. If possible, surface water should be guided to locations outside the disaster-prone areas.

b) The kind and size of drainage facilities should be selected properly through hydraulic calculations.

In order to protect the infiltration of surface water into the slope and to improve the stability of the road shoulder, the following measures are commonly used.

a) Vegetation work, such as seeding and sodding; and

b) Slope protection works, such as stone masonry, grouted riprap, concrete paving, asphalt paving, and concrete cribs.

6.3 Selection of Countermeasures

6.3.1 Classification of Countermeasures

Countermeasures for road slips are classified into five general categories based on their functions and purposes as shown in Table 6.1 and summarized as follows:

a) Earthworks - to provide space for shifting the road (Figure 6.1).

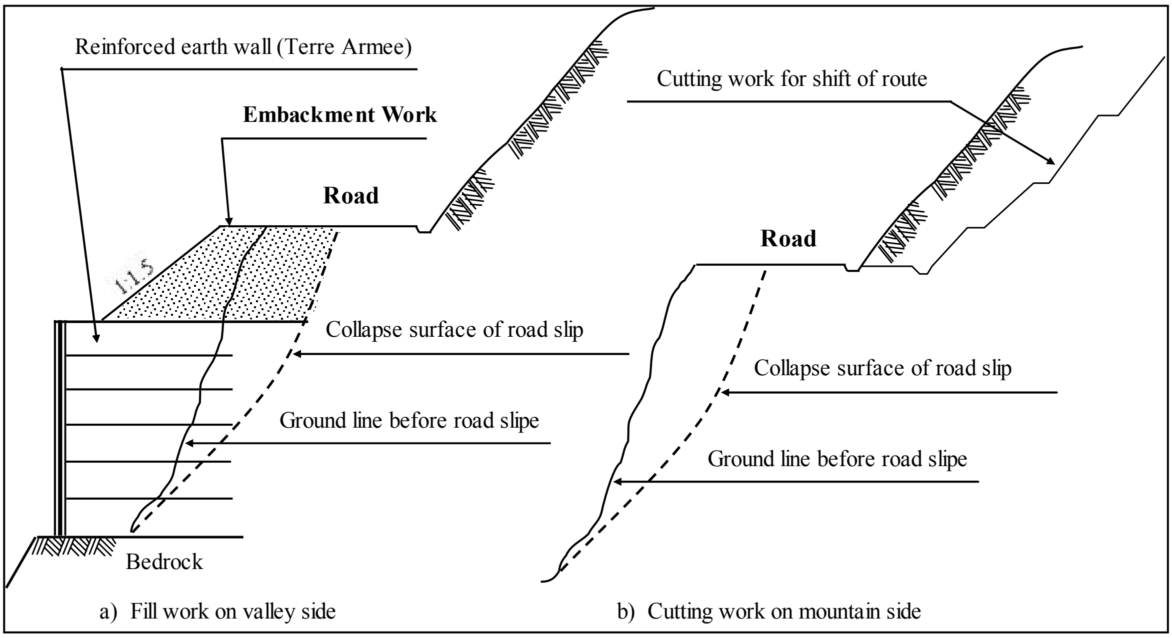


Figure 6.1 Conceptual Illustration of Earthworks for Road Slips

b) Surface cover - to stop the infiltration of surface water into the slopes.

c) Drainage - to drain surface and ground water to improve the stability of the road shoulder.

d) Slope protection - to protect the slope from the infiltration of surface water, erosion and weathering, and to prevent road slips.

e) Walls and other structures - to retain the steep slope of the road shoulder and to prevent road slips (Figure 6.2).

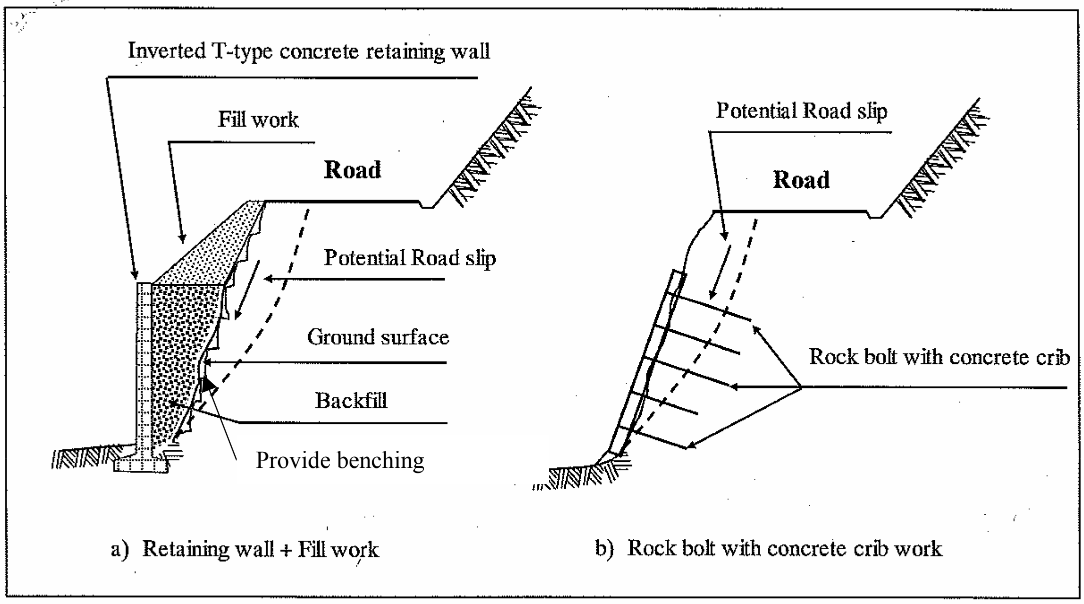


Figure 6.2 Conceptual Illustration of Structures for Road Slips

6.3.2 Criteria for Selection of Countermeasures

Adequate and effective measures for preventing road slips are selected in consideration of topographical and geological conditions, the conditions of the road and road shoulder, the size of the potential road slips, and the function of each countermeasure. Figure 6.3 gives a flowchart for the selection of countermeasures for road slips. Table 6.2 summarizes the application of these countermeasures.

The following criteria are used for the selection of countermeasures.

a) If there is a potential road slip, water action by infiltration and scouring must be eliminated by using surface cover, drainage and/or slope protection work so that the erosion on the road shoulder will be minimized. When these methods are not enough to ensure the stability of the road shoulder, other methods should be adopted in combination.

b) In selecting countermeasures, it is essential to consider the causes of the road slips and the conditions of the road slopes, as well as the terrain and ground conditions at the place of the works, the difficulty of execution of the works, its endurance and the ease of maintenance.

c) Earth work, whether complete or partial, is always a preferred method if topographical conditions are suitable because of the low cost of initial construction and maintenance. However, slope protection should also be implemented for the surface protection of the earth work.

d) When some structures such as reinforced earth walls, retaining walls, rock bolts with concrete crib work, etc. are used to stabilize road slips, surface draining works should be installed for protection against scouring and infiltration regardless of the results of the stability analyses.

Table 6.1 Classification of Countermeasures for Road Slips

CLASSIFICATION		TYPE OF WORK
1. EARTHWORK	Earthwork	Cutting
		Filling
2. SURFACE COVER	Vegetation	Seed spraying
		Seed mud spraying
		Turfing (Sodding)
3. DRAINAGE	Surface Drainage	Drainage ditches
	Subsurface Drainage	Horizontal drain holes
4. SLOPE WORK	Pitching Work	Stone pitching
		Block pitching
		Concrete pitching
	Paving work (for road shoulder)	Concrete paving
		Asphalt paving
	Cribs	Concrete block cribs
		Cast-in-place concrete cribs
		Shotcrete cribs
	Anchoring	Soil nailing
		Rock bolts
5. WALLS AND OTHER STRUCTURES	Retaining Walls	Concrete retaining walls[1)]
		Gabion retaining walls
	Reinforced earth	Reinforced earth walls[2)]
	Others	Sand bag

Note: 1) Concrete retaining walls include five types [refer to Table 3.9 of Chapter 3].
2) For reinforced earth walls, refer to Table 6.3.

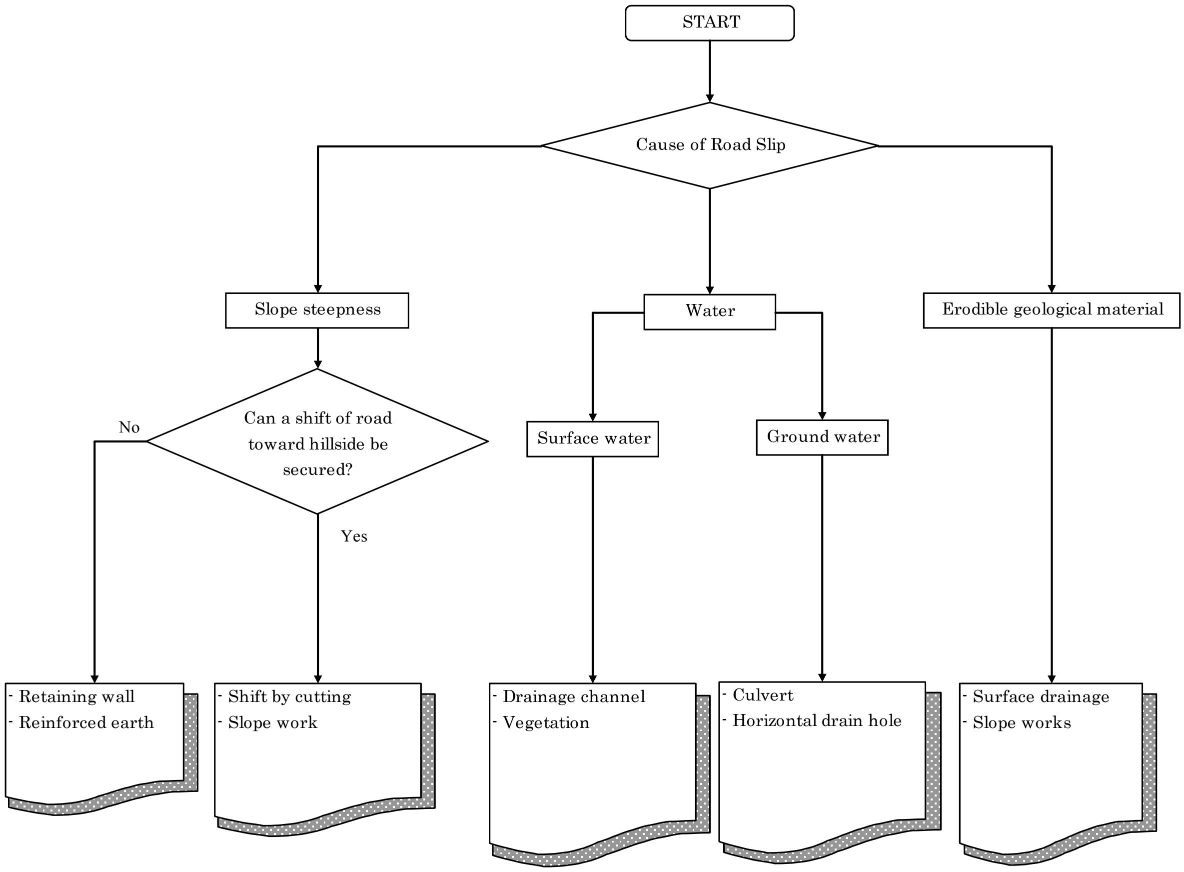


Figure 6.3 Selection Flowchart for Countermeasures against Road Slips

Table 6.2 Application of Countermeasures against Road Slips

TYPE OF WORK		Durability	Maintenance	Construction Ease	Construction Cost	Degree of Safety
1. EARTH WORK	Cutting	○	◎	○	◎	◎
	Filling	○	△	○	◎	○
2. SURFACE COVER	Seed spraying	○	○	○	◎	△
	Seed mud spraying	○	○	△	◎	△
	Turfing (Sodding)	○	○	△	◎	△
3. DRAINAGE	Drainage ditches	○	○	◎	◎	○
	Horizontal drain holes	○	△	○	○	△
4. SLOPE WORK	Stone pitching	○	○	◎	◎	○
	Block pitching	○	○	◎	○	○
	Concrete pitching	○	○	◎	○	○
	Concrete paving	○	○	◎	○	○
	Asphalt paving	○	○	◎	○	○
5. WALLS AND OTHER STRUCTURES	Concrete retaining walls	◎	◎	○	○	◎
	Gabion retaining walls	◎	◎	◎	◎	○
	Reinforced earth walls	◎	◎	◎	△	◎
	Sand bags	◎	◎	◎	△	◎

Note: ◎ = Very good or very easy, ○ = Good or easy, △ = Good or easy in some cases.

6.4 Design of Main Countermeasures

6.4.1 Reinforced Earth Walls

This method, which has the function of a retaining wall, has been widely used in unstable sites in mountainous areas in recent years. It is a technically attractive and cost-effective technique for increasing the stability of natural soil and constructed fill slopes and for reducing earth pressures against retaining walls. The method is ideal for very high or heavily loaded retaining walls because of its high load-carrying capacity.

The method consists of three parts, namely, 1) wall facing materials, 2) reinforcement materials and 3) backfill materials. Wall facing materials include precast concrete blocks and concrete panels, cast-in-place concrete and steel wire boxes. Reinforcement materials include steel belts (strips), anchor plates or bars, welded wire sheets, geotextiles, geogrids, and fibers. Backfill materials are non-cohesive granular soils.

(1) Purpose

Reinforced earth walls are used to prevent small-scale soil collapse and road slips on steep and large slopes in lieu of retaining walls. The method is the best solution to situations such as restricted right-of-way and steep road slips.

(2) Design Considerations

The method requires the inclusion of tensile resistant elements in a soil mass to improve its overall shearing strength and thereby increase the capacity of the retaining wall. Figure 6.4 gives the conceptual mechanism of reinforced earth walls.

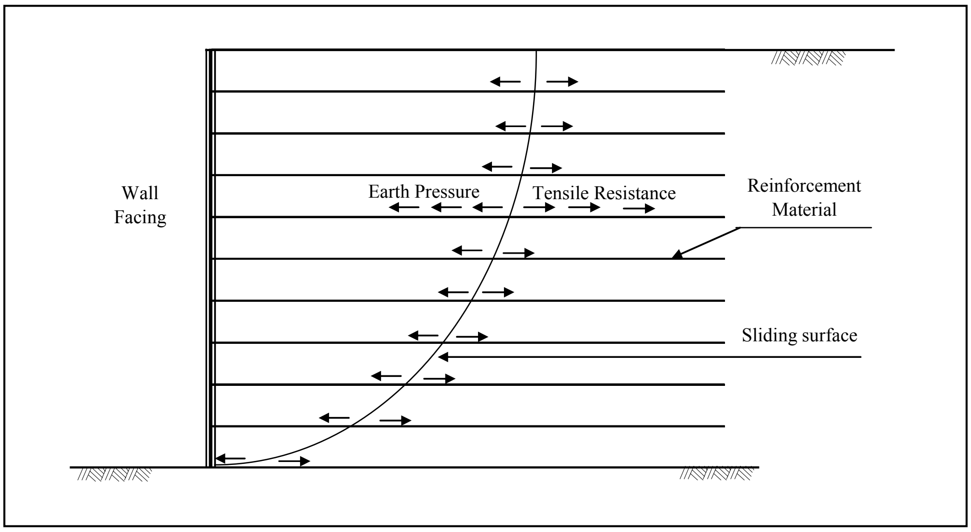


Figure 6.4 Conceptual Mechanism of Reinforced Earth Walls

Since the first reinforced earth wall (Terre Armee) was developed in the 1960s, many other types of reinforced earth walls have been developed. Table 6.3 summarizes the methods and the characteristics of the most typical reinforced earth walls. Figure 6.5 gives the images of reinforced earth walls.

Table 6.3 Typical Reinforced Earth Walls

Method	Reinforcement Materials	Wall Facing Materials	Characteristics	Remarks
Terre Armee Wall	Steel belts (Strips)	Concrete panels	Improve the retaining function of the wall by tensile resistance due to the increased frictional force between strips and backfill.	• Granular soil with low friction • Galvanized (corrosion treatment) steel strips should be used
Anchor Reinforced Earth Walls	Anchor plates & bars	Concrete panels	Improve the strength of the retaining wall by applying tensile force from the anchor plate.	• Sandy or gravely soils having high friction • Corrosion treatment for steel bars
Geotextile Reinforced Earth Wall	Geotextiles	Concrete panel and block, cast-in-place concrete, Steel wire box	Reduce the load on the retaining wall by increasing the frictional force between the geotextiles and the backfill.	• Angular gravels will damage the geogrids. • Tensile strength of geogrids is subject to deterioration by high temperature.

Source: Modification from reference No. 3 Highway Earthwork Series, MANUAL FOR RETAINING WALLS, Published by Japan Road Association, March 1999.

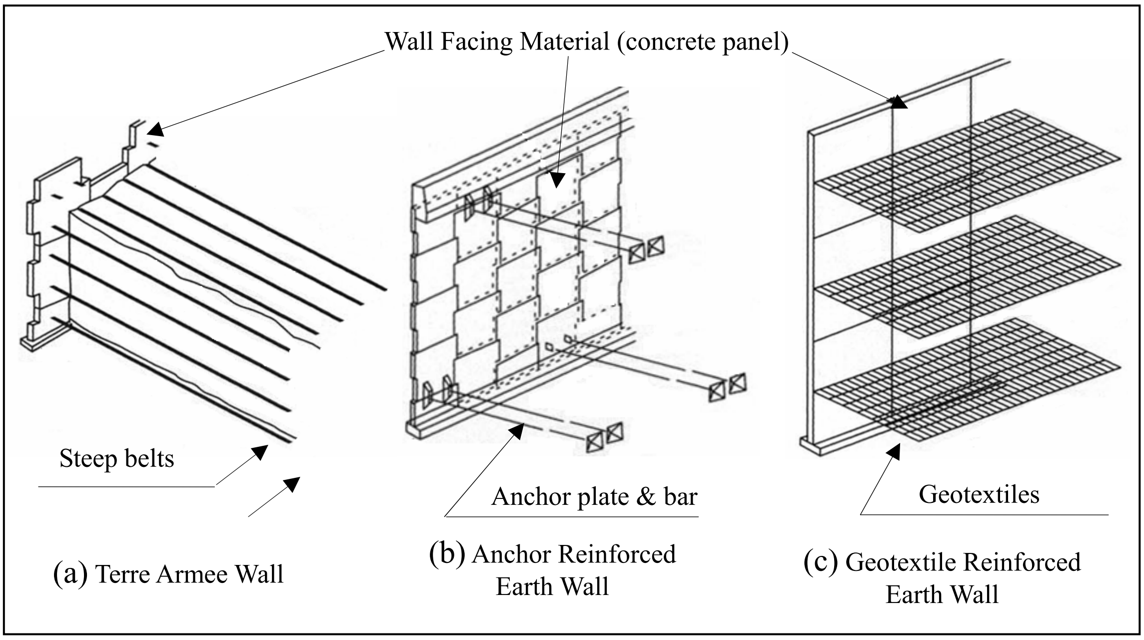


Figure 6.5 Schematic Drawing of Reinforced Earth Walls

In principle, the design of reinforced earth walls includes (a) Internal stability analysis, (b) External stability analysis, and (c) Overall stability analysis, as graphically shown in Figure 6.6.

For (b), the stability analyses are similar to that for retaining walls, including sliding, overturning and bearing capacity of the foundation.

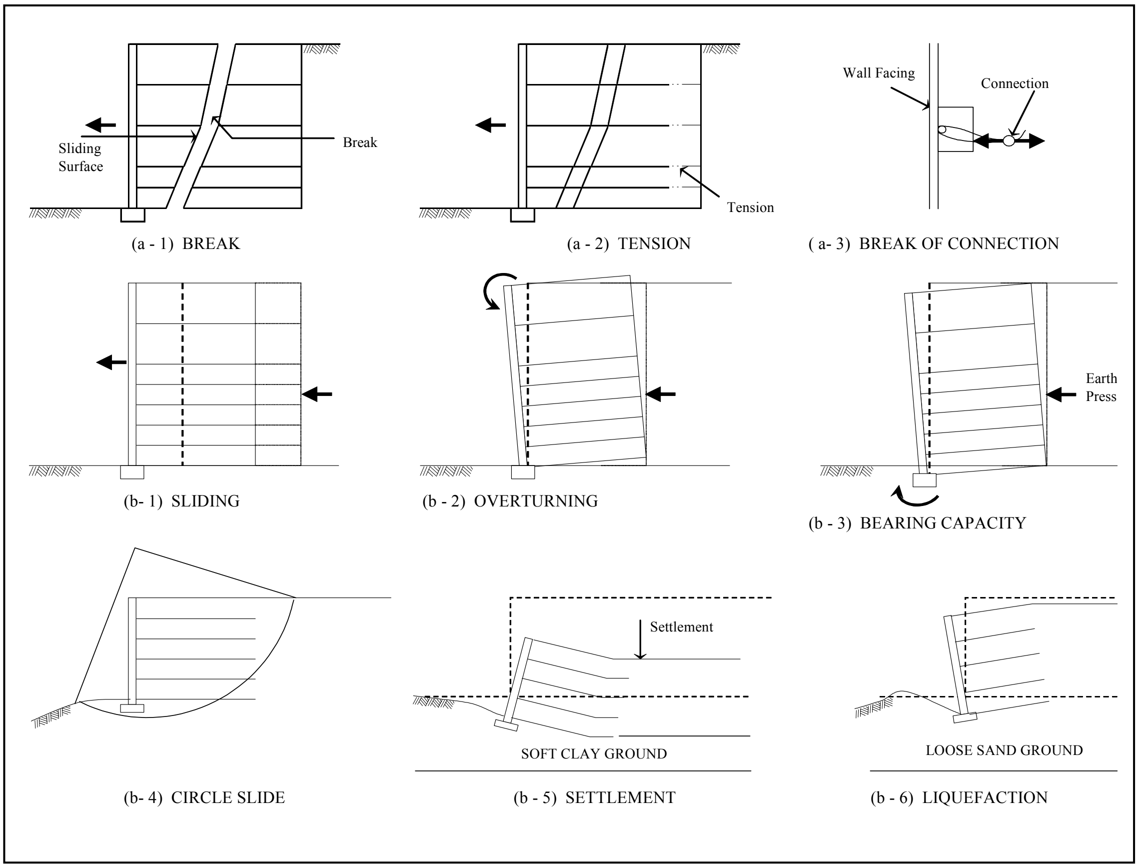


Figure 6.6 Collapse Modes and Issues to be Considered in Design

Figure 6.7 gives the general design procedure for reinforced earth walls. Geotechnical parameters relevant to reinforced earth wall design include unit weight, stress strength of the backfill and ground, and bearing capacity of the ground. Detailed guidance on the selection of such parameters is in the other chapters of this Guide.

For each design situation, concentrated or distributed loads, which may result in forces acting on the reinforced earth wall, are evaluated. The general types of direct loads are a) Deadweight, b) Surcharge, c) Earth pressure, d) Water pressure and e) Seismic load.

No common method for stability analysis is applicable to all reinforced earth walls. Table 6.4 gives a comparison of stability analysis among the typical reinforced earth walls.

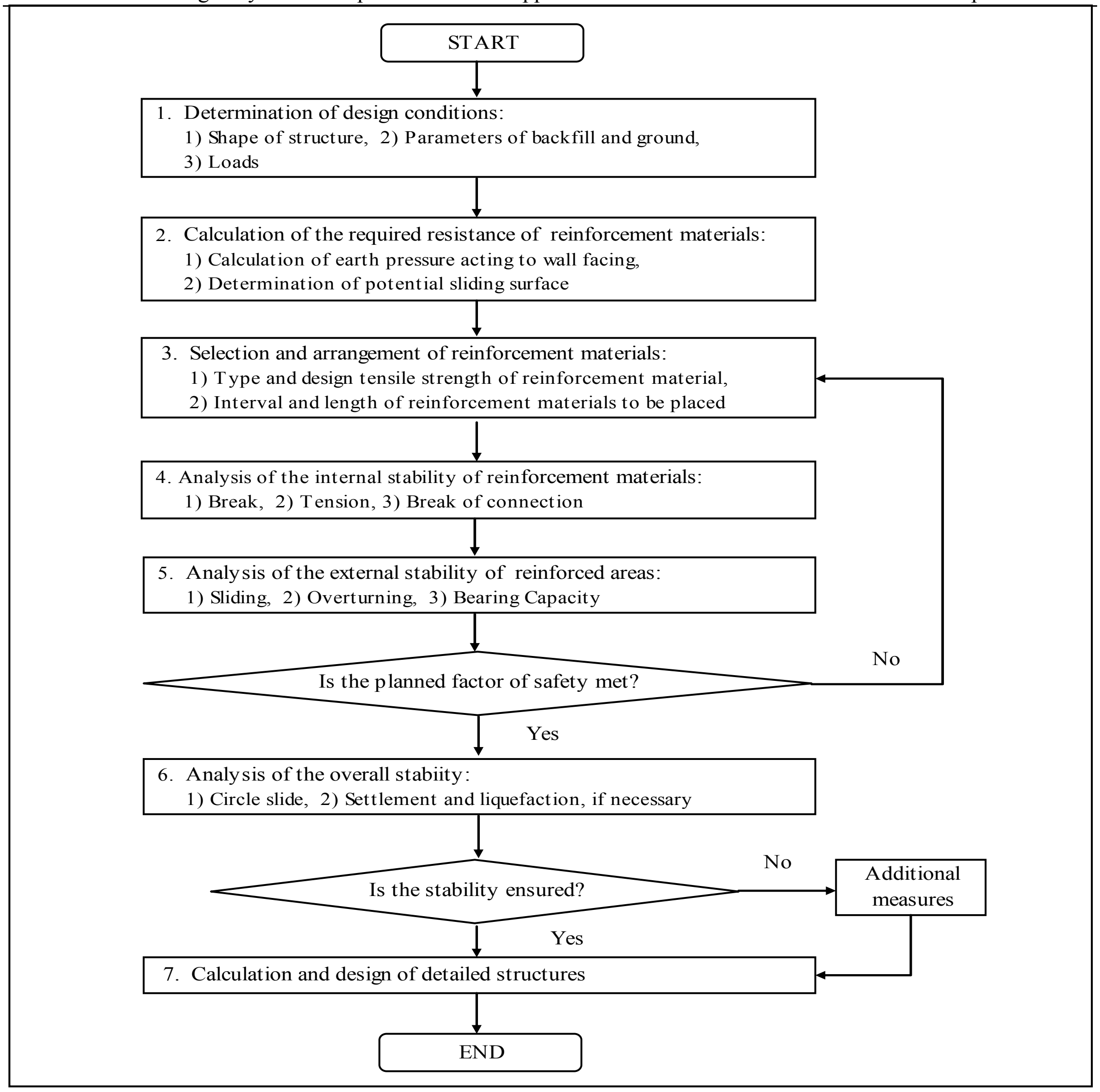


Figure 6.7 Design Procedure for Reinforced Earth Walls

Table 6.4 Comparison of Stability Analysis for Typical Methods

	Items to be evaluated	Terre Armee Wall	Anchor Reinforced Earth Wall	Geotextile Reinforced Earth Wall
Internal	Sliding line for calculation	2 straight lines	Circle line	Active failure line
	Break of reinforcement material	○	○	○
	Tension of reinforcement material	○	○	○
	Internal sliding	—	○	—
External	Circle slide	○	○	○
	Sliding of wall	—	○	○
	Overturning of wall	—	○	—
	Bearing capacity of ground for walls	—	○	○

Note: ○ = Must be evaluated, — = No need to be evaluated.

Source: Modification from reference No. 7 DESIGN AND CONSTRUCTION MANUAL FOR MULTISTAGE ANCHOR TYPE REINFORCED EARTH WALL, Third Edition, Published by Public Works Research Institute, October 2002.

The retaining effect of reinforced earth walls depends primarily upon the tensile resistance between the reinforcement materials and backfill materials. The effective tensile resistant force (R/Fs) is calculated by using the following equation.

$$\frac{R}{F_s} = \frac{2(c+\sigma\tan\phi)\times L_E}{F_s} \quad \cdots\cdots (6.1)$$

Where,

R=Tensile resistance force of reinforced material in unit width (kN/m)

F_s=Factor of safety for tensile resistance

c=Cohesion between reinforcement material and backfill material (kN/m^2)

φ=Frictional angle between reinforcement material and backfill material (degrees)

L_E=Embedding length=length of reinforcement material below sliding surface (m)

Table 6.5 gives the effective tensile resistance forces of typical reinforcement materials in the case of backfill materials having a frictional angle of 30 degrees.

The selection of appropriate granular backfill materials in the reinforced earth mass is critical for developing the effective tensile resistance of the reinforced earth walls. The grain size of the backfill material to be used should be in the range of 75 mm (fine fraction) to 300 mm (coarse fraction).

Table 6.5 Effective Tensile Resistance Force of Typical Reinforcement Materials

Reinforcement Materials	Dimension of Reinforcement Materials	Conditions of Placement	Effective Tensile Resistance Force (kN/m)
Geogrids	1 to 3.7 m in width	1) 100%	1) $\sigma\tan30^{o}\times L_E$
		2) 50%	2) $\sigma\tan30^{o}\times L_E$
Steel belts (strips)	60 mm	1) ⊿B=1.5m	1) $(0.93+\sigma\tan1.6^{o})\times L_E$
		2) ⊿B=1.0m	2) $(1.39+\sigma\tan2.5^{o})\times L_E$
		3) ⊿B=0.75m	3) $(1.86+\sigma\tan3.3^{o})\times L_E$
		4) ⊿B=0.50m	4) $(2.79+\sigma\tan4.9^{o})\times L_E$
		5) ⊿B=0.375m	5) $(3.72+\sigma\tan6.6^{o})\times L_E$
		6) ⊿B=0.25m	6) $(5.58+\sigma\tan9.7^{o})\times L_E$
Anchor plates & bars		⊿B=0.75m, $L_E\geqq1.2$m	$\sigma\tan28.3^{o}$, (Fs =3.0)

Notes: (1) The effective tensile resistant forces were calculated on the basis of backfill with a frictional angle of 30 degrees.
(2) ⊿B = Horizontal interval of reinforcement materials.

Source: Modification from reference No. 19 Ogawa et. al Bulletin of Civil Engineering Works 1998.11, Latest Technical Status of Reinforced Soil

Table 6.6 gives the applicability of backfill materials for different types of reinforced earth walls.

Table 6.6 Applicability of Backfill Materials

Methods	Reinforcement Materials	Backfill Materials	
		Fine Fraction	Coarse Fraction
Geotextile Reinforced Earth Wall	Geogrids	Less than 50%	
Terre Armee Wall	Strips	Less than 25%	$G_M \leqq$ 300 mm
Anchor Reinforced Earth Wall	Anchor plates & bars	$W_L \leqq$ 50% or fine fraction is more than 50% when $W_L \geqq$ 50%	$G_M \leqq$ 300 mm

Note: G_M = Maximum diameter grain size, W_L = Liquid limit.

In order to maintain the reinforcement effectiveness of the reinforced earth walls, backfill drainage must be carefully considered and designed. Figure 6.8 gives an example of a road slip restored using a Terre Armee Wall.

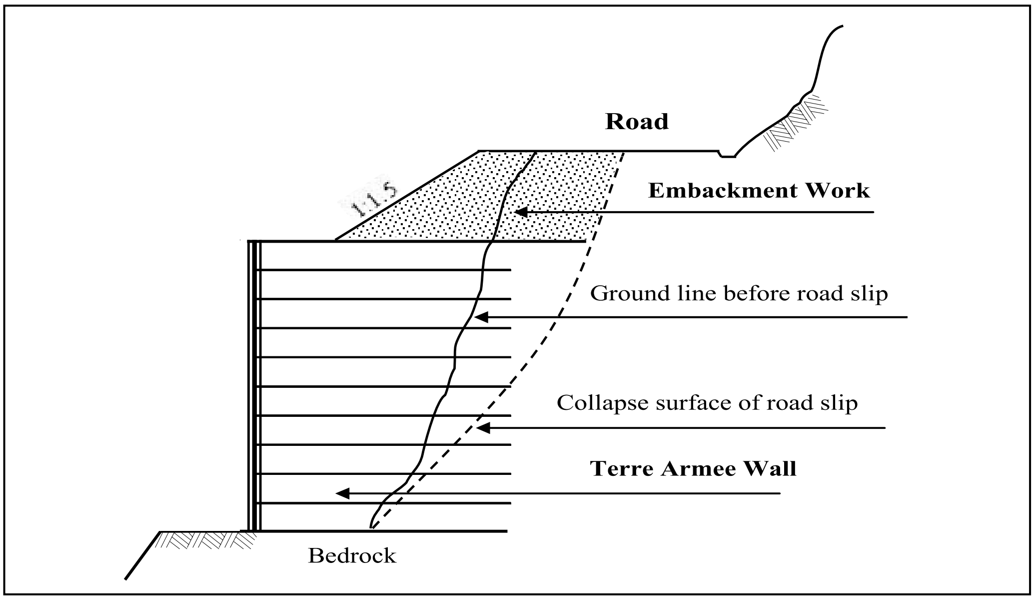


Figure 6.8 Example of a Road Slip Restored Using a Terre Armee Wall

6.4.2 Sand Bag Walls

Sand bag walls (trade name: solpack) are among the newly developed geotextile reinforced earth walls in Japan. Similar to geotextile sheet reinforcement, the method provides the retention effect of a wall by using a number of geotextile bags filled with granular soils. Because sand bag retaining walls consist of many sand bags, the resistance and stability of the method provides significant load-bearing capacity against both static and dynamic loads. The ease and speed of construction reduces overall cost and makes it ideal for the urgent treatment of road slope disasters.

(1) Purpose

Sand bag walls are generally designed to function as retaining walls, that is, they retain soil mass on steep slopes or in restricted right-of-way situations. Typical applications include the restoration and stabilization of road slips, highway retaining walls on steep slopes, and embankment walls for temporary or permanent road widening.

(2) Design considerations

Sand bag walls are designed in the same way as leaning concrete retaining walls and concrete crib retaining walls. Figure 6.9 gives a design flowchart for sand bag walls.

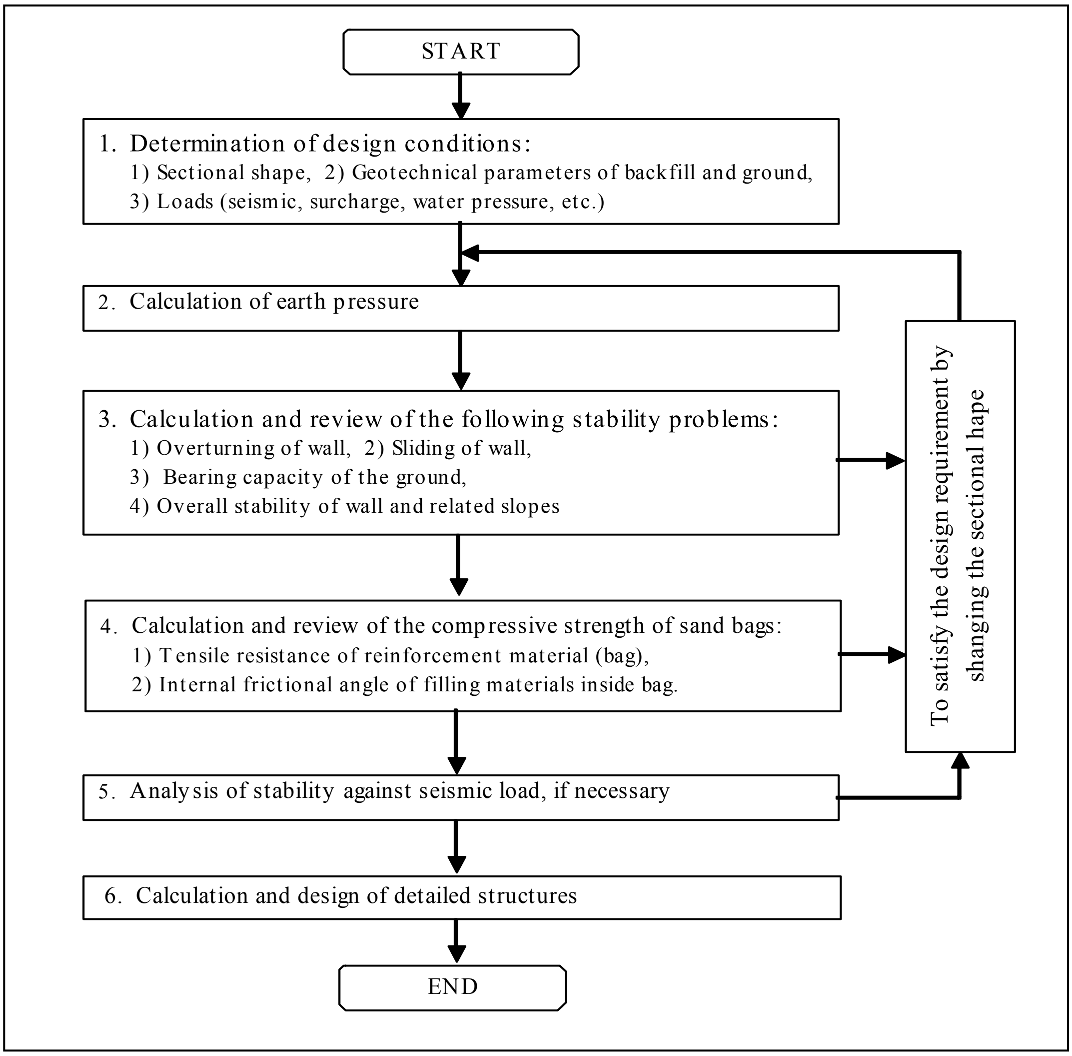


Figure 6.9 Design Flowchart for Sand Bag Walls

The stability of the method is reviewed by using the following equations, based on the criteria given in Table 6.7.

Table 6.7 Criteria for the Stability Analysis of Sand Bag Walls

Item	In Normal Case	In Seismic Case
1) Overturning	e ≦ B/6	e ≦ B/3
2) Sliding	Fs ≧ 1.5	Fs ≧ 1.2
3) Bearing capacity	Fs ≧ 3.0	Fs ≧ 2.0
4) Compressive strength	Fs ≧ 3.0	Fs ≧ 2.0

Note: e = Acting range of resultant, Fs = Factor of safety, B = Base width of wall.

Source: Modification from reference No. 3 Highway Earthwork Series, MANUAL FOR RETAINING WALLS, Published by Japan Road Association, March 1999.

(a) Stability analysis for overturning of wall

$$e = \frac{B}{2} - \frac{\sum Mr - \sum Mo}{\sum V} \quad \cdots\cdots (6.2)$$

Where,

e= Acting range of resultant (m)

d= Acting point of resultant (m)

$\sum V$= Sum of vertical loads acting on base slab (kN/m)

$\sum Mr$= Resistant moment for base slab (kNm)

$\sum Mo$= Overturning moment for base slab (kNm)

B= Width of base slab (m)

(b) Stability analysis for sliding of wall

$$Fs = \frac{\sum V \times \mu + c \times B}{\sum H} \quad \cdots\cdots (6.3)$$

Where,

Fs: Factor of safety for sliding

$\sum V$= Sum of vertical loads acting on base slab (kN/m)

$\sum H$= Sum of horizontal loads acting on base slab (kN/m)

μ= Friction coefficient of base slab

c= Cohesion of base slab or sand bags (kN/m^2)

B= Width of base slab (m)

(c) Stability analysis for bearing capacity of foundation

$$q =\leq q_a = \frac{q_u}{Fs} \quad \cdots\cdots (6.4)$$

Where,

q= Bearing capacity of the ground (kN/m^2)

q_a= Allowable bearing capacity of the ground (kN/m^2)

q_u= Limiting bearing capacity of the ground (kN/m^2)

Fs= Factor of safety for bearing capacity of the ground

(d) Stability analysis for sand bags

$$q_s = 2 \times \frac{T}{B}(m \times K_p - 1)(\frac{m}{m+1})^2 \quad \cdots\cdots (6.5)$$

Where,

q_s= Compressive strength of sand bags (kN/m^2)

$m=B/H$

B= Loading width of sand bag wall (m)

H= Height of sand bag wall (m)

T= Tensile resistance of bag reinforcement materials (kN/m)

Kp= Coefficient of passive earth pressure.

In checking the strength properties of the fill material inside the bag, the internal frictional angle of the fill materials is indirectly estimated on the basis of the soil classification. In the case of good-quality gravel or crushed rock blocks, their internal frictional angles should be more than 35 degrees. Therefore, the design frictional angle should be less than the estimated values.

Reinforcement materials (bag) provide tensile reinforcement to the filling materials. The reinforcement materials should be a proprietary product with a corresponding endorsement certificate. The strength of the reinforcement material should be checked for compliance with the product specifications.

Because geotextiles are subject to vandalism and deterioration from ultraviolet light, the exposed sand bags must be covered with precast concrete, vegetation, soil, sheets or other materials for long-term protection.

Figure 6.10 gives an example of a road slip restored by using a Sand Bag Wall.

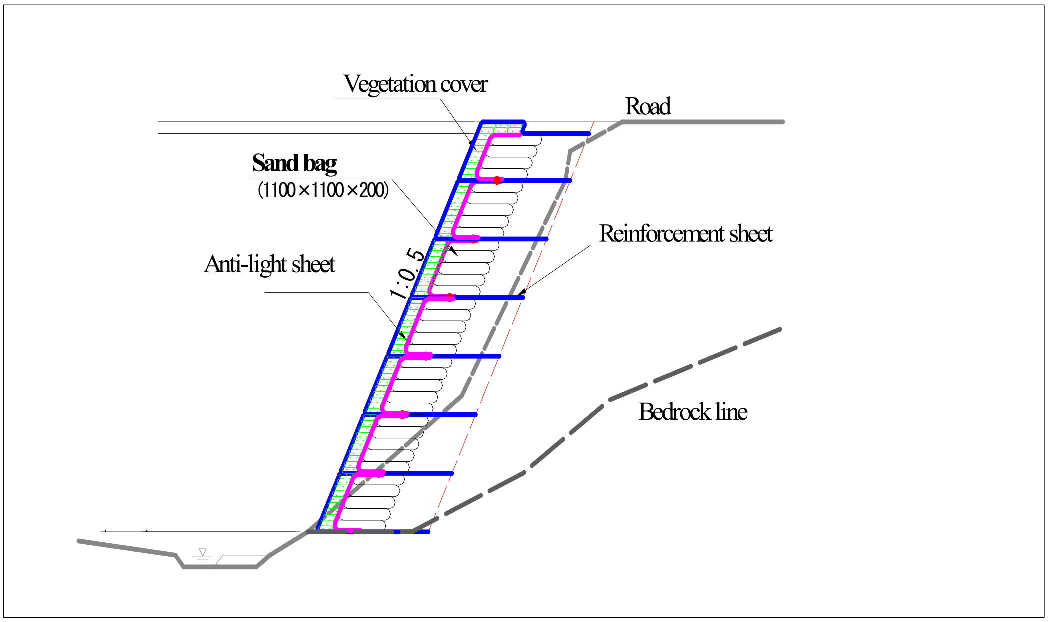


Figure 6.10 Example of Road Slip Restored by Using a Sand Bag Wall