CHAPTER 7

COUNTERMEASURES AGAINST DEBRIS FLOW

7.1 General

Debris flow is the fast movement of rock fragments, earth and mud mixed with water, along a valley or a mountainous stream. Because of its speed, debris flow is dangerous to life and property, destroying objects in its path.

Debris flow countermeasure plans for hazardous streams are, in principle, formulated to cope with debris flow rationally and effectively, considering the frequency and scale of debris flow occurrences.

Debris flows involve three areas, namely, the source area, transport zone, and accumulation area. The countermeasures for debris flow are different for each of these areas and they should be considered separately.

For source areas, the type and extent of conceivable countermeasures shall basically be the same as those for soil slope collapses and landslides. Design considerations and purposes of these methods are given in Chapters 3 and 5, respectively. However, because of the wide area involved, vegetation and cutting works are the most cost-effective.

This chapter will focus on methods to be used for the transport zones and accumulation areas relevant to road facilities.

Moreover, design of river works relevant to road slope disasters shall refer to Technical Standards and Guidelines for Planning and Design, Volume III, SABO (EROSION AND SEDIMENT CONTROL) WORKS, *Project for the Enhancement of Capability in Flood Control and Sabo Engineering of DPWH*, March 2002.

7.2 Selection of Countermeasures

7.2.1 Classification of Countermeasures

Table 7.1 provides the general classification of countermeasures for debris flow. The principal countermeasures are classified into three categories according to their functions and the location of implementation; a) Debris flow capturing works, b) Debris flow guiding works and c) Debris flow prevention works.

(1) Debris flow capturing works

Sabo dams (stepped dams) are a typical example of this type of structure, and include impermeable and permeable types. Their main functions are to: (1) reduce the volume of sediment discharge and (2) prevent the movement of sediments on streambeds, consequently reducing the impact of debris flow, as shown in Figure 7.1.

Table 7.1 Classification of Countermeasures for Debris Flow

CLASSIFICATION		TYPE OF WORK
1. EARTH WORK	Earth Work	Removal
		Cutting
		Embankments
2. VEGETATION	Vegetation	Hydroseeding
		Re-Vegetation
3. DRAINAGE	Surface Drainage	Drainage Ditches (Channels)
	Water Ways	Stone Pitching Water Ways
		Concrete Pitching Water Ways
4. SLOPE WORK	Shotcrete Work	Shotcrete (mortar)
		Shotcrete (concrete)
	Crib Work	Crib Work
6. WALLS AND RESISTING STRUCTURES	Retaining Walls	Gabion Walls
		Stone Pitching Walls
		Retaining Walls (Gravity Type)
		Retaining Walls (Supported Type)
	Catch Work	Catch Gabions and Concrete Walls
	Causeways	Causeways
7. PROTECTION WORK	Rock Sheds	Debris Flow Sheds
	Sabo (Check) Dam	Slit Dams
		Check Dams (Sabo Dams)
8. OTHERS	Avoiding Problem Areas	Bridges (or Culverts)
		Route Relocation

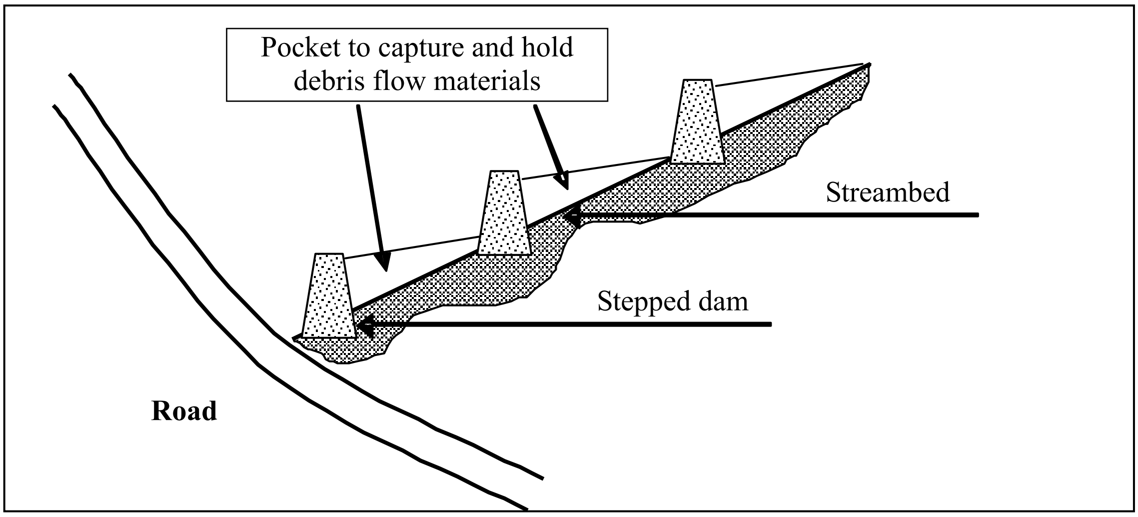


Figure 7.1 Conceptual Diagram of Stepped Dams

(2) Debris flow guiding works

Typical works are revetments, guiding levees, channels, bridges, culverts, and sheds. These measures are used to direct debris flows to a safe place and control the direct impact of debris flow on the objects (roads) to be protected, as shown in Figure 7.2.

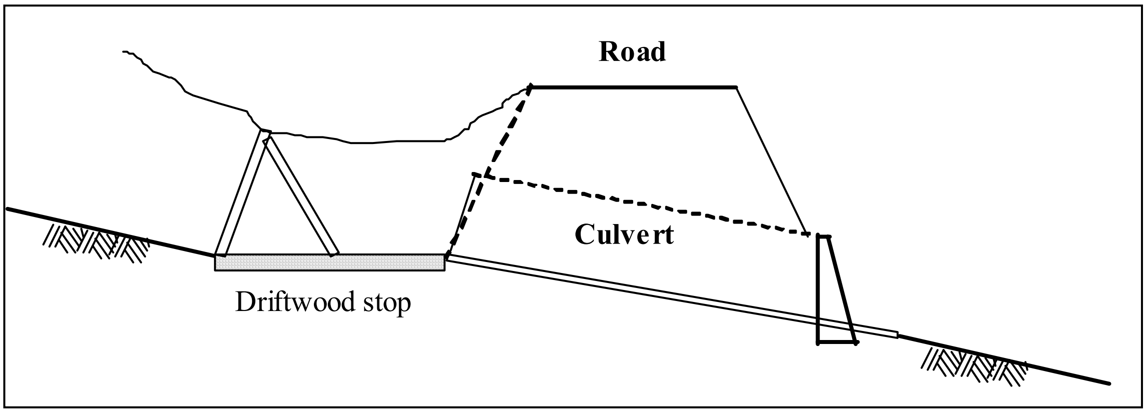


Figure 7.2 Conceptual Diagram of a Culvert

(3) Debris flow prevention works.

Debris flow usually occurs in which unstable sediments in a stream are abundant; thus, it is useful to prevent the supply of stream sediments from the mountainous slopes. Debris flow prevention works should be undertaken on mountainous slopes through forest work, vegetation and some types of structures to prevent soil slope collapse, landslides and other slope failures.

7.2.2 Criteria for Selection of Countermeasures

Figure 7.3 shows a flowchart for the selection of countermeasures for debris flows. In planning the countermeasures for a stream prone to debris flow, various types of countermeasures can be reasonably combined in consideration of the likely occurrence, frequency, volume (scale), flow characteristics, topography, and the objects to be protected.

The basic sabo plan for debris flow should be formulated to effectively control the harmful sediments within the affected area.

The heights of the streambed and road surface are the most important conditions for the selection of countermeasures against debris flows. For streams with a high frequency of debris flow occurrence, the following criteria are used for selection and planning.

a) If a road exists in the upper part of the debris flow accumulation area (where the slope of the streambed is steeper than 3 degrees), it is advisable for road to be relocated upstream or downstream of the existing road, as shown in Figure 7.4.

b) When the path of the debris flow passes below the road surface, a bridge or culvert is applicable, as shown earlier in Figure 7.2. Whereas a debris flow shed or cover would be used when the path of the debris flow is higher than the road surface, as shown in Figure 7.5.

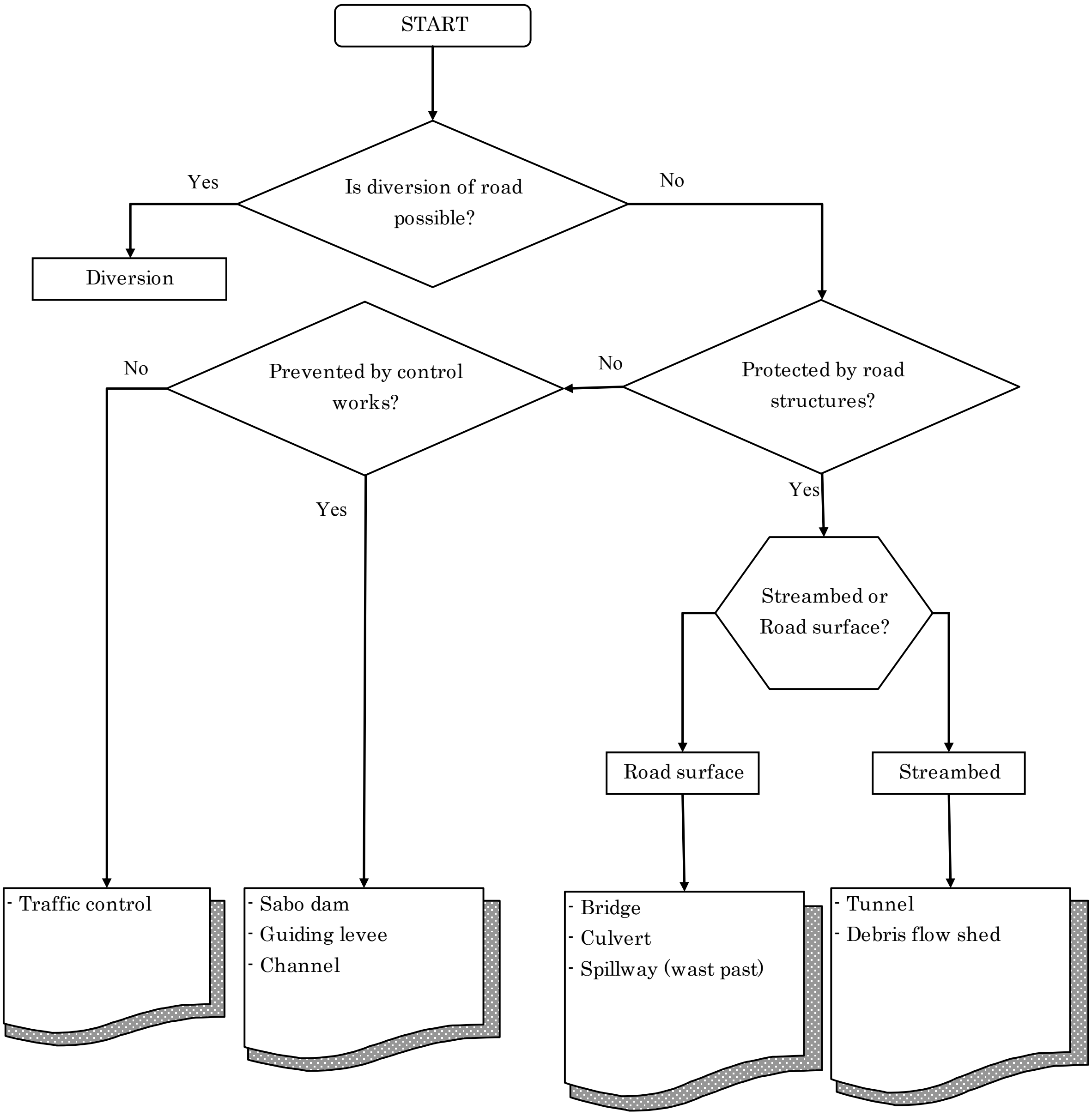


Figure 7.3 Selection Flowchart for Countermeasures against Debris Flows

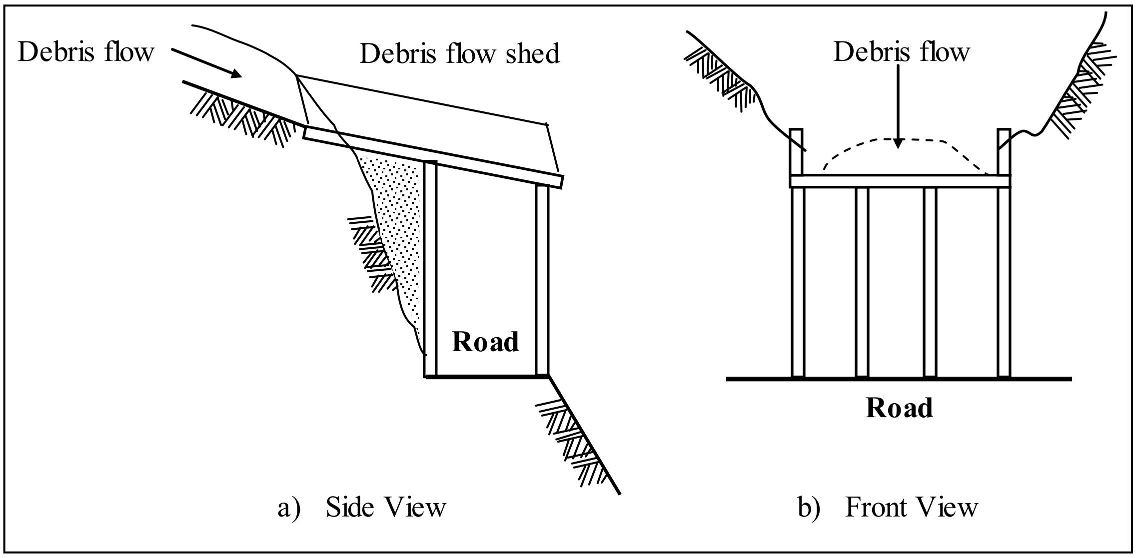


Figure 7.4 Conceptual Diagram of Debris Flow Sheds

c) When the path of the debris flow and the related road surface are of the same height, a causeway is cost-effective (Figure 7.6), where debris flow is allowed to pass over the road surface without presenting an obstacle to the debris flow. In this case, the road surface should have thick pavement that is resistant to the scouring caused by debris flows.

d) The design sediment volume (sediment discharge) is calculated on the basis of surveys of deposits within the streambed, including topographical analysis, field surveys, and records of past debris flow.

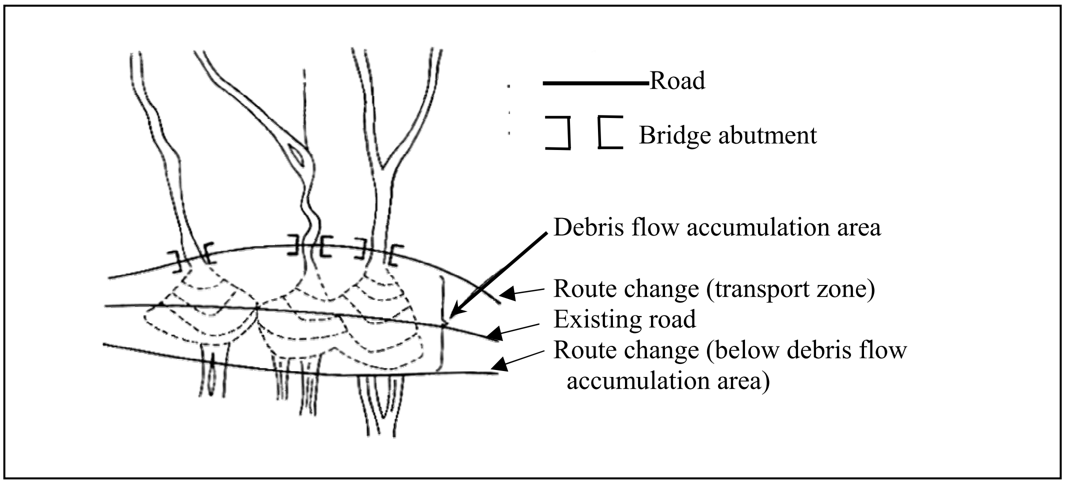


Figure 7.5 Conceptual Diagram for Route Changes

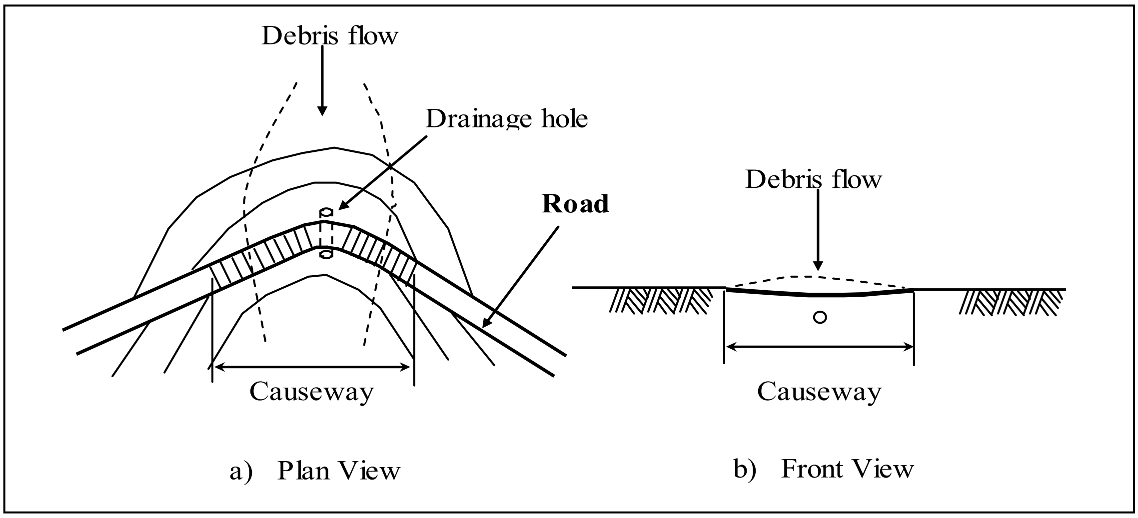


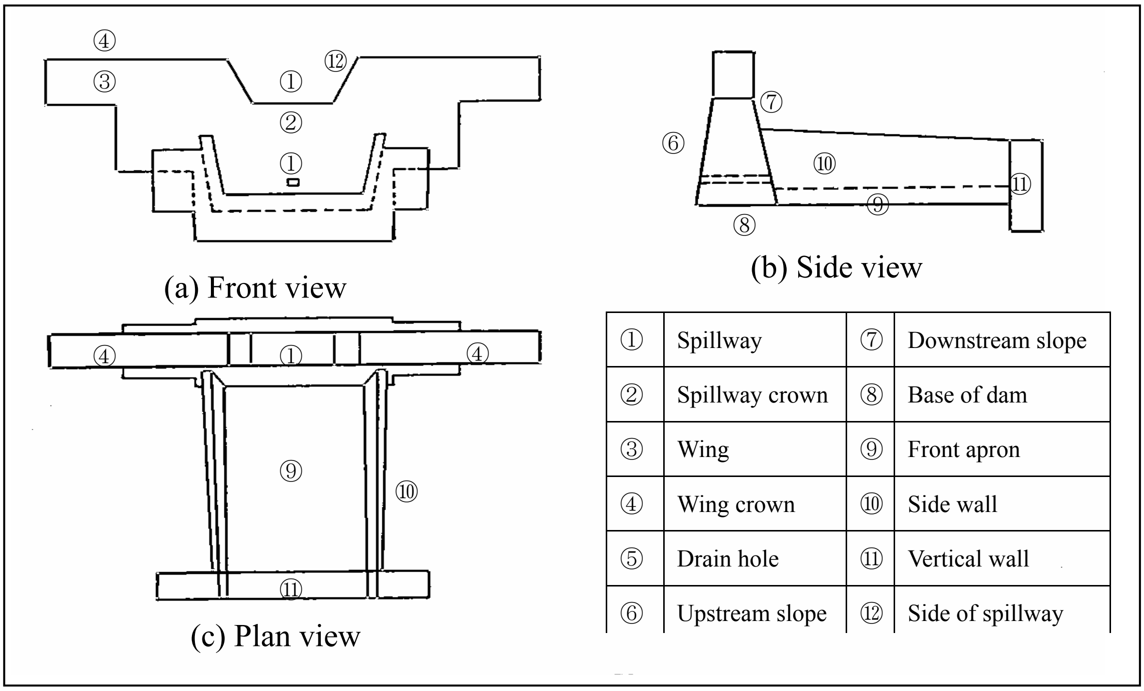
Figure 7.6 Conceptual Diagram of Debris Flow Causeway

7.3 Design of Main Countermeasures

7.3.1 Sabo Dam for Debris Flow

(1) Classifications

Sabo dams are the most common countermeasure against debris flow. They are generally constructed from masonry, concrete, reinforced concrete, steel cribs, etc. Figure 7.7 diagrammatically illustrates the dam section and nomenclature.



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

Figure 7.7 Diagrammatical Dam Section and Nomenclature

Sabo dams are classified into the following five types according to their purpose.

a) Spur consolidation dam

b) Riverbed erosion control dam

c) Riverbed sediment runoff control dam

d) Debris flow control dam

(a) Spur consolidation dam

A spur consolidation dam prevents hillside failure and further collapse of an adjacent area by raising the riverbed at a spur (hillside foot) through the accumulation and consolidation of sediment (Figure 7.8). It is constructed immediately below the hillside to be protected from erosion. The height of the dam should be adequate to contain the projected sediment volume.

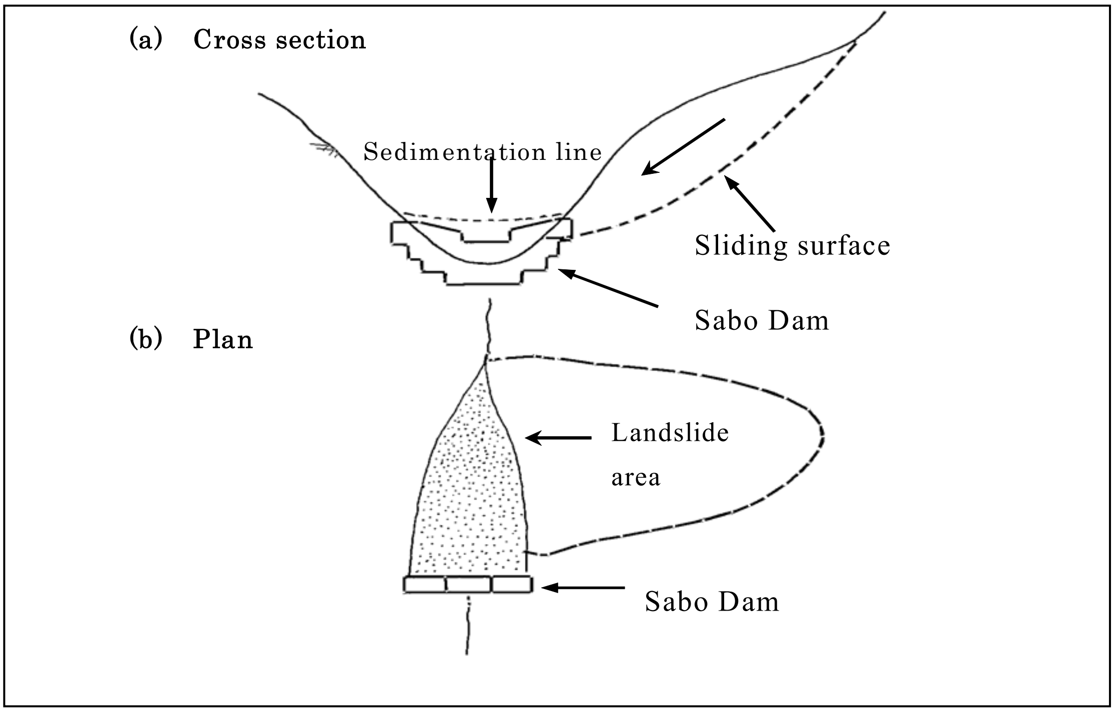


Figure 7.8 Typical Example of Landslide Stabilized by a Sabo Dam

(b) Riverbed erosion control dam

A riverbed erosion control dam prevents riverbed erosion and sediment production (Figure 7.9). It is constructed immediately downstream of a riverbed erosion area. Its height should be adequate to contain the riverbed erosion and sediment accumulation areas.

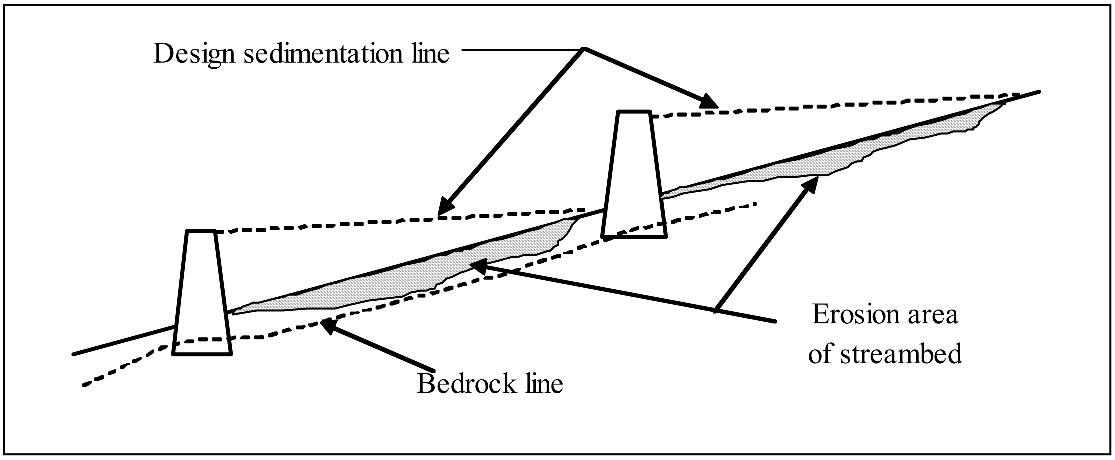


Figure 7.9 Stepped Dams for Riverbed Erosion Control

(c) Riverbed sediment control dam

Similar to a riverbed erosion control dam, a riverbed sediment control dam prevents further transport of unstable sediments that have accumulated on the riverbed. It is constructed immediately downstream of the accumulated riverbed sediments. The height of the dam should be adequate to contain the riverbed sediments within the accumulation area.

(d) Debris flow control dam

A debris flow control dam prevents or controls debris flow sediments. Its location and height is determined according to its purpose, such as prevention and elimination of debris flow.

In planning a sabo dam for the prevention of debris flow, its accumulating capacity is determined to provisionally be more than 30% of the design excess sediment that causes debris flow.

For eliminating debris flow, the location, height, shape and number of dams should be able to change debris flow area into a bed-load area.

(2) Purpose

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

(3) Design Considerations

In designing a sabo dam, the location and scale (height and section) of the dam is determined according to its purposes. The height of dam is sometimes restricted by the geological and topographical conditions at the dam's location, and therefore these should be given due consideration. In principle, the dam is located on stable ground beyond the unstable area because sabo dams are easily destroyed by slope failure when constructed in an unstable area. Locating the dam in a narrow section with a wider section upstream is desirable for improving cost-effectiveness. Also, the sabo dam should be located close to the related road.

Sabo structures are designed according to the intended functions/purposes and should be stable enough to withstand all the expected design forces. Figure 7.10 gives the general design procedure for a sabo dam for debris flow.

In designing the opening section for debris flow, the width of the crest opening, generally over 3m, should be determined on the basis of the width of the existing streambed. The height of the opening is determined considering the design depth, freeboard and the maximum diameter of the boulders expected to be contained in the debris flow.

START

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1. Determination of general design conditions:
   1) Catchment area, 2) Gradient of present streambed, 3) Bearing capacity of dam foundation, 4) Design return period and design rainfall per day (R_{24})

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2. Determination of design parameter of debris flow:
   1) Design flood discharg for debris flow, 2) Design sediment discharge for debris flow, 3) Peck discharge, 4) Depth and velocity of debris flow, 5) Hydro force of debris flow

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3. Design of opening section:
   1) Width of crest opening, 2) Design discharge (1.5 design flood discharge),
   3) Design depth for design discharge, 4) Freeboard for design discharg,
   5) Height of opening

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4. Design of dam body for debris flow:
   1) Calculation of all load, 2) Calculation of the moments at upstream end,
   3) Stability Analysis (overturning, tensile stress, sliding, bearing capacity of foundation)

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5. Design of dam foundation:
   1) Settlement of foundation ground, 2) Erosion and scouring of foundation

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6. Design of other appurtenances:
   1) Wing (sectional shape, wing end, wing slope), 2) Front protection works

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END

Figure 7.10 Design of Sabo Dam for Debris Flow

The design of the dam body is based mainly on the stability analyses of the dam body in terms of overturning, sliding and foundation bearing resistance. The general criteria for stability analysis for sabo dams are given in Table 7.2. Stability against the settlement of the foundation ground as well as the potential for the dam base to slide across the foundation ground should be considered.

Table 7.2 Criteria for Stability Analysis of a Dam Body

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 dam body.

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

The combination of loads to be used for the stability calculations of the dam section for sabo dams considering the debris-flow hydro force are summarized in Table 7.3. The unit weight of water in the calculation of the hydrostatic pressure in a debris flow should be 11.8 kN/m^3 because the earth and uplift pressures are not considered.

Table 7.3 Combination of Loads for Stability Calculations of a Dam Body

Dam height	During ordinary time	During debris flow	During flood
Less than 15 m		• Hydrostatic pressure • Earth pressure • Debris-flow hydro force	• Hydrostatic pressure
More than 15m	• Hydrostatic pressure • Earth pressure • Uplift force • Inertial force during earthquake • Dynamic water pressure during earthquake	• Hydrostatic pressure • Earth pressure • Uplift force • Debris-flow hydro force	• Hydrostatic pressure • Earth pressure • Uplift force

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

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

7.3.2 Causeways

As shown earlier in Figure 7.6, a debris flow causeway is a simple structure to guide debris flow passing over the road surface. The method is cost-effective only when debris flow occurs at low speed.

(1) Purpose

A causeway is implemented to guide debris flow to pass in the designated direction, thereby preventing damage from debris flow.

(2) Design Considerations

In planning and designing a debris flow causeway, the main consideration are a) The height of the road surface and the height of the streambed at the road site; b) The slope of the streambed upstream of the road; and c) The scale of debris flow and the maximum size of debris flow sediments to be expected.

Debris flow causeway work allows debris flow to pass over only when the streambed immediately upstream of the road is at the same height as the road surface at the location of the causeway. When the streambed is higher than the road surface, debris flow sediments will fall on to the road surface with great energy leading to considerable damage to the road surface and vehicles, and injury to passengers. When the streambed is lower than the road surface, the road will be an obstruction to the debris flow. Figure 7.11 presents the typical layout of a debris flow causeway.

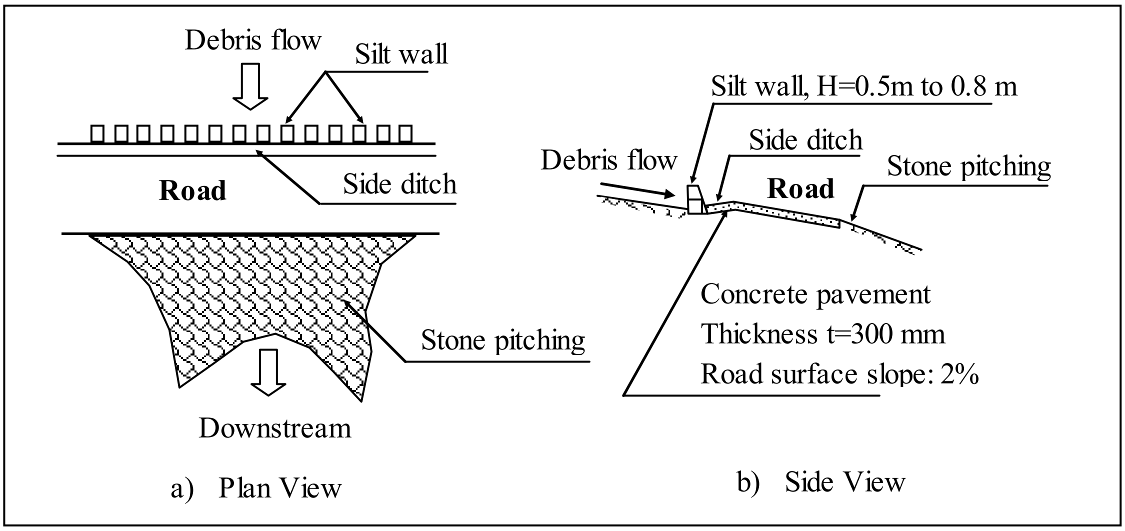

Figure 7.11 Typical Layout of Debris Flow Causeway

When the slope of the streambed is steeper than 5 degrees, debris flow moves fast and with high energy, causing greater damage to the road when it passes over.

A silt wall is recommended to be installed at the hill side to reduce the speed of debris flow and to remove the bigger rock blocks from the debris flow sediments. The silt walls should be gabions or concrete retaining walls.