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砂防基本計画策定指針（土石流・流木対策編）解説（英訳）

土砂災害研究部　砂防研究室

Technical Guideline for Establishing Sabo Master Plan against Debris Flow and Driftwood

Sabo Planning Division
Sabo Department

国土交通省　国土技術政策総合研究所

National Institute for Land and Infrastructure Management
Ministry of Land, Infrastructure, Transport and Tourism, Japan

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概　要

本資料は，国総研資料第904号「砂防基本計画策定指針(土石流・流木対策編)解説」を英訳したものである。

キーワード：土石流、流木、砂防基本計画

Synopsis

This note is the translation of the technical note of NILIM No.904 (Manual of Technical Guidelines for Establishing Sabo Master Plan against Debris Flow and Driftwood, originally written in Japanese in April, 2016).

Keywords: Debris flow, Driftwood, Sabo master plan

Disclaimer

This is a tentative translation of the original written in Japanese in April, 2016. However, some portions are modified or are not translated in case that they seem to be impossible to understand for those who don't know the context of the Japanese system of the technology standard or the domestic situations in Japan.

If what is translated in English is found to be different from what is written in Japanese version, the latter is always true.

This tentative translation could be subject to be changed without any prior notice.

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General Principles

1. Purpose of the Guideline

The Technical Guideline for Establishing Sabo Master Plans against Debris Flows and Driftwood (hereinafter, “Guideline”) presents basic concepts of debris flow and driftwood countermeasures to prevent sediment disasters caused by debris flows and driftwood. It also presents the minimum required items to be applied, which is based on the “*Technical Criteria for River Works*”. This Guideline aims to keep and promote the technical level related to debris flow and driftwood countermeasures.

2. Contents of the Guideline

The Guideline presents the criterion for technical matters related to countermeasure plan, a part of the Sabo masterplan against debris flow and driftwood. Section 1 of the Guideline explains the basic concept of Sabo planning for debris flow and driftwood countermeasures, Section 2 presents basic items in debris flow and driftwood countermeasure planning, and Section 3 describes the debris flow and driftwood control plan. Further, Section 4 discusses the spatial distribution plan of countermeasure structures against debris flow and driftwood and Section 5 defines the sediment and driftwood removal plan. Furthermore, technical matters related to the design of Sabo structures are presented in the "*Technical Guideline for Designing Sabo Facilities against Debris Flow and Driftwood*".

Contents of the Guideline are to be revised periodically according to the improvement of technology.

3. Application of the Guideline

The Guideline shall be applied to prepare the Sabo master plan against debris flow and driftwood. However, it may not be exerted in case the application of the Guideline is not rational. Further, if a more appropriate method is available, such method can be adopted.

Section 1. Overview

> The Sabo master plan against debris flow and driftwood is formulated to protect human lives, property, living environment, and natural environment from sediment disasters caused by debris flows and driftwood, and to contribute to land conservation.
>
> The plan is developed by clarifying and surveying the conditions of the river, natural environment, and characteristics of the history, culture, and economy of the area to be protected.

Explanation

The Sabo master plan against debris flow and driftwood is enacted based on the Guideline. The Sabo master plan against debris flow and driftwood must be based on comprehensive evaluations of the social environment, natural environment, culture, history, and other regional and economic characteristics of the target basin. The evaluation shall include the past occurrence of debris flows and driftwood in the debris flow-prone rivers.

Further, the Guideline can be applied with necessary modifications to target basins where debris flow may occur even outside of debris flow-prone river. However, in such case, appropriateness of application shall be carefully examined considering similarity of the phenomena in debris flow-prone river.

Most debris flows reach a point with riverbed slope of 2° (approximately 1/30) or more. However, runout distances of debris flows shall be determined based on past disasters in the target basin, condition of sediment deposition in the river, and maximum grain size.

The Sabo master plan against debris flow and driftwood is conducted by referring to the flow chart in Figure 1.

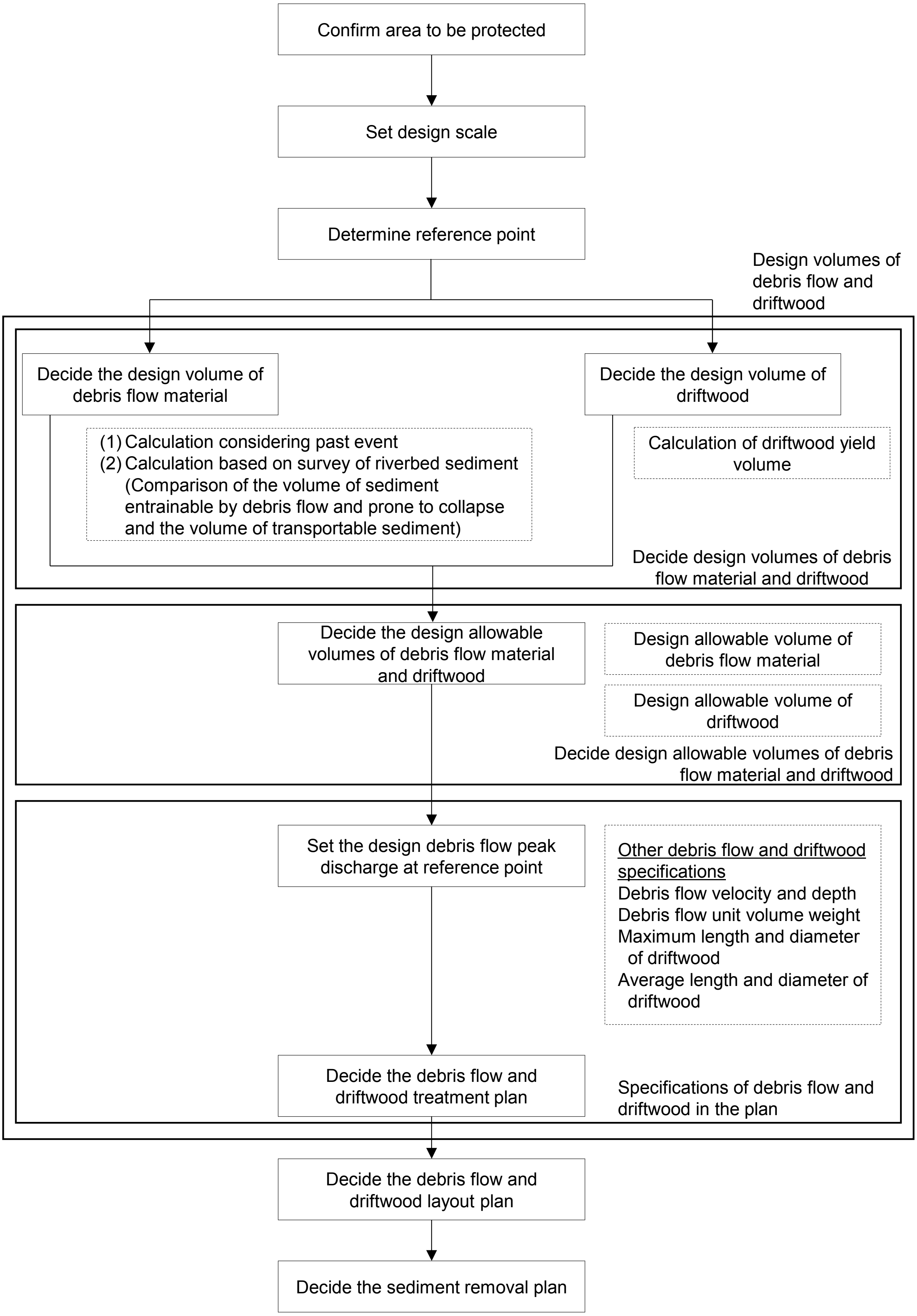

Figure 1 Flow chart of debris flow and driftwood countermeasure planning

Section 2. Basic items in debris flow and driftwood countermeasure planning

2.1 Basic guideline to planning

Debris flow and driftwood countermeasure planning shall be formulated to manage the debris flows and driftwood in a rational and effective manner. Thus, sediment disasters caused by debris flows and driftwood can be prevented.

Explanation

The purpose of countermeasures against debris flow and driftwood shall be achieved upon completion of the project based on the plan. Destructive force of debris flow and driftwood, and sediment inundation caused by blockage of narrow section and/or bridge due to driftwood has an enormous impact on human life, houses, and infrastructures.

Non-structural measures such as warning and evacuation systems shall be implemented to protect human life, houses, and infrastructures from debris flow and driftwood before the completion of the Sabo project. They are also needed for the debris flow of which scale exceeds the design scale. The debris flow with design scale is typically calculated considering annual exceedance probability of rainfall.

Design debris flow and driftwood volumes shall be reviewed and the debris flow and driftwood countermeasure plan shall be revised if the condition of target basin is drastically changed by natural phenomena such as large-scale landslide, occurrence of debris flow, earthquake, slope instability due to volcanic eruption, or by artificial causes such as development of the basin and change of vegetation.

2.2 Objects of protection

> The objects of protection in debris flow-prone rivers are the population, homes, farmlands, and public facilities in the debris flow risk zone. These objects shall be determined by considering the direction and distance from the reference point, and elevation difference between riverbed and foundation of properties.

Explanation

The objects of protection are determined based on the *Debris Flow-prone River and Debris Flow Risk District Survey Methods (tentative)*[1]. The Guideline is applied with necessary changes to plan for Sabo structures in a target basin where debris flow may occur even outside of debris flow-prone rivers.

2.3 Design scale

The design scale of debris flow and driftwood countermeasure plan shall be assessed based on the volume of debris flow material or the exceedance probability of rainfall according to the target basin characteristics.

The Guideline shall not be applied to the following cases:

- debris flow formed by sediment produced by the large-scale collapse of a mountain slope,
- breaching of a natural dam following landslide,
- volcanic mudflow triggered by snow melts,
- volcanic mudflow due to breaching of a crater lake.

Explanation

In principle, debris flow due to the rainfall of the design scale's exceedance probability (in principle, 24-hour rainfall or daily rainfall with 1 / 100 annual exceedance probability) is estimated empirically and theoretically.

In a debris flow and driftwood countermeasure plan, the volume of "debris flow with design scale" and driftwood can be determined based on past disaster records on the volume of debris flow material in the river.

2.4 Reference point

Reference point is a point where the volumes of sediment and driftwood are determined. The point is fundamentally set on the upstream of the area to be protected.

If necessary in enacting the debris flow and driftwood control plan, supplementary reference points are set at locations where debris flow and driftwood countermeasure facilities is to be built, or at locations where the pattern of sediment transport changes (Figure 2), or at river junctions with tributaries. Further, the source and scouring, transport, and deposition zones of a debris flow are determined according to the conditions of the river.

Explanation

The reference point is generally set at the outlet of a valley on the upstream of the area to be protected, or the downstream end of the transport zone of a debris flow. If countermeasure facilities will be built in the debris flow's deposition zone, the reference point shall be set downstream from the said countermeasure facility. Meanwhile, supplementary reference points, typically set upstream of the reference point, are fundamentally set at the locations where the countermeasure facilities will be built.

Locations where the pattern of sediment transport changes are shown in Figure 2.

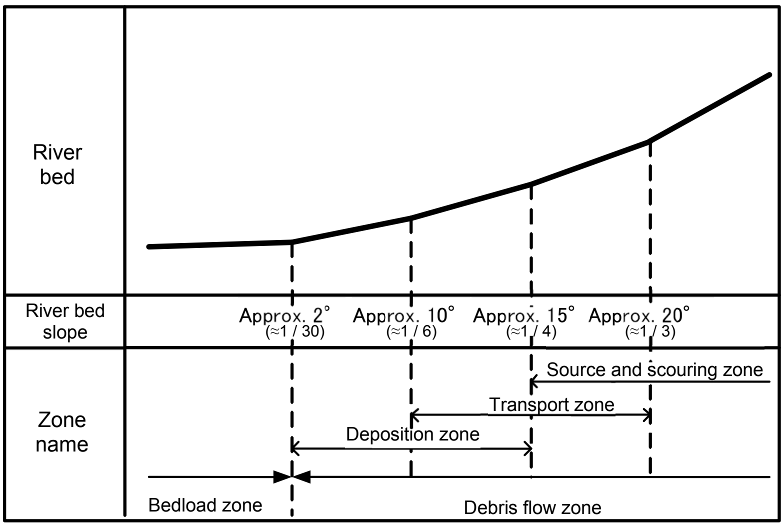

Figure 2 Changes of sediment transport pattern based on riverbed slope [1)]

2.5 Design volumes of sediment and driftwood

The design volumes of sediment and driftwood include the design volume of debris flow material and driftwood, design allowable volumes of debris flow material and driftwood, and the peak discharge of debris flow.

Explanation

The design volumes of debris flow material and driftwood, design allowable volumes of debris flow material and driftwood, and the peak discharge of debris flow at the reference point need to be calculated to clarify the “debris flow with design scale” and driftwood.

The volumes of sediment and driftwood are calculated based on the Guideline. The method to calculate the volumes of sediment and driftwood at supplementary reference points and at locations where countermeasure facilities are located is explained in the Guideline, Section 2.6.

It should be noted that the effect of driftwood to peak discharge of debris flow, flow velocity, water depth, and unit weight is not considered.

2.5.1 Design volumes of debris flow material and driftwood

2.5.1.1 Design volume of debris flow material

The design volume of debris flow material is the volume of sediment transported by the "debris flow with design scale" at the reference point. The calculation shall be conducted by presuming that no debris flow and driftwood facilities exist upstream.

Explanation

The design volume of debris flow material is calculated based on the method in the Guideline, Section 2.6.1. L_{dy11} and L_{dy12} in Equations (2) and (4) represent the length of the river or channel from the reference point to their most upstream. The definition of a river and the method of determining the first-order stream are based on the *Debris Flow-prone River and Debris Flow Risk District Survey Method (Tentative)*[1].

If the design volume of debris flow material calculated using the method in Section 2.6.1 is less than 1,000 m^3, the design volume of debris flow material shall be set to 1,000 m^3 [2]. However, this approach shall not be applied to volume of debris flow material calculated at the supplementary reference points. Peak discharge of debris flow is calculated using the largest surge of debris flow. Calculation method of the peak discharge is explained in Section 2.6.3.

In a volcanic area, particularly if the volcano is active, the design volume of debris flow material must be revised according to the volcanic activity and the changes in the target basin situation.

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(Appendix A) Estimation method of the design volume of debris flow material in a small ephemeral river

In a small ephemeral river, volume of entrainable sediment by debris flow including the volume of sediment prone to collapse can be assessed accurately by a detailed survey of thickness of entrainable sediment using a (knocking) cone penetration test. Only in such case, the volume of sediment based on the survey shall not be round up to 1,000 m^3 even if the design volume of debris flow material is less than 1,000 m^3. Note that the term "small ephemeral river" refers to those that meet all the following conditions:

- An ephemeral river where the terrain has a shape with obscure or no lateral boundary to the flow path, water is not flowing constantly, and no sediment movement at normal times.
- The riverbed slope on the upper stream of the reference point is 10° or more, hence the whole basin is categorized as the transport zone and the source and scouring zone of debris flow (Referring to Figure 2).

〜〜〜

2.5.1.2 Design volume of driftwood

The design volume of driftwood is the volume of driftwood discharged to the reference point which is transported by the “debris flow with design scale”. This volume is calculated by assuming no debris flow and driftwood facility exists upstream.

Explanation

The design driftwood discharge is calculated based on the method presented in the Guideline, Section 2.6.2. The values of L_{dy13} and B_d in Equation (7) of Section 2.6.2 are the same with the values from Section 2.5.1.1.

2.5.2 Design allowable volumes of debris flow material and driftwood

2.5.2.1 Design allowable volume of debris flow material

> The design allowable volume of debris flow material is the volume of sediment transporting through the reference point without causing any damage downstream.

Explanation

In principle, the design allowable volume of debris flow material is 0 (zero).

However, if sediment does not cause any damage downstream and it can be controlled by debris flow torrent training work, its volume may be considered as the design allowable volume of debris flow material.

2.5.2.2 Design allowable volume of driftwood

> The design allowable volume of driftwood is the volume of driftwood that does not cause disaster downstream of the reference point.

Explanation

In principle, the design allowable volume of driftwood is 0 (zero).

2.5.3 Peak discharge of debris flow at the reference point

> The peak discharge of debris flow is the maximum value of the discharge when “debris flow with design scale” passes the reference point. This peak discharge is calculated by assuming that no debris flow and driftwood facility exists upstream.

Explanation

The peak discharge of debris flow is calculated based on the method in this Guideline, Section 2.6.3.

2.6 Method to survey and calculate sediment and driftwood volumes

2.6.1 Method to calculate design volume of debris flow material

The design volume of debris flow material shall be comprehensively determined based on topographical maps and records of past disasters, after a field survey is conducted. In principle, the design volume of debris flow material shall be the smaller of two values: the volume of sediment entrainable channel deposits by debris flow and prone to collapse in the target basin and the volume of transportable sediment by "debris flow with design scale".

If basin-wide detailed surveys on collapsed slopes, sediment yield, and volume of debris flow material in past disasters have been conducted in the entire watershed (including the target basin), the design volume of debris flow material may be determined based on the survey results.

Explanation

Design volume of debris flow material is calculated based on the result of basin-wide survey of landslides and field surveys. If the directly measured value of volume of debris flow material is available, the design volume of debris flow material shall be calculated by considering the measured value.

(1) Volume of sediment entrainable by debris flow and prone to collapse in the target basin (V_{dy1})

$$V_{dy1} = V_{dy11} + V_{dy12} \quad \cdots (1)$$

$$V_{dy11} = A_{dy11} \times L_{dy11} \quad \cdots (2)$$

$$A_{dy11} = B_d \times D_e \quad \cdots (3)$$

Where,

V_{dy1} : volume of sediment entrainable by debris flow and prone to collapse in the target basin (m^3),

V_{dy11} : volume of entrainable channel deposits in the section from the reference point, supplementary reference point, or the point where the volume of debris flow material is to be calculated, to the furthest upstream point of the first-order stream (m^3),

V_{dy12} : volume of sediment prone to collapse (m^3),

A_{dy11} : average cross-sectional area of the entrainable channel deposits (m^2),

L_{dy11} : river length from the reference point, supplementary reference point, or the point where the volume of debris flow material is to be calculated, to the furthest upstream point of the first-order stream (m), as shown in Figure 3

B_d : average riverbed width where erosion is predicted to occur during debris flow (m),

D_e : average depth of the riverbed sediment where erosion is predicted to occur during debris flow (m).

B_d and D_e are estimated by referring to field survey and/or scouring situation during debris flow in nearby rivers. These values are used to calculate the sediment entrainable by debris flow and prone to collapse. To estimate B_d from the field survey (as shown in Figure 4(1)), it shall be estimated by classifying the riverbed deposition part and hillslope part. Classification of these parts can be referred to the change of river bank slope and difference of vegetation.

For estimation of D_e, not only cross-sectional situation of the sediment deposition but also the longitudinal continuity of the bedrock shall be considered by survey on bedrock exposure (Figure 4(1)). Figure 4(2) shows an example in a past debris flow disaster[3)] as a reference for D_e estimation.

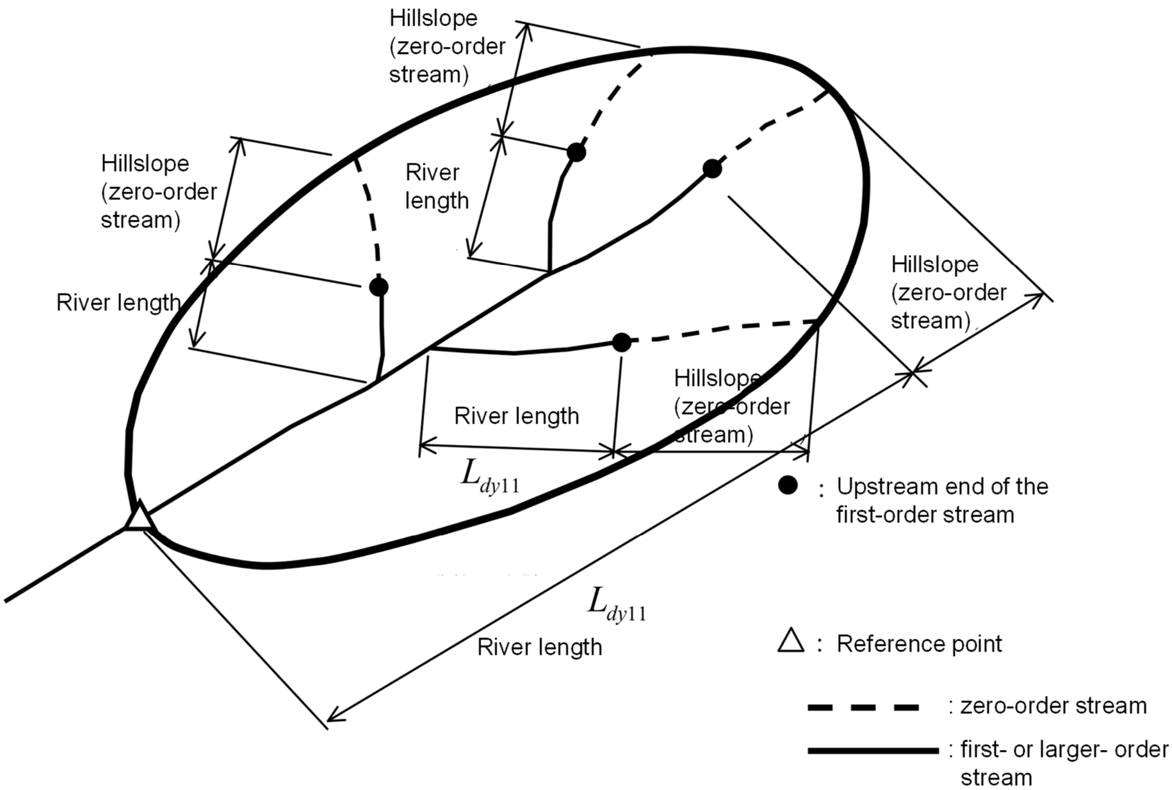

Figure 3 Measurement of L_{dy11}

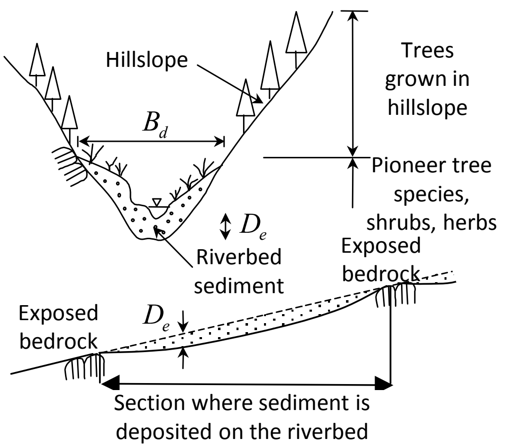

Figure 4(1) Method of measurement of erosion width and depth

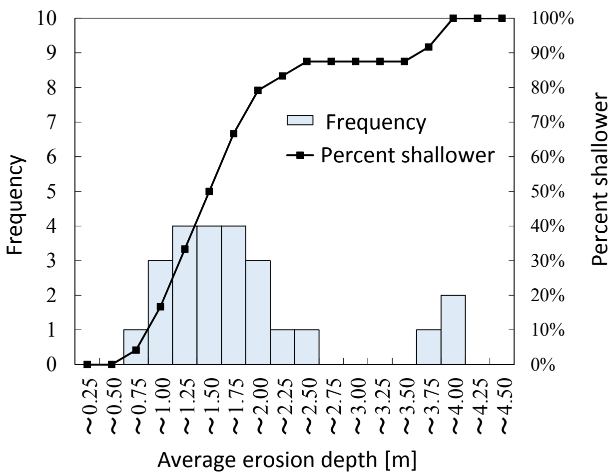

Figure 4 (2) Average erosion depth distribution

(Appendix B) Examples of average erosion depth (detailed example of Figure 4(2))

No.	Date	Prefecture	Cities	Name	Catchment Area (km^2)	Riverbed gradient (°)	Eroded Width (m)		Eroded Depth (m)		Maximum rainfall amount	
							mean	standard deviation	mean	standard deviation	1hour (mm)	24hour (mm)
1	Jul 29-30, 2011	Niigata	Minamiuonuma	Ubasawa	4.78	19.8	31.8	20.1	2.2	1.7	62.0	328.0
2	Jul 29-30, 2011	Niigata	Minamiuonuma	Futagosawa	0.78	27.0	27.6	13.0	3.9	2.4	62.0	328.0
3	Jul 29-30, 2011	Niigata	Minamiuonuma	Garasawa	1.60	22.4	10.0	5.9	1.1	0.7	62.0	328.0
4	Jul 29-30, 2011	Niigata	Minamiuonuma	Takatanasawa	0.82	23.6	15.9	7.0	3.7	2.2	58.3	321.2
5	Jul 29-30, 2011	Niigata	Minamiuonuma	Tsuchisawa	0.69	18.4	24.9	13.6	1.3	0.6	58.0	307.0
6	Sep 16-19, 2012	Mie	Inabe	Nishinogaitogawa	0.21	34.6	13.8	7.3	1.6	2.0	70.0	435.0
7	Sep 16-19, 2012	Mie	Inabe	Kotakigawa	1.39	25.3	22.6	5.8	3.9	2.0	70.0	435.0
8	Jul 11-12, 2012	Kumamoto	Aso	Daimonkawa	0.33	13.4	14.5	7.1	1.2	0.7	124.0	517.0
9	Jul 11-12, 2012	Kumamoto	Aso	Sakanashi area	0.09	19.3	42.2	19.3	1.6	1.3	124.0	517.0
10	Jul 11-12, 2012	Kumamoto	Aso	Shioigawa2	0.48	14.5	13.7	6.6	1.7	1.3	124.0	517.0
11	Jul 11-12, 2012	Kumamoto	Aso	Shinsyogawa3	0.07	28.2	16.9	6.9	1.0	0.6	83.0	417.0
12	Jul 11-12, 2012	Kumamoto	Aso	Doigawa	0.28	19.5	21.2	9.9	2.4	1.1	124.0	517.0
13	Jul 21, 2009	Yamaguchi	Hofu	Abetanikawa	0.53	15.0	16.0	5.7	1.9	0.9	60.0	266.0
14	Jul 21, 2009	Yamaguchi	Hofu	Yahatatanikeiryu	1.05	14.2	9.0	4.1	0.8	0.5	60.0	266.0
15	Jul 21, 2009	Yamaguchi	Hofu	Matugatanikawa	2.13	7.1	12.4	5.8	0.7	0.4	60.0	266.0
16	Jul 21, 2009	Yamaguchi	Hofu	Kamisatokawa	0.03	20.5	25.1	7.6	1.6	0.5	56.0	256.0
17	Jul 21, 2009	Yamaguchi	Hofu	Uedaminamikawa	1.10	12.2	15.9	8.0	1.1	0.6	60.0	266.0
18	Jul 8-11, 2014	Nagano	Nagiso	Nashisawa	2.27	18.4	25.6	11.6	1.8	1.2	76.0	143.0
19	Aug 9-10, 2013	Akita	Senboku	Kuyobutsusawa	0.03	17.0	41.7	10.3	1.3	0.9	58.0	189.0
20	Aug 19-20, 2014	Hiroshima	Hiroshima	Torigoekawa	0.34	16.2	15.9	7.1	1.0	0.5	87.0	247.0
21	Aug 19-20, 2014	Hiroshima	Hiroshima	Ueyamakawa	0.22	19.5	18.1	6.1	1.3	0.7	87.0	247.0
22	Aug 19-20, 2014	Hiroshima	Hiroshima	Yagibairinsawa	0.19	26.0	18.2	6.9	1.9	1.3	87.0	247.0
23	Aug 19-20, 2014	Hiroshima	Hiroshima	Jyourakuchikawa	0.03	22.3	18.9	5.4	1.3	0.5	87.0	247.0
24	Aug 19-20, 2014	Hiroshima	Hiroshima	Ⅰ-1-9-1010隣1	0.04	33.4	12.9	10.0	0.8	0.6	115.0	290.0

The volume of sediment prone to collapse (V_{dy12}) is calculated by one of the following methods.

(1-1) In case that the volume of sediment prone to collapse (V_{dy12}) can be estimated accurately

V_{dy12} in Equation (1) is the sediment volume (m^3) in the zero-order stream (ephemeral stream) and the hillslope which are predicted to collapse.

The zero-order stream is identified from contour lines using a 1/25,000 or larger-scale topographical map, or aerial LiDAR survey result. The zero-order stream is defined as a terrain where the depth (b) of the contour lines is less than its width (a), as shown in Figure 5.

In order to estimate the volume of sediment prone to collapse, the occurrence location, area, and collapse depth shall be estimated by considering the topographical and geological characteristics, distribution of the existing collapses, and results of field survey. There is a case [4)] where site reconnaissance and (knocking) cone penetration test are carried out to estimate it. Moreover, boring survey will be useful.

Volume bulking of the collapsed soil due to destruction of skeleton is not considered.

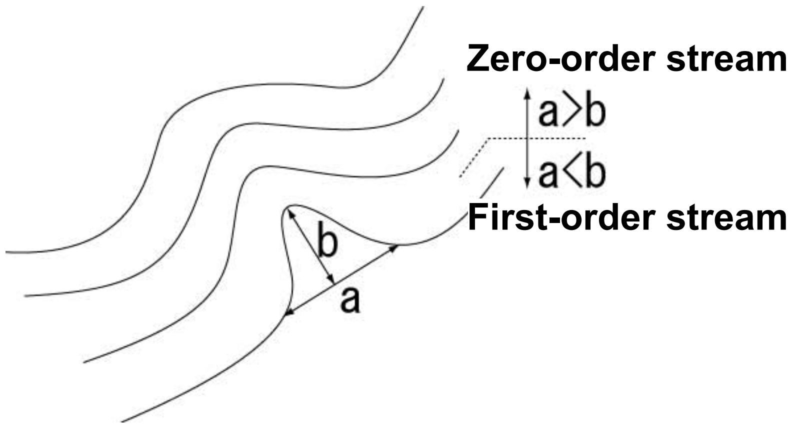

Figure 5 Topography of the zero-order stream

(1-2) In case that the volume of sediment prone to collapse (V_{dy12}) is difficult to be estimated accurately

The volume of sediment prone to collapse is estimated using the following equation considering the collapse in zero-order stream.

$$V_{dy12} \fallingdotseq \sum \left(A_{dy12} \times L_{dy12} \right) \quad \text{(4)}$$

$$A_{dy12} = B_d \times D_e \quad \text{(5)}$$

Where,

A_{dy12} : average cross-sectional area of the sediment prone to collapse in the zero-order stream (m^2),

L_{dy12} : river length from highest point of the first-order stream where the volume of debris flow material is calculated to the farthest point in the target basin (m) (Figure 6). If any tributary exists, its length shall be added.

If the sediment yield on hillslope and river banks is intense and the volume of sediment entrainable by debris flow and prone to collapse is expected to increase in the near future, the volume of this sediment yield needs to be estimated and cumulated, even though the volume of sediment prone to collapse is small, because the survey is conducted immediately after the occurrence of debris flows, for example.

(1-3) Survey to accumulate measured values

To calculate volume of transported sediment by considering past experiences, survey of flow condition when a debris flow occurs is necessary. For the field surveys on volume of transported sediment, aerial LiDAR or unmanned aircraft (e.g., drones) survey may be used. In particular, a method[6] to calculate volume of transported sediment by comparing aerial LiDAR survey data of before and after debris flow occurrence is usefull.

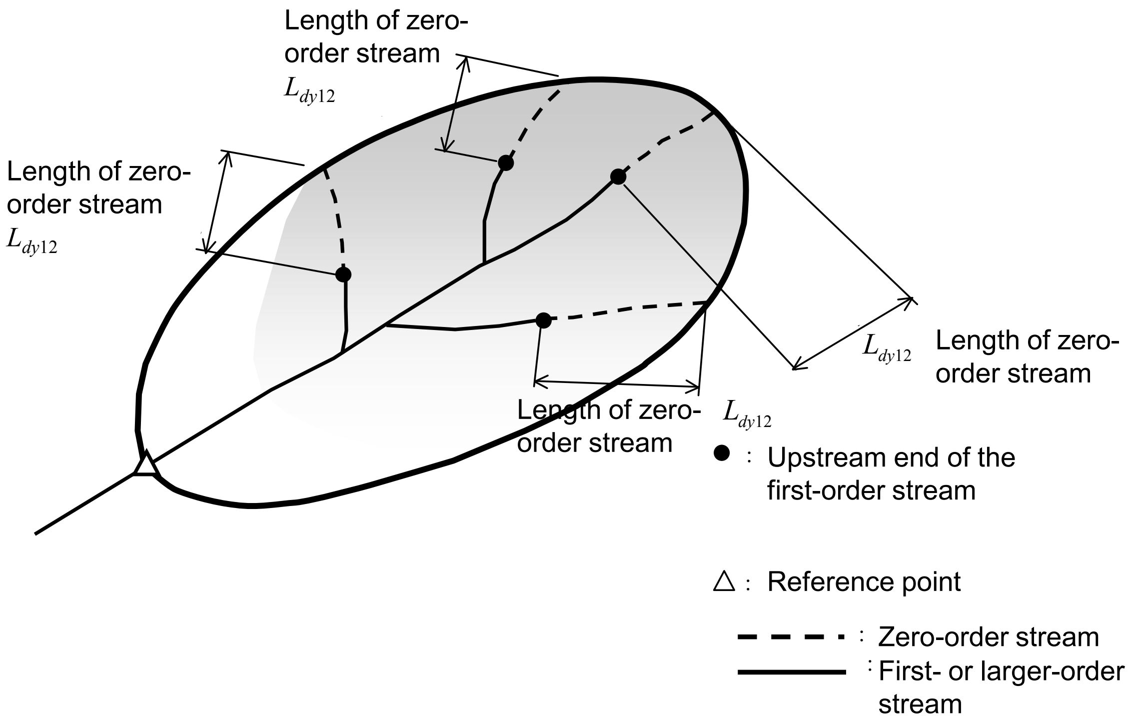

Figure 6 Measurement of L_{dy12}

(2) Volume of transportable sediment by the "debris flow with design scale" (V_{dy2})

Volume of transportable sediment by "debris flow with design scale" is calculated by obtaining the total water volume as the product of multiplying the rainfall of the annual exceedance probability (P_p, mm) by the target basin area (A, km^2). This total water volume is then multiplied by concentration of debris flow (C_d). Moreover, the discharge adjustment factor (K_{f2}) is also considered in the calculation.

$$V_{dy2} = \frac{10^3 \cdot P_p \cdot A}{1-K_v}\left(\frac{C_d}{1-C_d}\right)K_{f2} \qquad (6)$$

C_d is calculated with reference to the Guideline, Section 2.6.3. Although Equation (12) is Takahashi's Equation for a slope of 10-20°, it is assumed to be applied to gentle slope of lower than 10°. P_p is determined by studying the region's rainfall characteristics and disaster characteristics. Typically, 24-hour rainfall is generally used. K_v is the porosity of about 0.4. K_{f2} is the discharge adjustment factor determined based on the target basin area (Figure 7), where the upper and lower limit is principally set to 0.5 and 0.1, respectively.

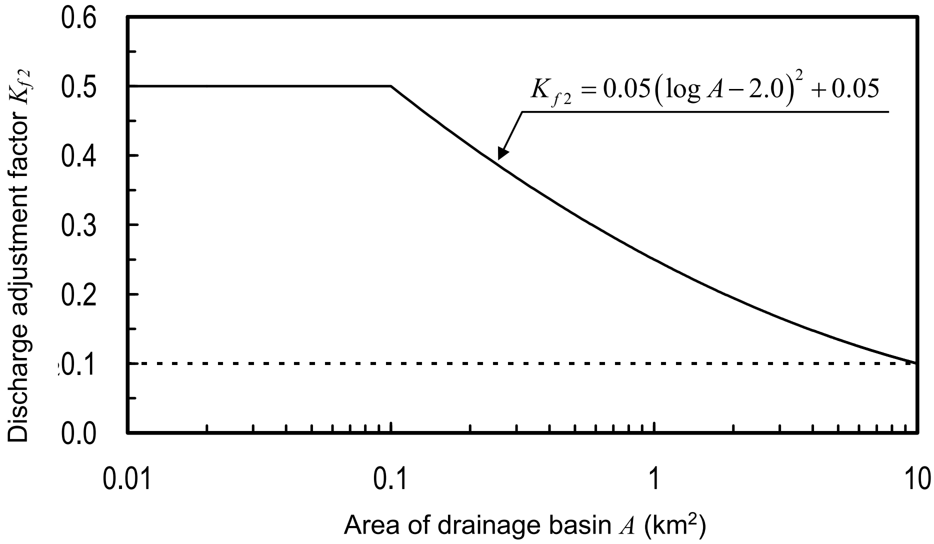

Figure 7 Discharge adjustment factor[4)]

2.6.2 Method to calculate design volume of driftwood

The design volume of driftwood is obtained by multiplying the estimated driftwood yield by the driftwood runoff ratio.

Explanation

The design driftwood runoff ratio (ratio of driftwood discharged to the exit of the valley to the driftwood yield) is reportedly between 0.8 and 0.9, when debris flow and driftwood facilities do not exist[7)]. The design volume of driftwood is the total tree volume calculated assuming no debris flow and driftwood facility exists in the target basin.

To clarify the design volume of driftwood, surveys of condition in the target basin, factors of yield, locations, quantity, length, and diameter of driftwood need to be conducted. Further, survey to estimate possible damages caused by driftwood also need to be carried out.

First, the surveys are begun with checking of the current condition of the target basin to clarify the condition of the forest.

Next, results of the survey of the forest condition are comprehensively assessed to hypothesize the factors causing driftwood yield.

Third, a survey to estimate the driftwood yield volume and location, and a survey to assess the volume, length, and diameter of driftwood that will flow down and deposit, are required to be conducted.

From these surveys, the damage caused by driftwood is estimated and the volume, length, and diameter of the driftwood that shall be controlled are determined.

(1) Survey of forest conditions

The standing trees, vegetation, and fallen trees (except log and lumber) are investigated preliminarily in the upstream area from the point where the design volume of driftwood is to be calculated.

(2) Survey of factors causing driftwood

The results of the survey of forest conditions are assessed comprehensively to determine the factors causing driftwood yield.

Determining the factors causing driftwood is vital to estimate the locations where driftwood will occur, its volume, length, weight, diameter, and the damage it will cause. If the slope is steep and brittle, debris flow or slope failure tends to occur during torrential rain. Along with such debris flow and slope failure, trees flow into river courses and become driftwood. Further, studying the damage caused by past cases of driftwood disaster is an effective method to estimate the factors causing driftwood.

Table 1 shows the factors causing driftwood yield.

Table 1 Causes of driftwood yield

Source of driftwood	Causes of driftwood yield
Discharge of standing trees	(1) Sliding of standing trees due to slope failure (2) Occurrence of debris flow and subsequent recruitment of standing trees (3) Erosion of river banks and/or riverbed by debris flow and recruitment of standing trees.
Discharge of fallen trees	(4) Recruitment of fallen trees due to pest damage or typhoon on river bed (5) Re-mobilization of fallen trees discharged in the past and remained in river bed (6) Re-mobilization of fallen trees discharged by snow avalanches

(3) Survey of the yield location, volume, length, and diameter of driftwood

The location of yield, volume, length, and diameter of driftwood are surveyed based on the causing factors from the field surveys of hillslope, interpretation of aerial photographs, and information of past disasters. Logs and timbers deposited on the riverbed are not included in the volume of driftwood yield.

(3-1) Causing factors and location of yield

A field survey is conducted, aerial photographs are interpreted, and past disasters are studied to determine the factors causing the yield and location where driftwood will occur.

(3-2) Calculation of driftwood yield volume based on field survey

Based on the determined driftwood causing factors and locations, the length and diameter of driftwood are surveyed to calculate the volume of driftwood yield.

The following method (herein this section called direct survey method) is used to directly survey the quantity, length, and diameter of trees and driftwood at the location where driftwood potentially occurs. In the direct survey method, it is necessary to estimate the location where driftwood will occur accompanied with debris flow and slope failure. For this estimation, the source and scouring zone and the transport zone where driftwood would occur need to be assessed based on Section 2.6.1 of this Guideline. After the source and scouring zone and the transport zone where driftwood would occur due to heavy rain is assumed, the quantity, length, and diameter of generated driftwood is estimated by surveying the standing trees, fallen trees, and driftwood quantity (number and volume) accumulated in the riverbed from the past disasters. Such survey is conducted by field survey and interpretation of aerial photographs, or their combination.

Direct survey method is classified into two sub-methods: (a) surveying all trees and driftwood within the range of the target area (hereinafter: complete survey method) and (b) surveying a number of samples at typical locations (hereinafter: sampling survey method). However, since complete survey method often requires hard effort to cover a wide target area, the sampling survey method is usually used.

Topographical maps and aerial photographs are used to interpret the approximate density, height, and species of trees in the source and scouring zone and transport zone of slope failure and/or debris flow. Based on this result, the source and scouring zone and transport zone are divided into several sub-zones so that each sub-zone has the same vegetation and forest type. Then, sampling survey (for an extent of 10 m × 10 m) is conducted in each sub-zone, where the number, species, height, and breast height diameter of the trees in each sub-zone are examined. The Guideline survey items are as follows:

(1) Density or number	:	number of trees, fallen trees and driftwood per 100 m^2
(2) Diameter	:	breast height diameter of trees, average diameter of fallen trees and driftwood.
(3) Length	:	height of trees, or lengths of fallen trees and driftwood

The volume of driftwood yield is calculated by the following procedure and equations. If the source and scouring zone and transport zone of debris flow consist of multiple forest type, the volume of driftwood yield (V_{wv}) is calculated for each forest type and then summed up. The width and length of the zero-order stream and the collapsed slope in the equation below conform to part 2.6.1 of the Guideline.

$$V_{wy} = \frac{B_d \times L_{dy13}}{100} \times \sum V_{wy2} \quad \cdots\cdots (7)$$

$$V_{wy2} = \pi \cdot H_w \cdot R_w{}^2 \cdot \frac{K_d}{4} \quad \cdots\cdots (8)$$

Where,

V_{wy} : volume of driftwood yield (m^3),

B_d : average width of riverbed where erosion is predicted to occur during a debris flow (m),

L_{dy13} : river length from the point where the driftwood yield is calculated to the farthest point in the target basin (m) as shown in Figure 8(1),

V_{wy2} : single tree volume (m^3),

ΣV_{wy2} : tree volume per 100 m^2 in the sampling survey (m^3/100 m^2),

H_w : tree height (m),

R_w : breast height diameter (m),

K_d : breast height coefficient (see Fig. 8 (2)).

If the aerial LiDAR measurement data of the target basin in the recent years is available, the height and number (density) of trees required to calculate the volume of driftwood can be extracted from it. For instance, the aerial LiDAR data was used to determine the forest type classification and volume of driftwood yield in a survey that covers a wide area[8)].

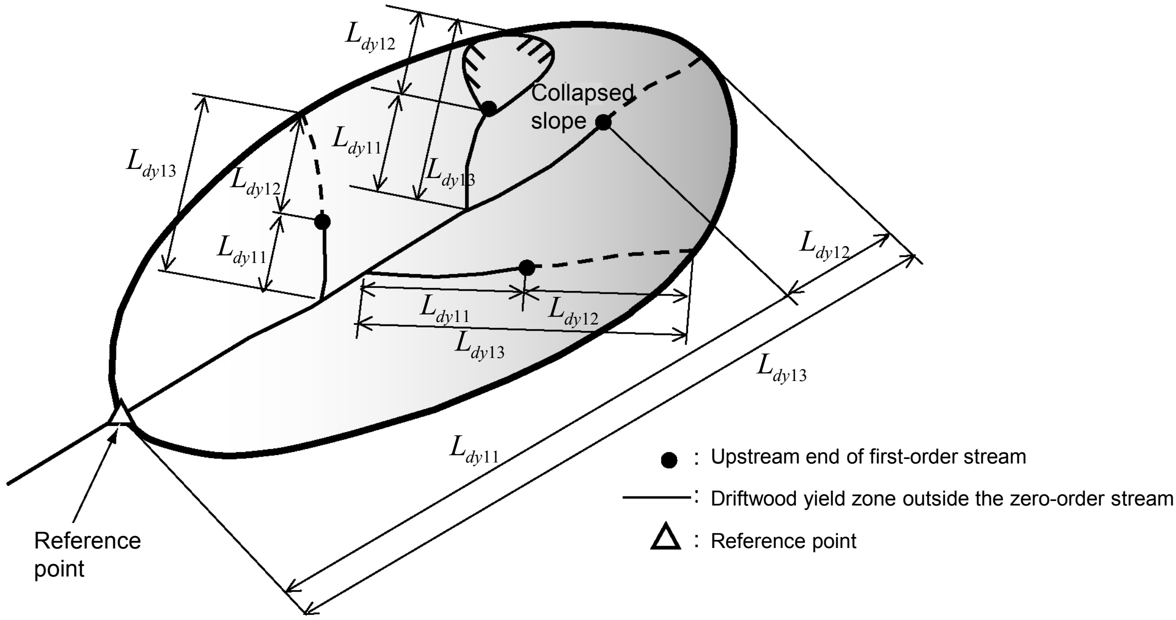

Figure 8(1) Length of driftwood yield zone (m) L_{dy13}

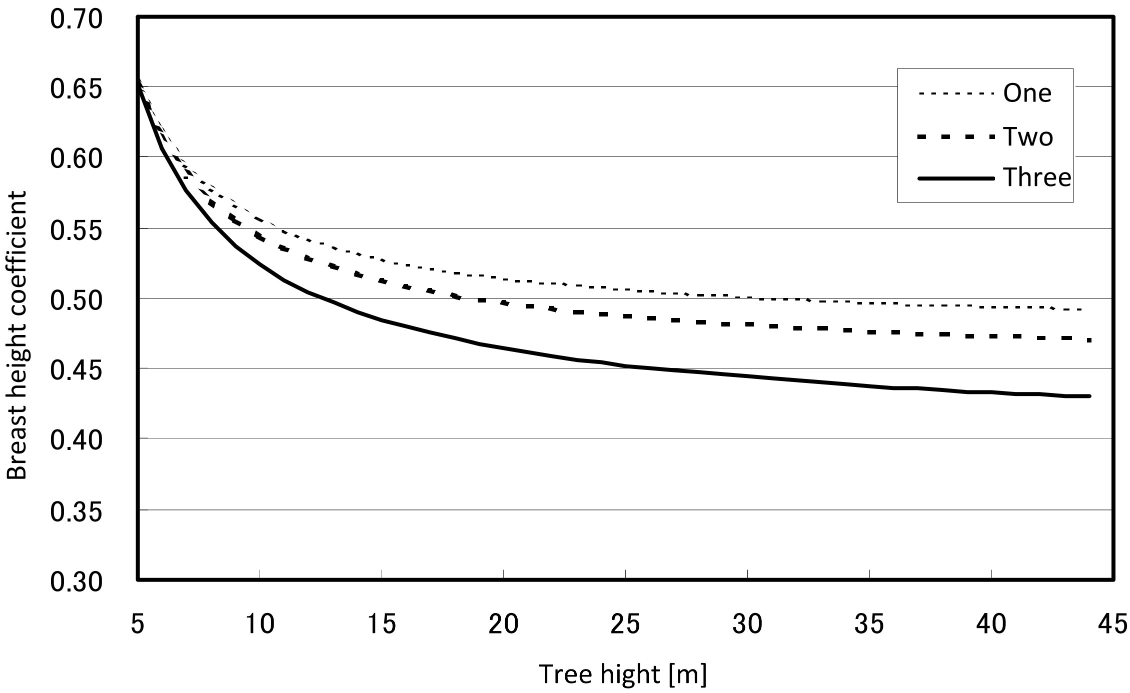

Figure 8(2) Breast height coefficient [9)]

(Remarks) One : Yezo spruce, Sakhalin fir

Two : Japanese cypress, sawara cypress, hiba arborvitae, umbrella pine

Three : Red cedar, pine, Japanese fir, Japanese hemlock, and other broad leafed and coniferous trees

Source: Plotted based on data in (Mine Ichizo (1958): *Forest Mensuration*, Asakura Publishing, page 146)

(3-3) Calculation of the volume of driftwood yield based on measured values

If there are cases of driftwood generated in neighboring rivers and related data about the volume of driftwood yield per unit of area of the target basin (V_{wy1}, m^3/km^2) is available, the design volume of driftwood can be calculated by the following equation.

$$V_{wy} = V_{wy1} \times A \quad (9)$$

Where A: target basin area (km^2) (basin area with riverbed slope of 5° or more).

As a reference, Figure 9 shows the survey results of driftwood transported by debris flows. The figure shows the relationship between the target basin area of the river and the driftwood yield by coniferous and broad-leaved trees. If V_{wy1} is set as approximately 1,000 m^3/km^2, the plots obtained from past events could be roughly covered (Figure 9).

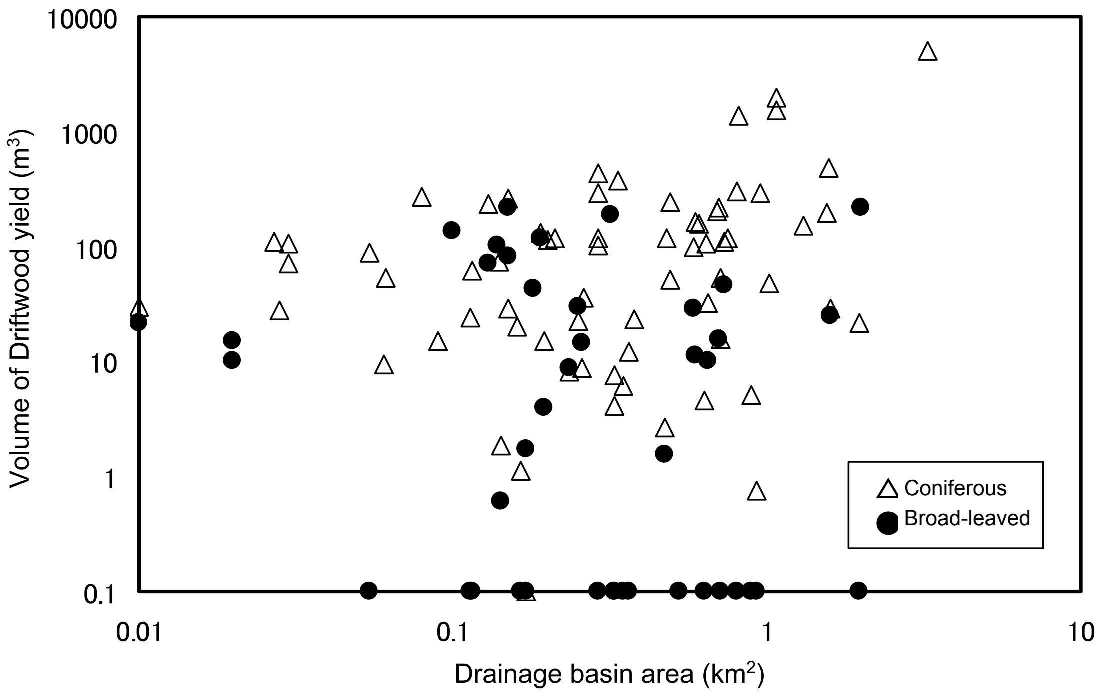

Figure 9 Target basin area – volume ofdDriftwood yield

2.6.3 Method to calculate peak discharge of debris flow

The peak discharge of debris flow can be obtained based on the volume of debris flow material. However, if the peak discharge of debris flow can be estimated using another method i.e., measured values for the same target basin is available, this value may be used.

Explanation

(1) Setting of the peak discharge of debris flow based on the volume of debris flow material

Figure 10 shows the relationship of total sediment volume containing in a debris flow with its peak discharge based on the observed peak discharge data of debris flows at Mt. Yakedake, Sakurajima, for example. The relationship of the average peak discharge with the total discharge of the debris flow is presented in Equation (10)[10)].

$$Q_{sp} = 0.01 \cdot \sum Q \qquad (10)$$

$$\sum Q = \frac{C_* \cdot V_{dqp}}{C_d} \qquad (11)$$

Where,

Q_{sp} : peak discharge of debris flow (m^3/s),

ΣQ : total debris flow volume containing in a debris flow (m^3),

V_{dqp} : sediment volume discharged by the largest surge of debris flow (including void) (m^3),

C_d : concentration of debris flow,

C_* : volumetric concentration of sediment deposited on the riverbed (approximately 0.6).

The lower limit of V_{dqp} is 1,000 m^3. This value applies to the design of all the debris flow and driftwood countermeasure facilities except when Section 2.5.1.1 of this Guideline "(Appendix A) Estimation method of the design volume of debris flow material on hillslopes" is applied.

The concentration of debris flow is obtained by the following equilibrium concentration equation[11)].

$$C_d = \frac{\rho \tan\theta}{(\sigma-\rho)(\tan\phi - \tan\theta)} \qquad (12)$$

Where,

σ : density of gravel (approx. 2,600 kg/m^3),

ρ : density of water (approx. 1,200 kg/m^3),

ϕ : internal friction angle of sediment deposited on a riverbed (degrees) (approximately 30-40°, 35° is typically used),

θ : riverbed surface slope (degrees).

The riverbed surface slope used to calculate the debris flow peak discharge is the riverbed surface slope at the point where the "volume of sediment predicted to be transported by the largest surge of debris flow" is calculated. It should be no less than 10° which is considered to be the lower end of the transport zone. Note that the riverbed slope is basically the average riverbed slope in the section of about 200 m upstream of the planned location. This riverbed slope is calculated from the topography of before the facility being designed. If the section of about 200 m upstream of the planned location cannot represent the riverbed slope, a section shall be selected as the alternative according to the condition of the river.

When the calculated value (C_d) is larger than $0.9C_*$, C_d is assumed to be equal to $0.9C_*$. Meanwhile, if the calculated value (C_d) is smaller than 0.3, C_d value is assumed to be 0.3

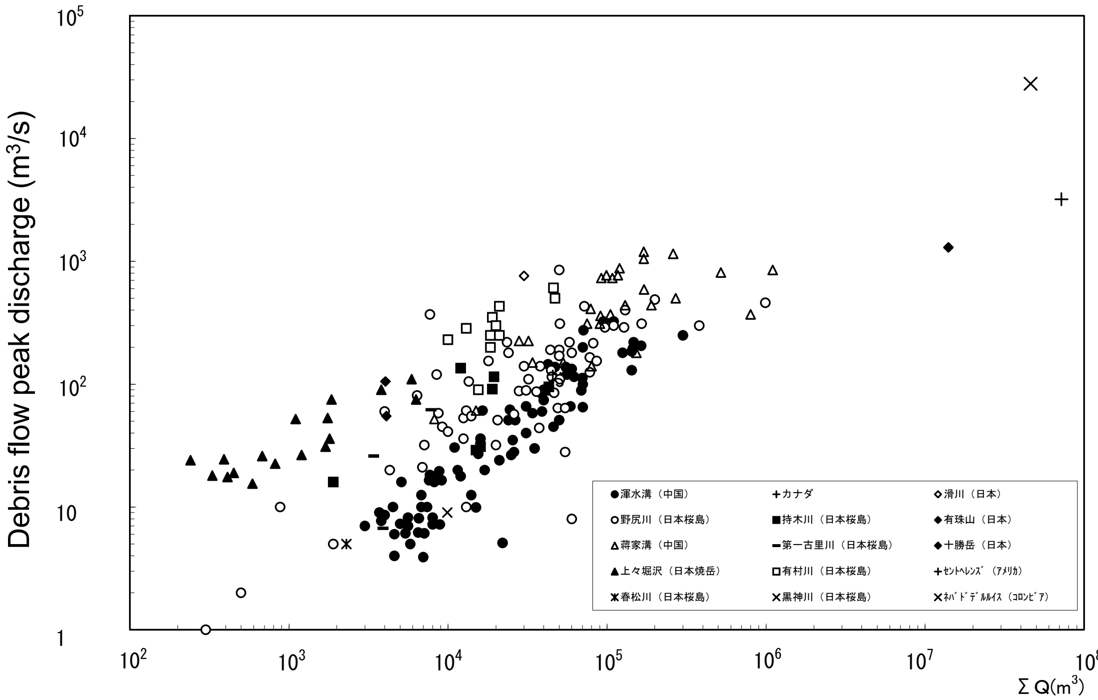

Figure 10 Correlation of peak discharge with ΣQ[10] (ΣQ is written as Q_T in the original work)

(2) Survey to collect measured values

To calculate the debris flow peak discharge using the measured values, survey of the actual condition of debris flow peak discharge is necessary. The following methods can be used to determine the peak discharge of debris flow by measured values.

1) Estimation from debris flow tracks

If traces and cross section of debris flow are apparent, flow velocity and the largest depth of debris flow are estimated and peak discharge is calculated.

2) Estimation from the velocity obtained from video image analysis

If a video record of the debris flow is available, it shall be analyzed to calculate the flow velocity. Field survey shall be conducted at the point where the flow velocity is calculated, and then the cross-section of flow is estimated. Peak discharge is calculated by multiplying the cross-sectional area of flow with the flow velocity. Another method is direct measurement of water level using a non-contact water level gauge to estimate the cross-section of flow.

* Calculation method of sediment volume discharged by the largest surge of debris flow V_{dqp}

Depending on surveys of past disasters, there are few cases where sediment is being discharged simultaneously from all tributaries. Hence, the maximum value of a peak discharge of debris flow is estimated from the maximum volume of sediment among multiple debris flow surges that occur during one flood event.

The sediment volume discharged by the largest surge of debris flow (V_{dqp}) is the smaller volume of the sediment entrainable by debris flow and prone to collapse and the transportable sediment by the largest surge of debris flow. For the estimation of V_{dqp}, it is assumed that there is no other Sabo facility in upstream of the point where the "sediment volume discharged by the largest surge of debris flow" is estimated. Sediment entrainable by debris flow and prone to collapse is calculated for each tributary in the upstream of the point where the "sediment volume discharged by the largest surge of debris flow" is calculated. Then, the largest value among these volumes is selected. Meanwhile, the transportable sediment by the design debris flow is calculated using Equation (6) but with the area (A) upstream of the point where the "sediment volume discharged by the largest surge of debris flow" is calculated.

Note that the point where V_{dqp} is calculated is different from that where the design volume of debris flow material is estimated.

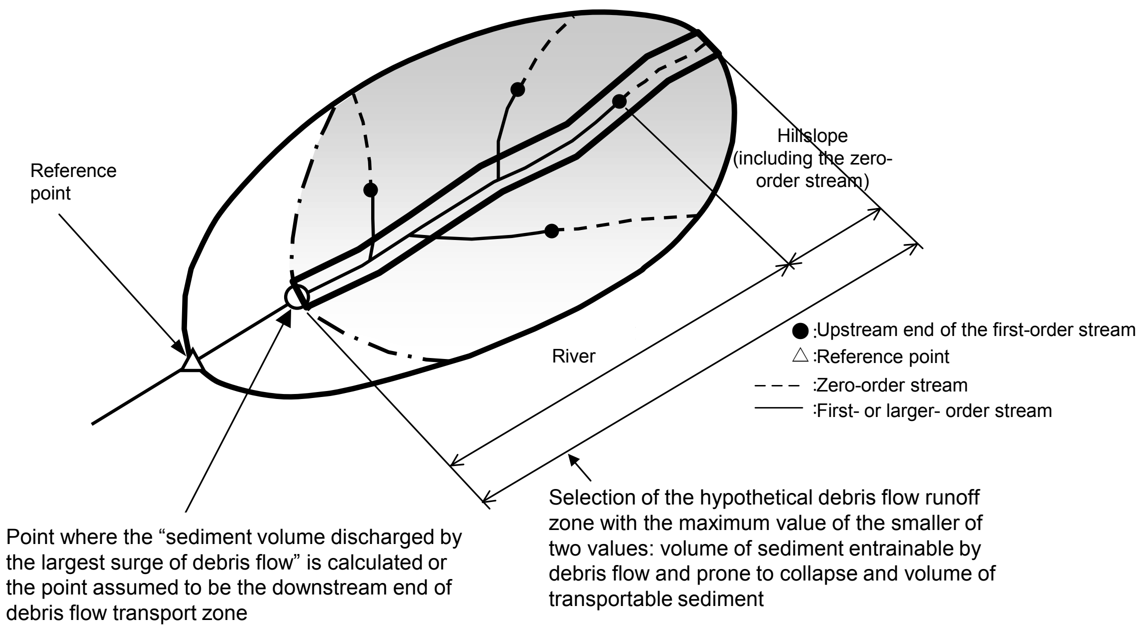

Figure 11 Mindset of hypothetical debris flow transport zone

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(Appendix C) Calculation of the peak discharge of debris flow based on rainfall

The debris flow mechanisms are assumed as follows: (1) riverbed deposits are severely eroded by flowing water which then become a debris flow, (2) collapsed hillslope sediment transformed to a debris flow as it is, and (3) the collapsed hillslope sediment blocks flowing water by forming a natural dam, creating a debris flow when the natural dam breaks. The rainfall-based calculation is a method to obtain the peak discharge of debris flow in mechanism (1) by predicting the peak discharge of water without sediment hydrologically, as explained below. Values of peak discharge calculated by Equation (10) and Equation (14) mentioned below vary depending on target basin area, rainfall, and volume of transported sediment.

If the ratio of the design volume of debris flow material to the area of target basin is 100,000 m^3/km^2, the 24-hour or daily rainfall (P_p) is 260 mm, and the target basin area is 1 km^2 or less, the result of the theoretical equation is smaller than the empirical equation.

The peak discharge of debris flow is obtained based on rainfall as follows.

$$Q_{sp} = K_q \cdot Q_p \quad \text{.......} (13)$$

Where,

Q_{sp} : peak discharge of debris flow (m^3/s),

Q_p : peak discharge of water without sediment under rainfall with the design exceedance probability (m^3/s),

K_q : coefficient.

The peak discharge of debris flow Q_{sp} (m^3/s) is obtained from the relationship with the peak discharge of water without sediment Q_p (m^3/s) [12]:

$$Q_{sp} = \frac{C_*}{C_* - C_d} \cdot Q_p \quad \text{.......} (14)$$

(Example of peak discharge of debris flow calculation)

When $\sigma = 2{,}600$ (kg/m^3), $\rho = 1{,}200$ (kg/m^3), $\phi = 35°$, and $\tan\theta = 1/6$, then the C_d value based on Equation (12) is 0.27. This value is smaller than 0.3, thus C_d value is assumed to be 0.3 and $Q_{sp} = 2 \times Q_p$ based on Equation (14).

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2.6.4 Method to calculate the peak discharge of water without sediment

The peak discharge of water without sediment shall be calculated by rational equation.

① Flood concentration time

The flood concentration time is, in principle, obtained by the following equation [13].

$$T_f = K_{p1} \cdot A^{0.22} \cdot P_e^{-0.35} \quad \text{......(15)}$$

Where, T_f: flood concentration time (min), A: target basin area (km^2), P_e: effective rainfall intensity (mm/h), and K_{p1}: coefficient = 120.

② Average rainfall intensity

The average rainfall intensity during the flood concentration period is obtained from the 24-hour rainfall as shown by the following Mononobe equation[14].

$$P_a = \frac{P_{24}}{24}\left(\frac{T_f}{24}\right)^{K_{p2}} \quad \text{......(16)}$$

Where, P_a: average rainfall intensity during the flood concentration time (mm/h), P_{24}: 24-hour rainfall (if P_{24} cannot be obtained, it can be substituted by daily rainfall (P_{day}) ($P_{24} \approx P_{day}$), K_{p2}: constant (K_{p2} = -½).

③ Effective rainfall intensity

Effective rainfall intensity is obtained by the following equation.

$$P_e = K_{f1} \cdot P_a \quad \text{......(17-1)}$$

Where K_{f1}: peak discharge coefficient. If K_{p2} is assumed to be -½, the effective rainfall intensity is obtained by the following equation based on T_f and P_a.

$$P_e = \left(\frac{P_{24}}{24}\right)^{1.21} \cdot \left(\frac{24 \cdot K_{f1}{}^2}{\frac{K_{p1}}{60} \cdot A^{0.22}}\right)^{0.606} \quad \text{......(17-2)}$$

④ Peak discharge of water without sediment

The peak discharge of water without sediment is obtained by Rational equation such as the following equation.

$$Q_p = \frac{1}{3.6} \cdot K_{f1} \cdot P_a \cdot A = \frac{1}{3.6} \cdot P_e \cdot A \quad \text{......(18)}$$

2.6.5 Method to calculate debris flow velocity and depth

The debris flow velocity and depth shall be estimated based on theoretical equation, empirical equation, and measured values.

Explanation

(1) Setting of debris flow velocity and depth based on debris flow peak discharge

The velocity of a debris flow U (m/s) can be represented by Manning's equation as shown below. This is a result obtained from the compiled observation results at Mt. Yakedake, Namekawa River, and Sakurajima Island[11).

$$U = \frac{1}{K_n} D_r^{2/3} \left(\sin\theta\right)^{1/2} \qquad (19)$$

Where,

D_r : debris flow hydraulic radius (m),

θ : riverbed surface slope (degrees),

K_n : roughness coefficient (s.m$^{-1/3}$).

The riverbed surface slope (θ) is adequately determined based on Table 2 depending on the items for usage. The value of the roughness coefficient (K_n) is much larger than that for the flow of the water without sediment. The K_n for the front part of debris flow flowing through a natural river course is 0.10 [15)]. The velocity (U) and depth of the debris flow (D_d, here $D_d = D_r$ for convenience) are obtained for the front part.

The debris flow depth D_d (m) is obtained by simultaneously solving Equations (19), (20), and (21) based on the width of the flow B_{da} (m) and the peak discharge of debris flow Q_{sp} (m^3/s).

$$Q_{sp} = U \cdot A_d \qquad (20)$$

Where, A_d: cross-sectional area of debris flow peak discharge (m^2).

In general, the debris flow due to the rainfall of the exceedance probability of the design scale flows through entire cross-section of the river. Therefore, the width of the debris flow B_{da} is shown in Figure 12, while the depth of the debris flow D_d is obtained by Equation (21).

$$D_d = \frac{A_d}{B_{da}} \qquad (21)$$

The velocity and depth of debris flow is calculated by using the average profile of three to five cross sections. These cross sections are randomly selected between the dam location and the upstream end of sedimentation, or the downstream end of the debris flow source and scouring zone. The average profile is often obtained by approximating each profile to trapezoids. However, if the profiles of cross sections quite differ each other and taking average might lead underestimation of debris flow momentum, the profile of cross section to calculate A_d shall be selected carefully. Moreover, if the profiles of cross section in the section where debris flow will deposit differs from that in the section upstream, the same is true.

(2) Survey for collecting measured values

The following methods are used to obtain the actual velocity of debris flow.

1) Debris flow velocity calculation from video or other image analyses

If a video that records the flow condition of debris flow is available, the flow velocity can be calculated by analyzing it.

2) Method of estimation from the tracks of debris flow on a river bend

If the debris flow drifts on outer bank on a river bend and the drift height can be surveyed on-site, the velocity of debris flow can be estimated based on the method of designing the curved section of debris flow torrent training work[16, 17].

Table 2 Definition of riverbed surface slope (θ)

Items for usage	Riverbed surface slope
When calculating the design external forces to perform stability analysis and structural calculations of the main structure and its wings: Concentration of debris flow (C_d) Debris flow velocity (U) Debris flow depth (D_d)	Riverbed surface slope before the facilities being built (θ_o)
When setting the spillway of a Sabo dam that allows the peak discharge of debris flow to pass: Overflow depth (D_d)	Design deposit surface slope (θ_p)

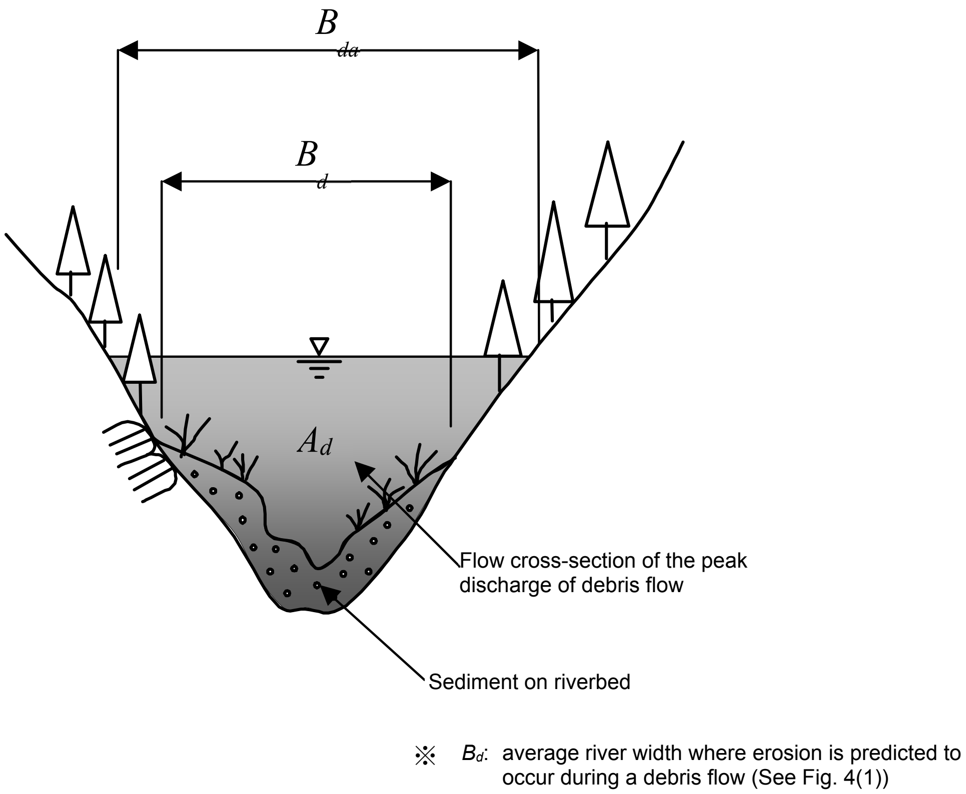


Figure 12 Image of debris flow cross-section and width of the flow B_{da}

2.6.6 Method to calculate debris flow unit weight

> The debris flow unit weight shall be estimated based on the measured values and on empirical and theoretical research.

Explanation

The debris flow unit weight γ_d (kN/m^3) is obtained by the following equation.

$$\gamma_d = \left\{ \sigma \cdot C_d + \rho \cdot \left(1 - C_d\right) \right\} g \qquad (22)$$

Where g: gravity acceleration (9.81 m/s^2), and γ_d: debris flow unit weight (kN/m^3). C_d is obtained by Equation (12).

(Note) Example of the debris flow unit weight measurement

To obtain the debris flow unit weight, several methods[18)] such as water gauge and load cell are available. Observation data from these methods have been accumulated.

2.6.7 Method to calculate drag force of debris flow

Drag force of debris flow is estimated using the flow velocity, depth, and unit weight of a debris flow.

Explanation

The drag force of debris flow is obtained by the following equation.

$$F = K_h \cdot \frac{\gamma_d}{g} \cdot D_d \cdot U^2 \quad \text{.......} (23)$$

Where,

F : drag force of debris flow per unit width (kN/m),

U : flow velocity of debris flow (m/s),

D_d : depth of the debris flow (m) obtained according to the Guideline, Section 2.6.5,

g : gravity acceleration (9.81 m/s^2),

K_h : coefficient (= 1.0), and

γ_d : unit weight of the debris flow (kN/m^3).

2.6.8 Method to calculate maximum boulder size

The maximum boulder size is estimated from field survey results.

Explanation

The maximum boulder size is used to design the overflow section and permeable section, and to obtain the impact load of boulder for structure design of a dam according to the *Technical Guideline for Designing Sabo Facilities against Debris Flow and Driftwood*.

To calculate the maximum boulder size, a frequency distribution is created by measuring the diameters of a total of more than 200 boulders located in the sections of 200 m upstream and 200 m downstream from the planned position of the Sabo dam. The 95% maximum size (D_{95}) in the distribution is defined as the maximum boulder size. Boulders shall be measured from the boulder groups on the riverbed which is considered to be the deposit of the front part of debris flow. It is noted that the obtained maximum boulder size (D_{95}) should be checked whether it is the representative value of the grain size distribution of the boulders around the location of the designed facility. If less than 200 boulders exist, the target grain size range of boulders (>256 mm) in the survey area shall be expanded until it reaches to 200 boulders, such as including smaller gravels Boulders that are angular, comprised of different material, considered to have certainly rolled down from the hillslope, and predicted not to mobilize as debris flow are excluded from measurement.

2.6.9 Method to calculate maximum length and diameter of driftwood

The maximum length and diameter of driftwood shall be estimated based on the survey result of driftwood discharge volume. Estimation of maximum length of driftwood shall consider the average flow width of the debris flow.

Explanation

The maximum length and diameter of driftwood are used to calculate the impact of driftwood in examining the structure of debris flow and driftwood facilities in the *Technical Guideline for Designing Sabo Facilities against Debris Flow and Driftwood*. The maximum length of driftwood is used to determine the spacing of the members in the driftwood retention work. The maximum length of driftwood, L_{wm} (m), is estimated by the following equations, assuming that the average width of debris flow is the "average riverbed width where erosion is predicted to occur during a debris flow", B_d (m), and that the maximum tree height of standing trees runoff from upstream is H_{wm} (m).

In case $H_{wm} \geq 1.3B_d$, then $L_{wm} \approx 1.3B_d$

In case $H_{wm} < 1.3B_d$, then $L_{wm} \approx B_d$

The maximum diameter of driftwood, R_{wm} (m), is assumed to be almost identical to the maximum breast height diameter of standing trees which is predicted to become driftwood in the upstream area (breast height diameter of the 95% largest tree of the expected driftwoods). In addition, fallen trees (except logs and timbers) that are expected to become driftwood shall also be surveyed. Underestimation of the maximum diameter shall be avoided.

2.6.10 Method to calculate average length and average diameter of driftwood

> The average length and average diameter of driftwood are estimated based on the survey results of design volume of driftwood (2.6.2 of the Guideline). The minimum flow width of the debris flow shall be considered when estimating the average length of driftwood.

Explanation

The average length of driftwood, L_{wa} (m), is calculated by the following equations, assuming that the minimum flow width of the debris flow is B_{dm} (m), and the average tree height of standing trees discharged from upstream is h_{wa} (m).

In case $h_{wa} \geq B_{dm}$, then $L_{wa} \approx B_{dm}$

In case $h_{wa} < B_{dm}$, then $L_{wa} \approx h_{wa}$

The average diameter of driftwood, R_{wa} (m) is assumed to be identical with the average breast height diameter of standing trees in the upstream area that are predicted to become driftwood.

Section 3. Debris flow and driftwood control plan

A debris flow and driftwood control plan is enacted for each debris flow-prone river so that the "debris flow with design scale" and contained driftwood can be rationally and effectively controlled.

Explanation

Debris flow and driftwood control plan is a plan to treat the design volumes of sediment and driftwood of Sabo facilities (hereinafter the "debris flow and driftwood countermeasure facilities"). These design volumes include the design capturing volume of debris flow and driftwood (design sediment capturing volume, design driftwood retention volume), design depositing volume of debris flow and driftwood (design sediment depositing volume, design driftwood depositing volume), and design volume of debris flow and driftwood prevention (design sediment prevention volume, design driftwood prevention volume).

3.1 Basics of enacting debris flow and driftwood control plan

A debris flow and driftwood control plan shall be enacted by considering the design volumes of sediment and driftwood, pattern of sediment movement, topography, objects of protection, etc. In this plan, the spatial distribution of debris flow and driftwood countermeasures facilities is set so that debris flow and driftwood are treated rationally and effectively.

If a debris flow torrent training work is planned and the volume controlled by it is set as the design allowable volume of debris flow material (the Guideline, Section 2.5.2.1), the grain size of transported sediment shall be scrutinized before the work is adopted. This is to avoid deposition in the work and subsequent flooding.

Explanation

A debris flow and driftwood control plan, referring to Section 4.3.1.1, encompasses the following volumes:

- design volume of debris flow material and driftwood (*V*),
- design allowable volume of debris flow material and driftwood (*W*),
- design capturing volume of debris flow material and driftwood by the debris flow and driftwood countermeasure facilities (*X*),
- design depositing volume of debris flow material and driftwood (*Y*), and
- design volume of debris flow and driftwood prevention (*Z*).

This debris flow and driftwood control plan shall satisfy Equation (24).

$$V - W - \left(X + Y + Z\right) = 0 \quad \text{(24)}$$

Where *V, W, X, Y,* and *Z* are calculated by the following equations.

$$V = V_d + V_w \quad \text{(25)}$$

$$W = W_d + W_w \quad \text{(26)}$$

$$X = X_d + X_w \quad \text{(27)}$$

$$Y = Y_d + Y_w \quad \text{(28)}$$

$$Z = Z_d + Z_w \quad \text{(29)}$$

Where,

V_d : design volume of debris flow material (m^3),

V_w : design volume of driftwood (m^3),

W_d : design allowable volume of debris flow material (m^3),

W_w : design allowable volume of driftwood (m^3),

X_d : design sediment capturing volume (m^3),

X_w : design driftwood retention volume (m^3),

Y_d : design sediment depositing volume (m^3),

Y_w : design driftwood depositing volume (m^3),

Z_d : design sediment prevention volume (m^3), and

Z_w : design driftwood prevention volume (m^3).

3.2 Design capturing volume of debris flow and driftwood

The design capturing volume of debris flow and driftwood is the volume of "debris flow with design scale" and contained driftwood captured by the debris flow and driftwood countermeasure facilities. The design capturing volume of debris flow and driftwood is the total of design sediment capturing volume and design driftwood retention volume.

Explanation

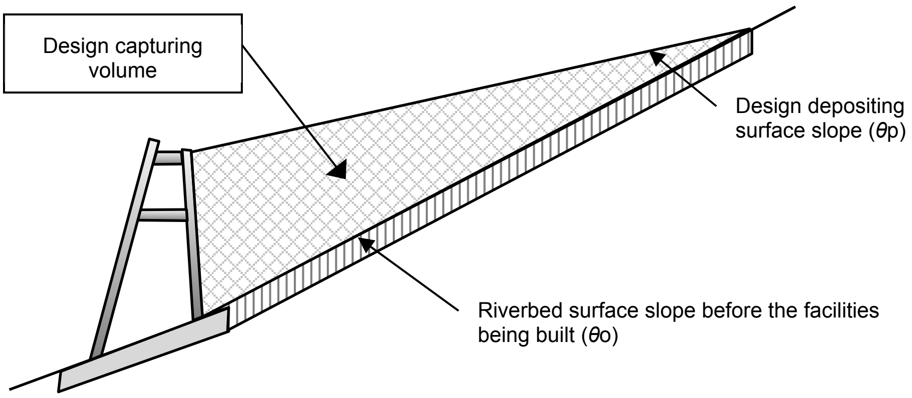
For open type Sabo dam, the design capturing volume of debris flow and driftwood is the space enclosed by the surface of the riverbed before the facilities being built and the assumed surface of the design depositing sediment (space indicated by diamond patterns in Figure 13). For closed type or semi-open type Sabo dam, the design capturing volume of debris flow and driftwood is the space enclosed by the surface of the depositing sediment in normal times and the assumed surface of the design depositing sediment (space indicated by diamond patterns in Figure 13).

The design depositing surface slope is generally 1/2 to 2/3 times of the riverbed surface slope before the facilities being built at the location of countermeasure facilities, depending on past records. However, since the "debris flow with design scale" is assumed not depositing on a slope steeper than 1/6, the maximum design depositing surface slope is 1/6 (tan θ). The deposit surface slope in normal times has an upper limit of half the riverbed slope before the facilities being built, according to past records.

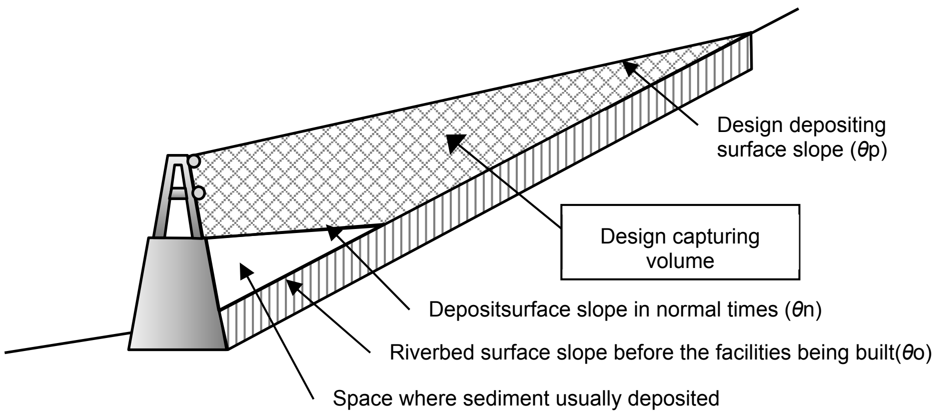
It is well known that the design deposit surface slope and deposit surface slope in normal times would be gentle in the region where specific geological condition exists such as decomposed granite and *shirasu*. Therefore, these design slopes shall be determined according to past records. Sediment that temporarily deposited on a steep slope used not to be re-eroded even in a long period, depending on the condition of water flow after the deposition. Therefore, design capturing volume of debris flow and driftwood shown in Figure 13 must be kept empty by sediment and driftwood removal works. The concept of the removal works is explained in Section 5 of the Guideline.

The concept of design capturing volume of debris flow and driftwood is shown in Figure 13.

- Open type Sabo dam



- Semi-open type Sabo dam



- Closed type Sabo dam

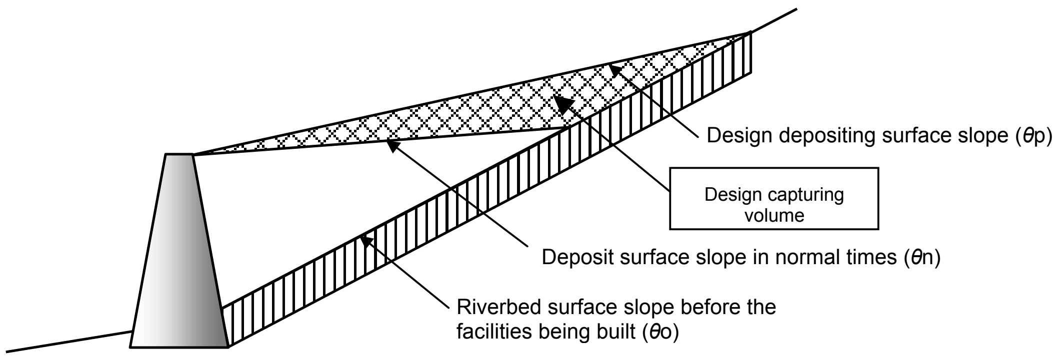


Figure 13 Concept of design capturing volume of debris flow and driftwood

3.2.1 Design sediment capturing volume

The design sediment capturing volume is the volume of sediment to be captured by debris flow and driftwood facilities in the volume of “debris flow with design scale” and contained driftwood.

Explanation

For open type Sabo dams, the design sediment capturing volume is equivalent to the space surrounded by the surface of riverbed before the facilities being built and the assumed surface of the design depositing sediment. While for closed and semi-open type Sabo dams, this space is surrounded by the surface of deposit in normal times and the assumed surface of the design depositing sediment. These spaces shall be kept empty by sediment and driftwood removal (diamond hatch pattern in Figure 13).

3.2.2 Design driftwood retention volume

The design driftwood retention volume is the volume of driftwood to be captured by debris flow and driftwood facilities in the volume of "debris flow with design scale" and contained driftwood.

Explanation

(1) Design driftwood retention volume of open type or semi-open type Sabo dam

Design driftwood retention volume for open type or semi-open type Sabo dam is calculated using Equation (30).

$$X_{w1} = K_{w11} \times X \qquad (30)$$

Where, X: design capturing volume of debris flow and driftwood by debris flow and driftwood facilities (m^3), X_{w1}: design driftwood retention volume by a main dam (m^3), K_{w11}: ratio of driftwood content to the design capturing volume of debris flow and driftwood (ratio of the design driftwood retention volume to the design capturing volume of debris flow and driftwood).

K_{w11} for open type or semi-open type Sabo dam is equal to the ratio of driftwood content (K_{w0}) to the design volume of debris flow and driftwood that is expected to flow into the dam (for K_{w0}, refer to this section (2)). Because open type or semi-open type Sabo dam captures both sediment and driftwood in debris flow at the same time, not selectively.

If the height of the opening part of a semi-open type Sabo dam is low, or the balance of the design driftwood retention volume in the opening part to the design driftwood depositing volume in the closed part under the opening part of the semi-open type Sabo dam is too small in other words, driftwood may not be sufficiently captured in the opening part due to ponding in the closed part. So that, in case that the total of the design driftwood retention volume in the opening part and the design driftwood depositing volume in the closed part exceeds the design capturing volume of debris flow and driftwood, the design driftwood retention volume and the design driftwood depositing volume of the semi-opening type Sabo dam shall be set to a value less than or equal to the driftwood retention volume in the opening part.

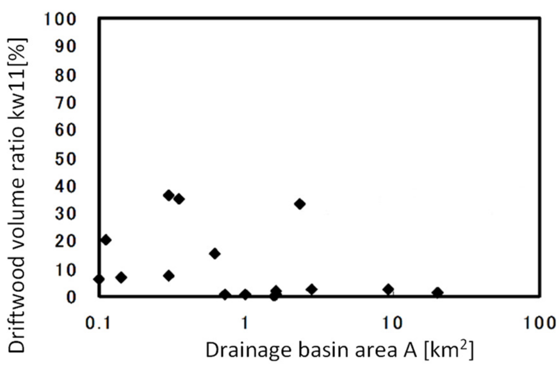


Figure 14 Driftwood volume ratio for open type Sabo dam

(2) Design driftwood retention volume by closed type Sabo dam

The design driftwood retention volume for the closed type Sabo dam is the smaller value between the result of Equation (31-1) and Equation (31-2). The design driftwood retention volume calculated by Equation (31-1) is obtained from the ratio of the design volume of driftwood to the design volume of debris flow material and driftwood which is expected to flow into the planned site for the Sabo dam. While the design driftwood retention volume calculated by the Equation (31-2) is obtained from the ratio of design driftwood retention volume to the design capturing volume of debris flow and driftwood in the Sabo dam.

Design driftwood retention volume by closed type Sabo dam

$$X_{w1} = K_{w0} \times X \times (1-\alpha) \text{………(31-1)}$$

$$X_{w1} = K_{w11} \times X \text{………(31-2)}$$

Where,

X : design capturing volume of debris flow and driftwood by debris flow and driftwood facilities (m^3),

X_{w1} : design driftwood retention volume by the Sabo dam (m^3),

K_{w0} : ratio of driftwood content to the design volume of debris flow material and driftwood which is expected to flow into the dam,

α : ratio of driftwood volume overflowed Sabo dam (approx. 0.5),

K_{w11} : ratio of driftwood content to the design capturing volume of debris flow and driftwood (if there have not been capturing cases in the target river, $K_{w11} = 2\%$ may be applied).

If a part of debris flow and driftwood is expected to be captured or retained by debris flow and driftwood countermeasure facilities upstream, K_{w0} shall be estimated after deduction of such volumes.

In experiments under certain conditions[19)], about a half of the driftwood that concentrated at the front part of the debris flow tends to overflow the closed type Sabo dam. Note that more data on the actual condition of driftwood discharge needs to be investigated to clarify its mechanism because driftwood transportation is a complicated phenomenon related to many factors including the flow condition of debris flow, riverbed slope around the Sabo dam, and the shape of depositing area.

○ The smaller between the two is the design driftwood retention volume (X_{w1})

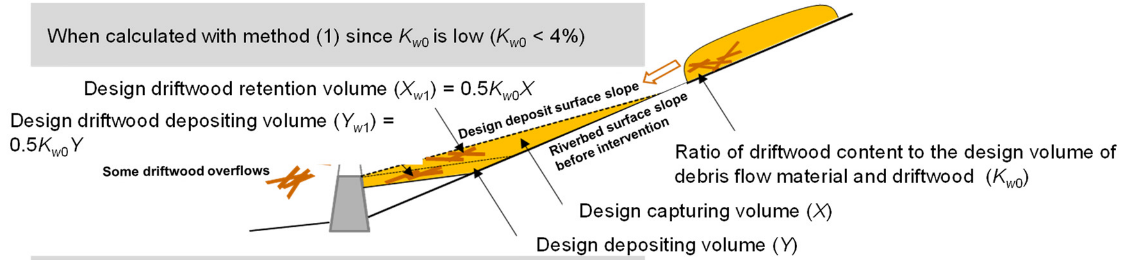
(1) Half of the quantity obtained by multiplying the design capturing volume (X) with the ratio of driftwood content to the design volume of debris flow material and driftwood (K_{w0})

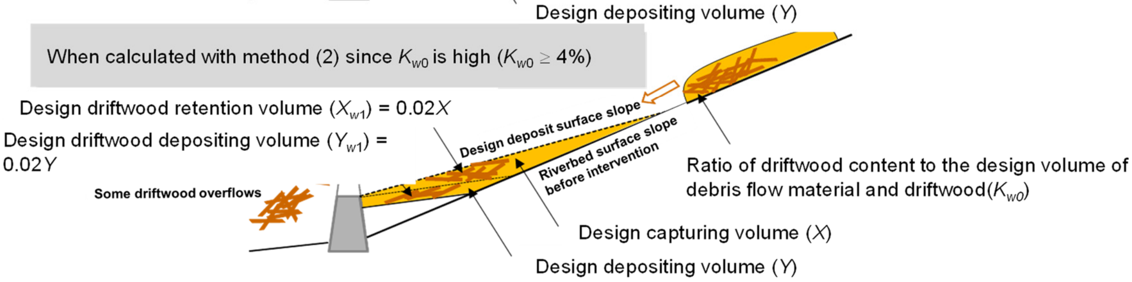
$K_{w0} \times X \times (1\text{-}\alpha)$ (ratio of driftwood volume overflowed Sabo dam $\alpha = 0.5$)

(2) 2% of the design capturing volume

$K_{w1} \times X$ ($K_{w1} = 2\%$)

○ The design driftwood depositing volume (Y_{w1}) shall be calculated in a similar manner





○ Facility with an open structure is required to capture all the driftwood and prevent overflow to downstream

Figure 15 Outline of the design driftwood retention/depositing volume in a closed type Sabo dam

(In the case of only one Sabo dam is planned in a target basin)

In principle, driftwood shall be retained by the main dam of closed-type Sabo dam. However, if a driftwood capturing work is required at the sub dam due to the limitation of topographic conditions, the design driftwood retention volume is calculated with Equation (32).

The design driftwood retention volume (X_{w2}, unit: m^3) by the sub-dam (limited to cases where a driftwood capturing work is installed at the sub-dam).

$$X_{w2} = A_w \times R_{wa} \quad \text{.......(32) (see the appendix D)}$$

Therefore,

$$X_w = X_{w1} + X_{w2} \quad \text{.......(33)}$$

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(Appendix D) Design driftwood retention volume in bedload zone

In the case of driftwood retention works installed in bedload zone, the retention driftwood volume shall be calculated assuming that the driftwood covers the reservoir surface with the depth equivalent to the average diameter of driftwood, for the sake of brevity (actually the accumulation situation of driftwood would be various). The projected area of a retained driftwood on the horizontal plane is calculated based on the total of the average length of driftwood (L_{wa}) multiplied by the average diameter of driftwood (R_{wa}).

Further, the area (A_w) of the driftwood deposition or retention pond of the driftwood retention work which is required to retain driftwoods with the design driftwood retention volume is estimated by the following equation.

$$A_w \geq \Sigma(L_{wa} \times R_{wa}) \quad \text{.......(34)}$$

The actual volume of the driftwood deposited on the depositing area or in the reservoir (V_{wc}) is represented by the following equation. However, the word “actual” in V_{wc} refers only to the volume of the driftwood, without any voids.

$$V_{wc} \approx A_w \times R_{wa} \quad \text{.......(35)}$$

In the bedload zone, driftwood is considered to flow on the surface of flowing water, separated from the sediment. Thus, a closed type Sabo dam is assumed not to retain driftwood.

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3.3 Design depositing volume of debris flow and driftwood

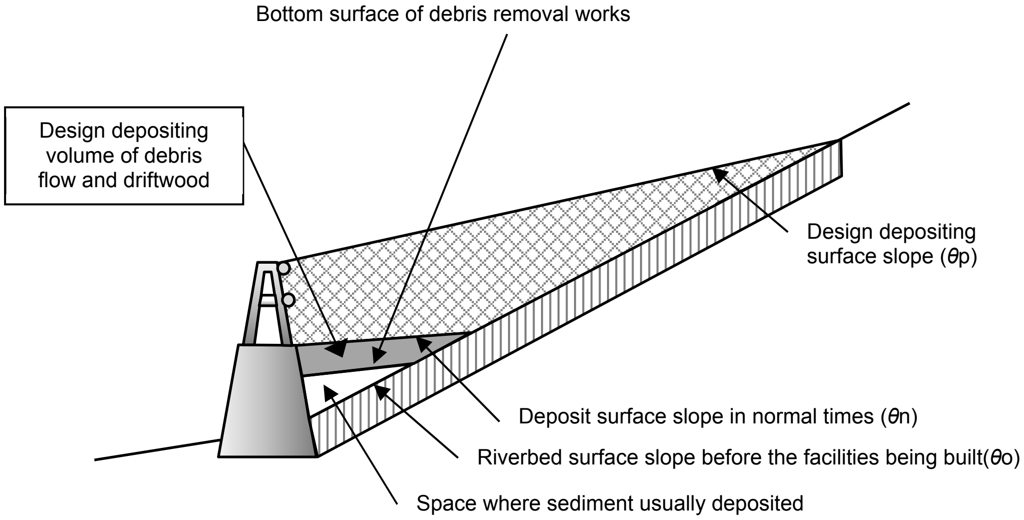
> The design depositing volume of debris flow and driftwood is the volume of "debris flow with design scale" and contained driftwood that is deposited upstream the debris flow and driftwood facility. The design depositing volume is the total of design sediment depositing volume and design driftwood depositing volume. The space equivalent to the design depositing volume of debris flow and driftwood shall be kept empty by sediment and driftwood removal in accordance with the sediment and driftwood removal plan.

Explanation

The design depositing volume of debris flow and driftwood differs depending on the type of debris flow and driftwood facility. In closed type and semi-open type Sabo dams, it shall be deposited in the space surrounded by the riverbed surface before the facilities being built and the deposit surface in normal times (grey colored in Figure 16). For debris flow depositing work, see the Guideline, Section 4.3.4. In order to make sediment and driftwood deposit effectively, the space equivalent to the design depositing volume of debris flow and driftwood shall be kept empty by the sediment and driftwood removal work because deposition may be proceeded by normal runoff events. The concept of sediment and driftwood removal are explained in Section 5 of the Guideline.

The concept of the design depositing volume for closed type and semi-open type Sabo dam is presented in Figure 16.

• Semi-open type Sabo dam



• Closed type Sabo dam

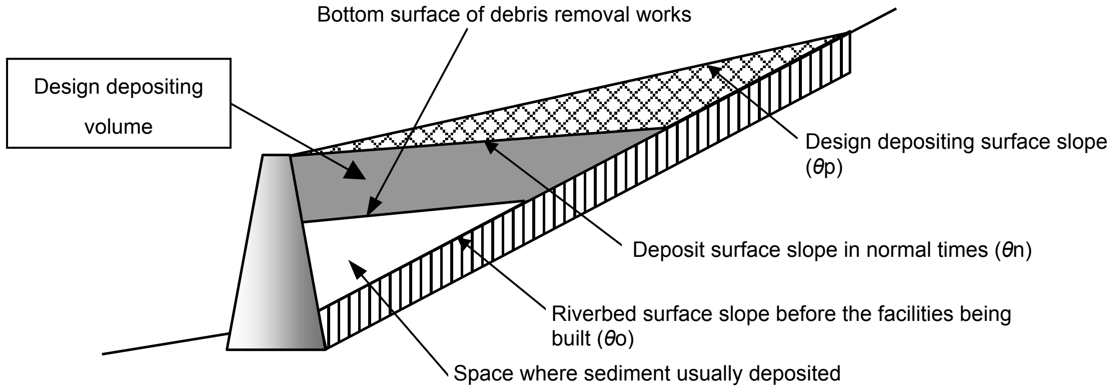


Figure 16 Concept of design depositing volume of debris flow and driftwood

3.3.1 Design sediment depositing volume

The design sediment depositing volume is the sediment volume deposited upstream a debris flow and driftwood countermeasure facility in the volume of the “debris flow with design scale” and contained driftwood.

Explanation

The design sediment depositing volume is the sediment volume that shall be deposited in the space equivalent to the design depositing volume (gray colored in Figure 16).

3.3.2 Design driftwood depositing volume

The design driftwood depositing volume is the volume of driftwood deposited upstream a debris flow and driftwood countermeasure facility in the volume of the "debris flow with design scale" and contained driftwood.

Explanation

The method to calculate the design driftwood depositing volume is the same with the method to calculate the design driftwood retention volume in Section 3.2.2. It is specified as follows:

(1) The design driftwood depositing volume for semi-open type Sabo dam

The design driftwood depositing volume for semi-open type Sabo dam is calculated using Equation (36).

$$Y_{w1} = K_{w12} \times Y \quad \cdots\cdots (36)$$

Where, Y: design depositing volume of the debris flow material and driftwood (m^3), Y_{w1}: design driftwood depositing volume of the main dam (m^3), K_{w12}: ratio of driftwood content to design depositing volume of the debris flow material and driftwood. The value of K_{w12} is similarly set as K_{w11} is set as explained in Section 3.2.2 (1).

(2) The design driftwood depositing volume for closed type Sabo dam

The design driftwood depositing volume for closed type Sabo dam is the smaller value between the calculation results of Equation (37-1) and Equation (37-2). This method is similar to the calculation of design driftwood retention volume in Section 3.2.2 (2).

$$Y_{w1} = K_{w0} \times Y \times (1 - \alpha) \cdot \cdot \cdot \cdot \cdot \cdot \cdot (37\text{-}1)$$

$$Y_{w1} = K_{w12} \times Y \times (1 - \alpha) \cdot \cdot \cdot \cdot \cdot \cdot \cdot (37\text{-}2)$$

Where, Y: design depositing volume of debris flow material and driftwood (m^3), Y_{w1}: design driftwood depositing volume of the main dam (m^3), α : ratio of driftwood volume overflowed Sabo dam, K_{w0}: ratio of driftwood content to the design volume of debris flow material and driftwood which is expected to flow into the dam, K_{w12}: ratio of driftwood content to the design depositing volume of debris flow material and driftwood. The values of α and K_{w12} are similarly set as α and K_{w11} are set as explained in Section 3.2.2 (2).

3.4 Design volume of debris flow and driftwood prevention

The design volume of debris flow and driftwood prevention is the volume not to be entrained by the "debris flow with design scale" and contained driftwood, prevented by a debris flow and driftwood countermeasure facility. The design volume of debris flow and driftwood prevention is the total of the design sediment prevention volume and the design driftwood prevention volume.

Explanation

The design volume of debris flow and driftwood prevention is set for volume of entrainable channel deposit, volume of sediment prone to collapse and volume of driftwood in the zone where the design volume of debris flow material and driftwood is evaluated.

3.4.1 Design sediment prevention volume

The design sediment prevention volume is the sediment volume not to be entrained by the “debris flow with design scale”, prevented by debris flow and driftwood countermeasure facilities.

Explanation

If any entrainable channel deposits exists, the design sediment prevention volume is calculated from the area between the intersection of the surface of design depositing surface and the surface of riverbed before the facilities being built and the location of Sabo dam (area with vertical pattern in Figure 17 (1) and (2)).

- For debris flow prevention work

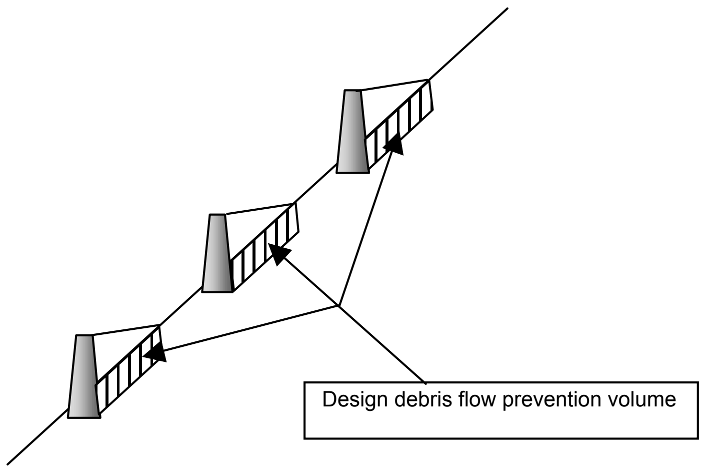
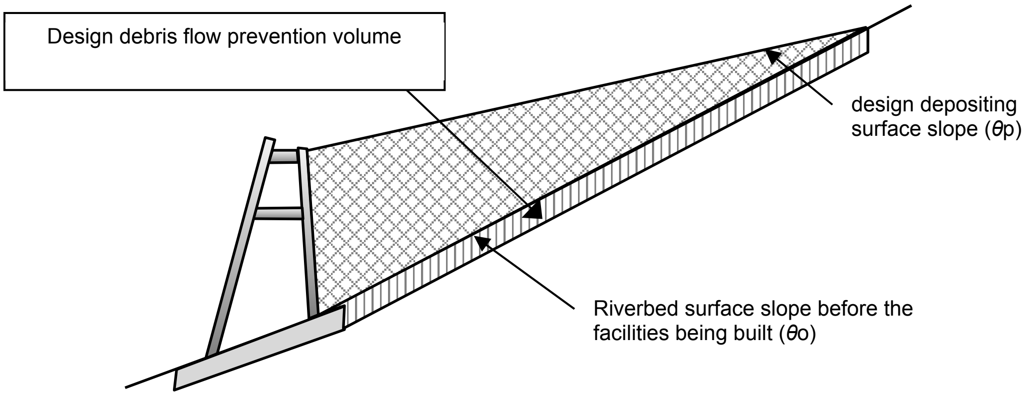


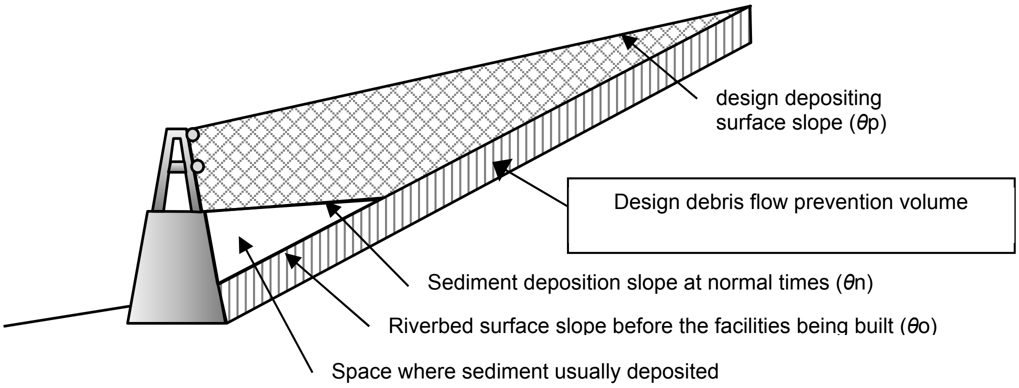
Figure 17 (1) Concept of design debris flow prevention volume

- For debris flow and driftwood capturing work

Open type



Semi-open type



Closed type

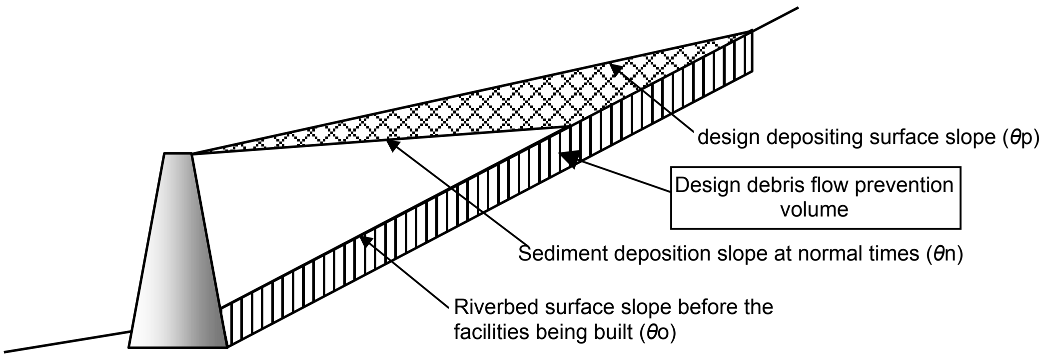


Figure 17 (2) Concept of design sediment prevention volume

3.4.2 Design driftwood prevention volume

The design driftwood prevention volume is the driftwood volume not to be recruited by the “debris flow with design scale”, prevented by debris flow and driftwood countermeasure facilities.

Explanation

The design driftwood prevention volume is set from the volume of driftwood in the zone where the design volume of driftwood is evaluated. The design driftwood prevention volume is equal to the deposited fallen trees and driftwood volume in the section between the intersection of the surface of riverbed before the facilities being built and the surface of deposit in normal times and the location of Sabo dam.

Section 4. Spatial distribution plan of facilities against debris flow and driftwood

4.1 General principles

> The debris flow and driftwood countermeasure facilities shall be spatially arranged to satisfy the design capturing volume of debris flow material and driftwood, design depositing volume of debris flow material and driftwood, and design volume of debris flow and driftwood prevention that were set in the debris flow and driftwood control plan.

Explanation

The debris flow and driftwood countermeasure facilities shall be spatially arranged to handle the amount of sediment and driftwood in the plan. Additionally, their impact on the natural environment and landscape shall be fully considered.

4.2 Principles of spatial distribution plan of facilities against debris flow and driftwood

> The spatial distribution of debris flow and driftwood countermeasure facilities shall be arranged so that they can rationally and effectively control debris flow and driftwood. Such spatial arrangement shall consider the design volumes of sediment and driftwood, sediment transport pattern, position of the protected area, etc. Debris flow and driftwood capturing work is the main countermeasure facility against debris flow and driftwood.

Explanation

Debris flow and driftwood capturing work, debris flow depositing work, debris flow torrent training work, and debris flow and driftwood prevention work are combined to determine the locations, height of the facilities, and other features of the facilities. Further, debris flow and driftwood capturing works is the main facilities against debris flow and driftwood. However, if the target basin is devastated, debris flow and driftwood prevention works shall be implemented appropriately.

This concept is identical with the application in non-volcanic and volcanic mountains. However, countermeasures are often difficult to be implemented in volcanic mountains particularly during volcanic activities. Countermeasure plan for volcanic mountains shall be established by considering the occurrence of large failures and large mudflows.

Further, the erosion control greenbelt, debris flow direction-controlling work, and debris flow torrent training work shall be considered by taking into account the land use of volcanic area, particularly during the volcanic activity.

4.3 Functions and locations of debris flow and driftwood countermeasure facilities

Debris flow and driftwood countermeasure facilities consist of (1) debris flow and driftwood capturing work, (2) debris flow and driftwood prevention work, (3) debris flow torrent training work, (4) debris flow depositing work, (5) erosion control greenbelt, and (6) debris flow direction-controlling work.

Explanation

The regular type of debris flow and driftwood countermeasure facilities is (1) the debris flow and driftwood capturing work.

Other facilities are (2) debris flow and driftwood prevention work, (3) debris flow torrent training work, (4) debris flow depositing work, (5) erosion control greenbelt, (6) debris flow direction-controlling work, etc.

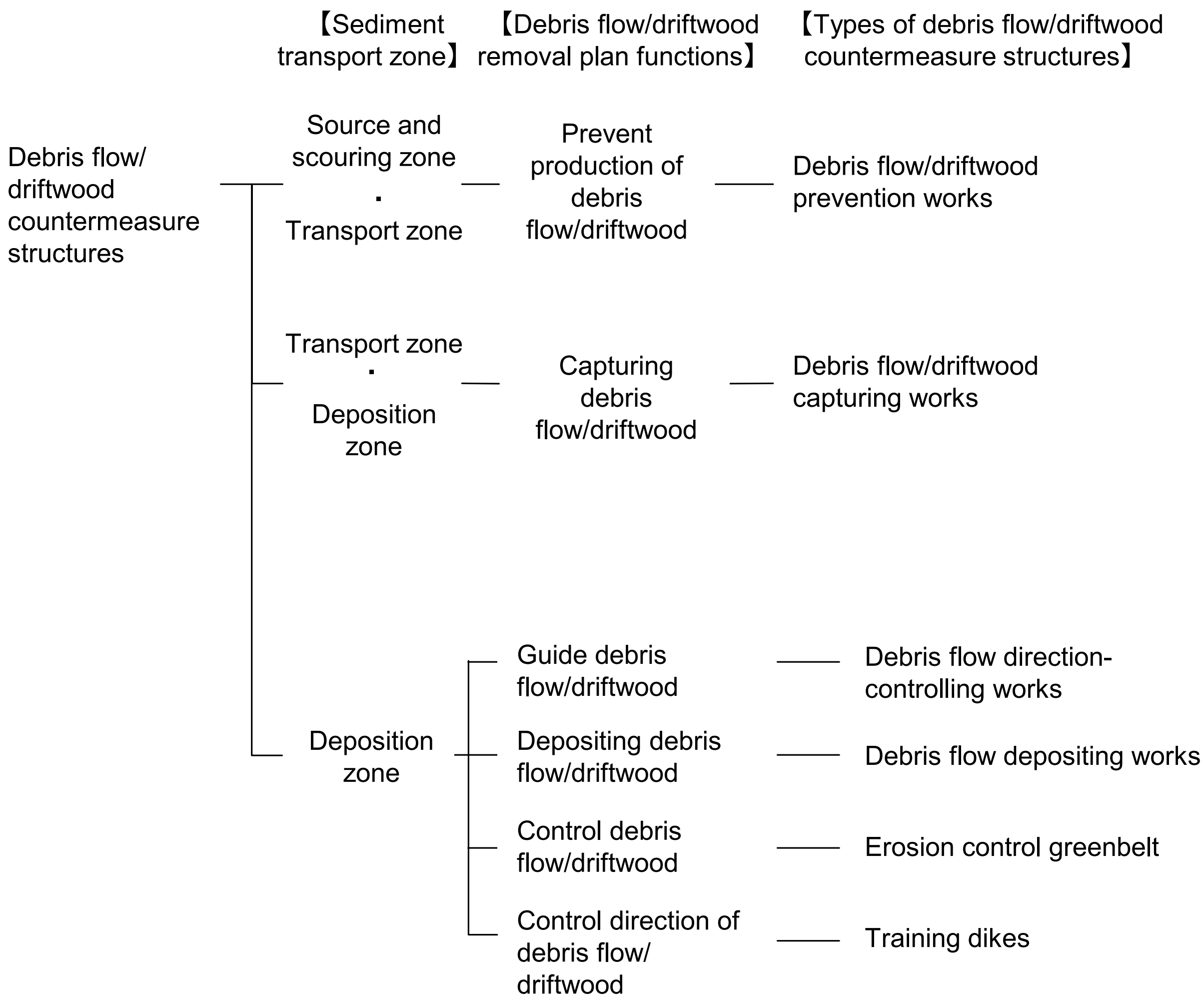


Figure 18 Types of debris flow and driftwood countermeasure facilities

4.3.1 Debris flow and driftwood capturing work

> Debris flow and driftwood capturing work is a debris flow and driftwood countermeasure facility aimed to capture debris flow and driftwood. Sabo dams shall be used as a debris flow and driftwood capturing work.

Explanation

When planning and arranging the debris flow and driftwood capturing work, the type and shape shall be determined by assuming the expected discharge of debris flow and driftwood as well as the grain size of the sediment, concentration of debris flow, size of driftwood (length and thickness), and the number of driftwoods. In addition, it shall be recognized that the sediment transport pattern of debris flow changes when the deposit surface slope in normal times changed significantly from riverbed surface slope before the facilities being built, or when the depositing area of the Sabo dam is long.

Sabo dam is mainly used as the debris flow and driftwood capturing work. However, debris flow breaker (drainage screen) is also considered as a debris flow and driftwood capturing work. This Guideline allows the application of debris flow and driftwood retention works other than Sabo dam.

4.3.1.1 Design volumes of sediment and driftwood controlled by Sabo dam

The types of Sabo dams are open type, semi-open type and closed type. Depending on the dam type, the design volumes of sediment and driftwood which is expected for Sabo dams include design capturing volume of debris flow material and driftwood, design depositing volume of debris flow material and driftwood, and design volume of debris flow and driftwood prevention.

Explanation

The design volumes of sediment and driftwood of Sabo dams include design capturing volume of debris flow material and driftwood, design depositing volume of debris flow material and driftwood, and design volume of debris flow and driftwood prevention as shown in Figure 19 (1) and (2).

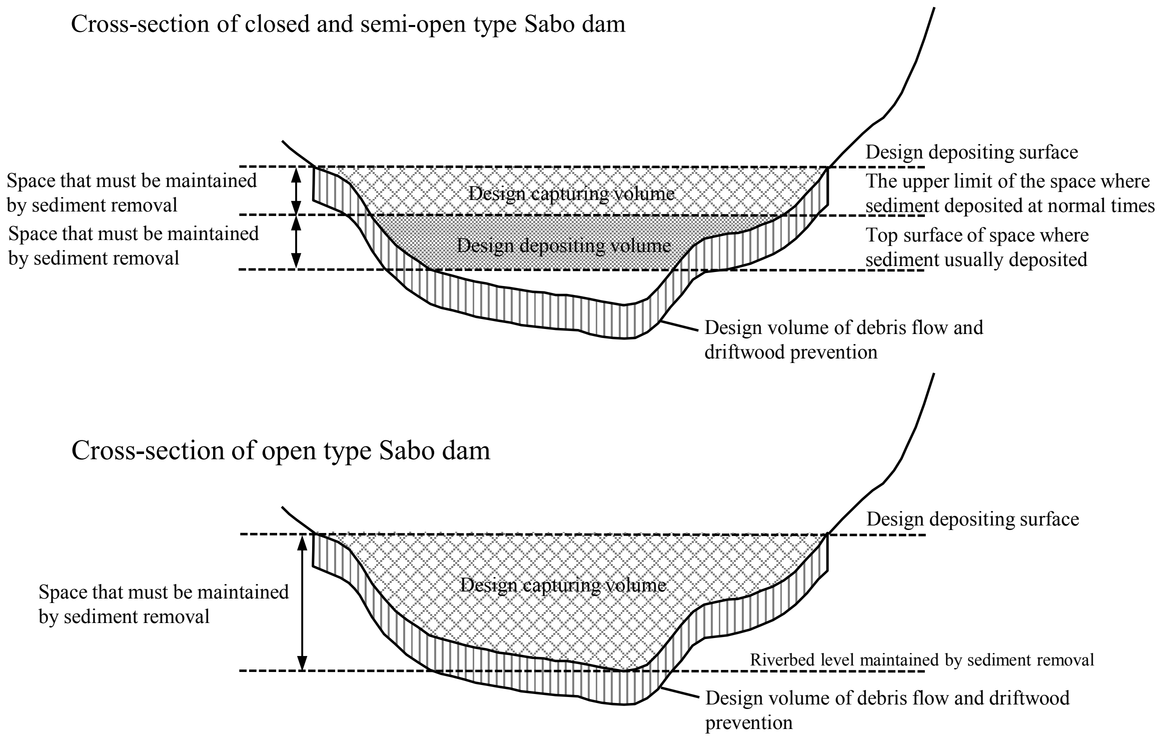
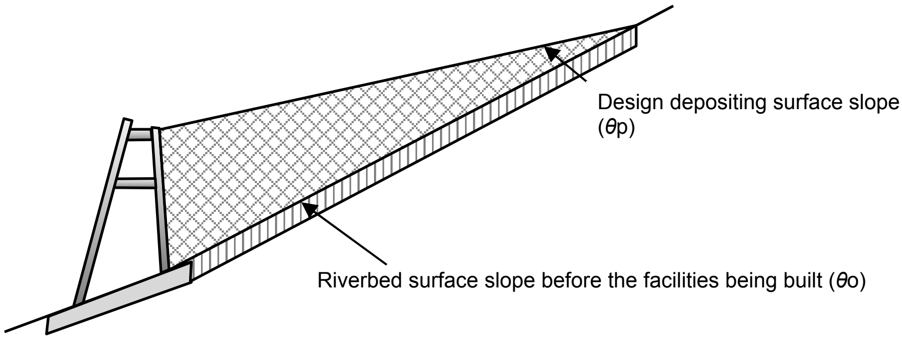


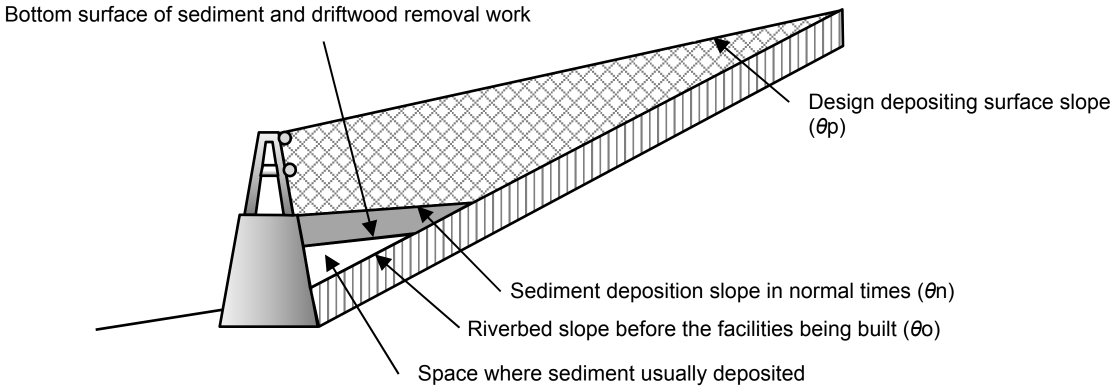
Figure 19 (1) Volume of sediment and driftwood depending on the type of Sabo dam

• Open type

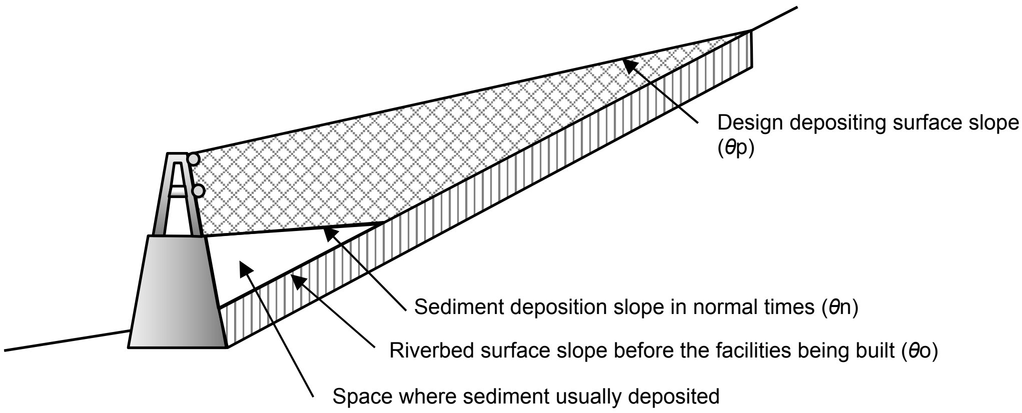


• Semi-open type

(If the space for design depositing volume can be ensured)

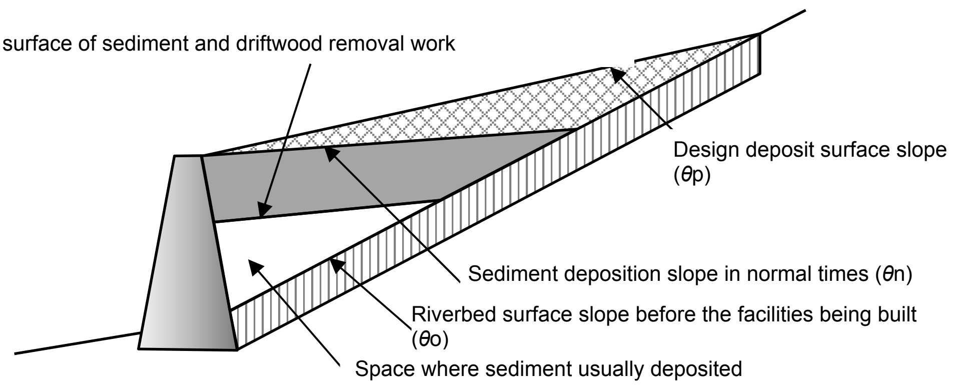


(If the space for design depositing volume cannot be ensured)



• Closed type

(If the space for design depositing volume can be ensured)



(If the space for the design depositing volume cannot be ensured)

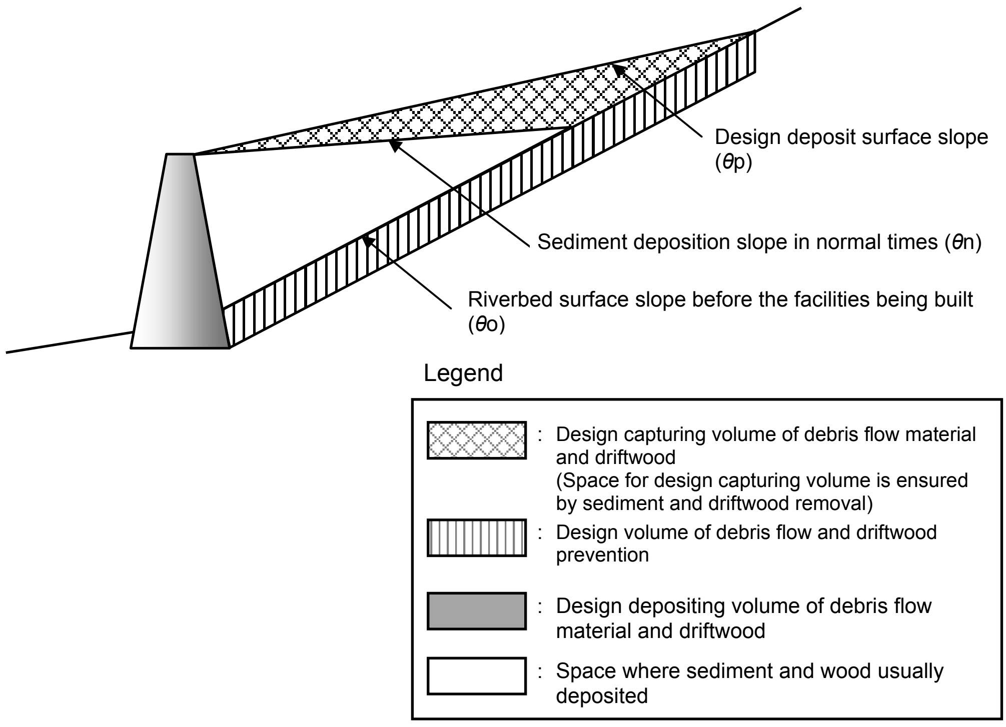


Figure 19 (2) Volumes of sediment and driftwood depending on the type of Sabo dam

4.3.1.2 Selection of the type of Sabo dam (open type, semi-open type, closed type)

> The type of Sabo dam shall be examined from field survey result and considering the characteristics of the target basin, the expected event, the economic efficiency and the site's environment. In principle, structures with open section is required to capture all driftwood that flows with the sediment.

Explanation

Sabo dam is constructed in the source and scouring zone with the main function of preventing the occurrence of debris flows and driftwood.

Meanwhile Sabo dam constructed in transport zone or deposition zone must primarily provide the following functions:

- Capturing debris flow
- Capturing driftwood
- Maintain the space corresponding to the design capturing volume of debris flow and driftwood
- Conserve river environment at normal times (continuity of the river)

Open-type facilities (e.g., open type Sabo dam, semi-open type Sabo dam, driftwood retention work, etc.) are required to capture all driftwood that flows with the sediment. Therefore, if the design allowable volume of driftwood is not zero or driftwood countermeasure facilities are planned separately, open or semi-open type Sabo dam shall be selected to capture/retain driftwood. Further, if driftwood retention work needs to be installed in the debris flow zone, it can be installed at the sub-dam.

In addition, sediment and driftwood removal plan needs to be considered to keep empty the design capturing volume of debris flow and driftwood regardless the dam type. For closed and semi-open type Sabo dams where design depositing volume of debris flow material and driftwood is planned, sediment and driftwood removal plan to keep empty the design depositing volume of debris flow material and driftwood need to be examined. The sediment and driftwood removal plan is explained in Section 5 of the Guideline.

4.3.1.3 Types and spatial distributions of open and semi-open Sabo dam

Open or semi-open type Sabo dam shall be designed to ensure that the open section shall be fully blocked by large stones, boulders, etc. so that the dam shall be capturing the designed scale of debris flow. In addition, the sediment transport pattern shall be considered when arranging the spatial distribution of open or semi-open type Sabo dam.

Explanation

(1) Basic concept on the spatial distribution of open and semi-open type Sabo dams

Open and semi-open type Sabo dams capture debris flow as the boulders carried by the debris flow block its open section. In addition, if the open section is fully blocked, the risk of captured sediment to flow downstream is almost non-existent. For this reason, open and semi-open type Sabo dams are usually situated in the debris flow zone.

On the other hand, open and semi-open type Sabo dams with the purpose of raising backwater and temporarily depositing sediment shall not be constructed in debris flow zone. It is due to the risk of accumulated sediment flowing downstream during the recession stage of flood.

(2) Precautions when arranging the spatial distribution and designing Sabo dam to capture debris flow

Open and semi-open type Sabo dams must satisfy the following conditions to capture debris flow.

① The open section shall be fully blocked by the "debris flow with design scale" and contained driftwood, but the structure shall not be destroyed during the debris flow.

If open or semi-open type Sabo dam is planned in the deposition zone, it shall be arranged considering the change of sediment transport pattern so that the entire open section is blocked by boulder and driftwood. If multiple Sabo dams are planned, a change in sediment transport pattern due to the open type Sabo dams located at the river upstream shall be considered.

② The open section shall not be blocked by bed load sediment transported by the flow during low to moderate rainfall.

Open type Sabo dam is expected to capture the design capturing volume of debris flow and driftwood without any sediment deposition during small or medium-sized flood. However, similar to closed type, open and semi-open type must be maintained by sediment and driftwood removal for example, after a debris flow has been captured.

Steel pipes or concrete used to construct the open section are categorized to those that maintain the stability of the structure (structural members) and those installed to capture the debris flow (functional members). Plastic deformation is allowed for the functional members as long as they can capture debris flow and driftwoods.

Furthermore, semi-open type can be adopted for the following cases:

- Driftwood capturing function needs to be enhanced beside prevention of debris flow and driftwood is required.
- It is expected that fine particle of sediment is dominant.
- Low sediment concentration is expected due to gentle slope.
- Muddy water due to flooding (other than debris flow) near the mouth of valley needs to be directed to downstream channel.

4.3.2 Debris flow and driftwood prevention work

Debris flow and driftwood prevention work is a debris flow and driftwood facility that prevents debris flows and driftwood.

Explanation

Debris flow and driftwood prevention work includes the restraint work on hillslopes, prevention works on riverbed or on riverbank.

4.3.2.1 Hillslope restraint work

A hillslope restraint work such as vegetation or other facilities shall be used to stabilize mountain slopes.

Explanation

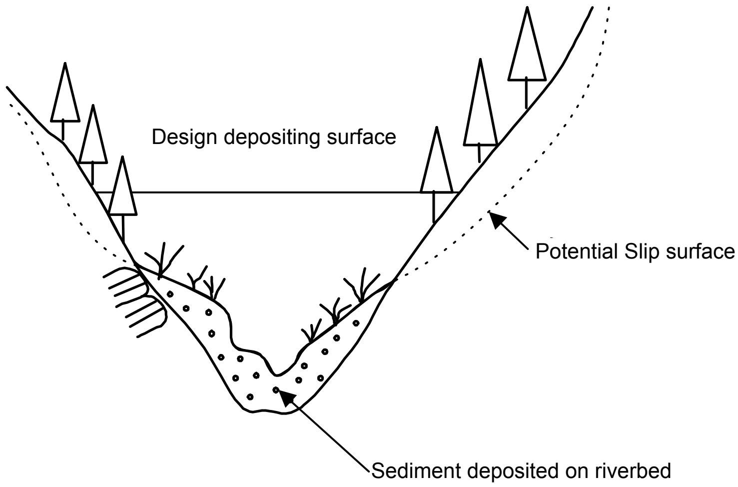
Hillslope restraint works are conducted to prevent the collapse of hillslopes that may cause debris flow and driftwood.

4.3.2.2 Riverbed sediment stabilization work

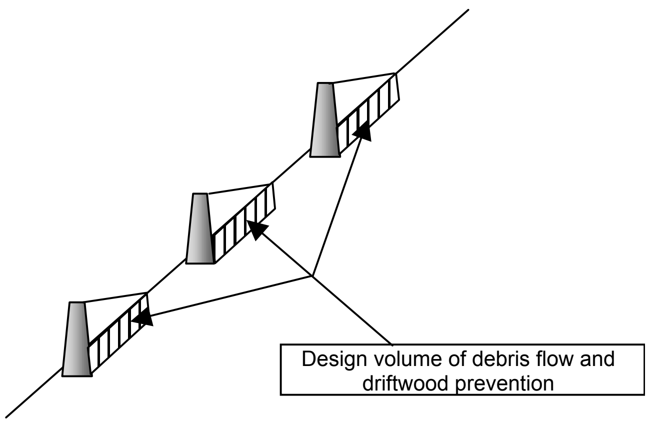
A riverbed sediment stabilization work shall prevent the collapse of river banks and the movement of sediments deposited on the riverbed by consolidation work or other methods.

Explanation

In order to prevent the movement of sediment deposited on riverbed and the collapse of river banks, consolidation work, revetment work for embankment, etc. are considered. To prevent the collapse of river banks (including hillslopes), sediment and driftwood removal shall not be performed for the riverbed sediment stabilization work.



Lateral cross-section



Longitudinal cross-section

Figure 20 Image of sediment and driftwood volume in the riverbed sediment stabilization work

4.3.3 Debris flow torrent training work

A debris flow torrent training work shall direct debris flow to a safe place, and shall have a cross section through which the peak discharge of debris flow for this section can flow down.

Explanation

Debris flow torrent training work must carefully consider the grain size of the sediment so that deposition does not occur inside the debris flow torrent training work, because deposition inside the debris flow torrent training work should cause overflow and inundation.

If there have been some facilities upstream, the capturing and/or depositing effects shall be considered to reduce the peak discharge.

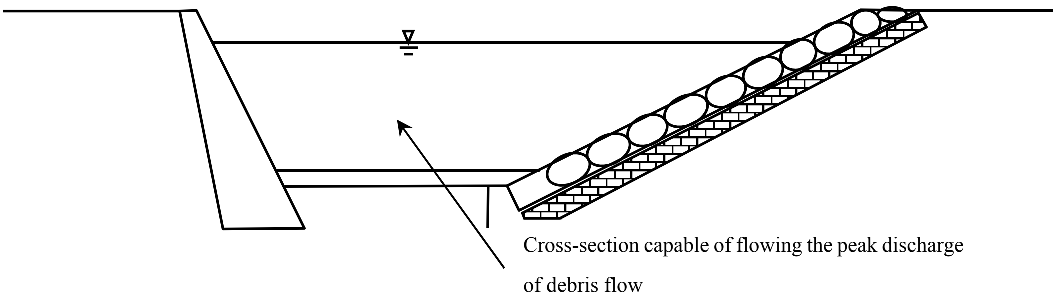


Figure 21 Debris flow torrent training work

4.3.4 Debris flow depositing work

Debris flow depositing works are the debris flow and driftwood countermeasure facilities that dissipate and deposit debris flows. Such structures include debris flow dispersion/depositing area and debris flow depositing channels.

Explanation

Debris flow depositing works shall deposit debris flows safely, and consist of two types: debris flow dispersion/depositing area and debris flow depositing channels.

(1) Debris flow dispersing/depositing area

A debris flow dispersing/depositing area is a land created by widening a channel where Sabo dams or groundsills are constructed at its upstream and downstream ends.

A debris flow dispersing/depositing area ensures a space to deposit the debris flow material and contained driftwood with the design depositing volume of debris flow and driftwood. Such space is secured by widening the channel and excavating its bed to reduce the bed surface slope.

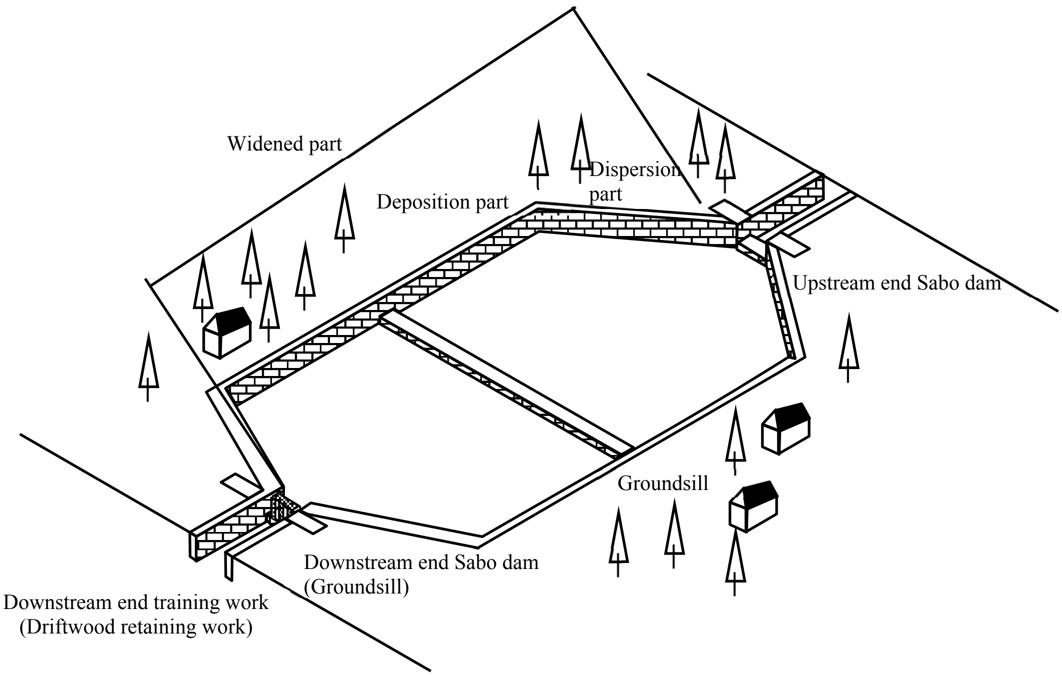


Figure 22 Debris flow dispersing/depositing area

(2) Debris flow depositing channel

A debris flow depositing channel is constructed to ensure a space to deposit the debris flow material and contained driftwood with the design depositing volume of debris flow and driftwood. Such space is created by excavating the channel to lower the riverbed slope. This method is used when a debris flow dispersion/depositing area is difficult to construct due to the development of residential land in the surrounding areas or due to the topographical conditions of the valley bottom plain.

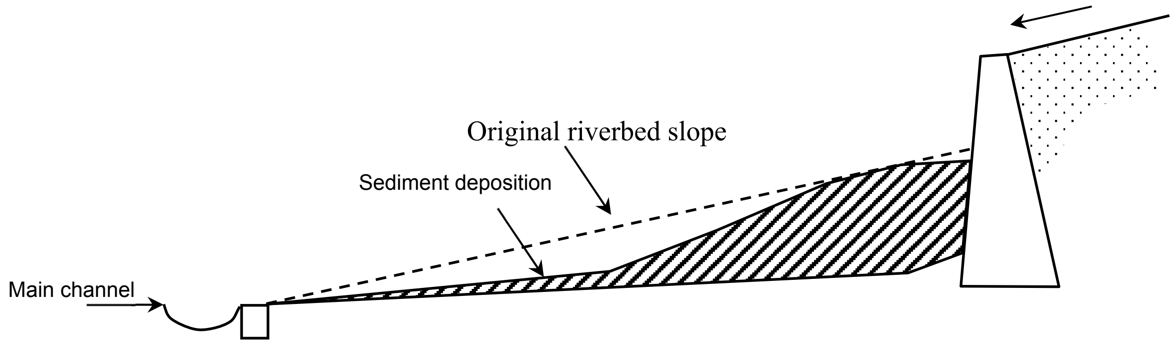


Figure 23 Debris flow depositing channel

4.3.5 Erosion control greenbelt

An erosion control greenbelt is a debris flow and driftwood countermeasures which aims to reduce the flow velocity and deposit the debris flow.

Explanation

As an erosion control greenbelt, debris flow and driftwood countermeasures such as consolidation work and debris flow direction-controlling work are combined with forests, main channel section, and other supplementary structures. Such combination is constructed near the downstream end of the deposition zone.

In principle, erosion control greenbelt is combined with debris flow direction-controlling works as a buffer between debris flows and properties to be protected on an alluvial fan land.

4.3.6 Debris flow direction-controlling works

A debris flow direction-controlling work is a debris flow and driftwood countermeasure work that controls the direction of a debris flow.

Explanation

If safe places to flow sediment downstream from the reference point are available, and the flowing process shall not cause any damage or disaster, the direction of the debris flow can be controlled by debris flow direction-controlling works.

Section 5. Sediment and driftwood removal plan

To maintain the debris flow and driftwood facility's full function, sediment deposition shall be inspected regularly after the occurrence of debris flow and sediment and driftwood removal shall be conducted as necessary. Further, if debris flow and driftwood control plan requires sediment and driftwood removal work, the way of transporting the sediment including a route shall be sought in advance.

Explanation

If debris flow and driftwood control plan requires sediment and driftwood removal work, the plan for sediment and driftwood removal shall be examined in the debris flow and driftwood control plan. The plan for sediment and driftwood removal includes methods of transportation, route for carrying out, destination of the removed sediment, frequency of sediment and driftwood removal, etc. In principle, sediment and driftwood removal is not conducted for riverbed sediment stabilization work.

Sediment and driftwood removal are classified to emergency removal which is conducted as an emergency measure after a debris flow event and periodic removal which is conducted based on regular inspections. The basic concepts are described below.

(1) Emergency sediment and driftwood removal

Urgent removal of sediment and driftwood transported by a debris flow is important to ensure the design capturing volume and the design depositing volume of debris flow and driftwood of a Sabo dam.

For this reason, an exceptional inspection shall be conducted to check the capturing status of the debris flow and driftwood countermeasure facility. If necessary, an emergency sediment and driftwood removal is performed in preparation for the next future debris flow.

(2) Periodic sediment and driftwood removal based on regular inspections

Periodic removal based on regular inspections is performed mainly to ensure the design depositing volume of debris flow and driftwood from the accumulation of sediment and driftwood.

As a result of the periodic inspections, sediment and driftwood removal shall be conducted if the design capturing volume and design depositing volume of debris flow and driftwood need to be empty.

Conducting the sediment and driftwood removal, removal shall not be started just upstream of the facility but be started from the upstream end of deposited area. This is to avoid the possible danger of an abrupt outburst of captured sediment and driftwood.

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Appendix E List of symbols

A	target basin area (km^2)
A_d	cross-sectional area of debris flow peak discharge (m^2)
A_{dy11}	average cross-sectional area of the entrainable channel deposits (m^2)
A_{dy12}	average cross-sectional area of the sediment entrainable by debris flow and prone to collapse in the zero-order stream (m^2)
A_w	plane area of the driftwood deposition or retention pond of the driftwood retention work (m^2)
B_d	average riverbed width where erosion is predicted to occur during debris flow (m)
B_{dm}	the minimum flow width of debris flow (m)
B_{da}	width of debris flow (m)
C_*	volumetric concentration of sediment deposited on the riverbed (approximately 0.6)
C_d	concentration of debris flow
D_{95}	grain size for which 95% of the material weight is finer
D_d	depth of the debris flow (m)
D_e	average depth of the riverbed sediment where erosion is predicted to occur during debris flow (m)
D_r	debris flow hydraulic radius (m)
F	drag force of debris flow per unit of width (kN/m)
g	gravitational acceleration (9.81 m/s^2)
H_w	tree height (m)
h_{wa}	average tree height (m)
H_{wm}	the maximum tree height (m)
K_d	breast height coefficient
K_{f1}	peak discharge coefficient
K_{f2}	discharge adjustment factor
K_h	drag coefficient (= 1.0)
K_n	roughness coefficient ($s \cdot m^{-1/3}$)
K_{p1}	coefficient for T_f
K_{p2}	coefficient for P_a
K_q	coefficient (= $C_* / (C_* - C_d)$)
K_{w0}	ratio of driftwood content to the design volume of debris flow and driftwood
K_{w11}	ratio of driftwood content to the design capturing volume of debris flow and driftwood
K_{w12}	ratio of driftwood to design depositing volume of the debris flow material and driftwood
K_v	porosity
L_{dy11}	river length from the reference point, supplementary reference point, or the point where the volume of debris flow material is to be calculated to the furthest upstream point of the first-order stream (m)
L_{dy12}	river length from highest point of the first-order stream where the volume of debris flow material is calculated to the farthest point in the target basin (m)
L_{dy13}	river length from the point where the driftwood yield is calculated to the farthest point in the target basin (m)
L_{wa}	average length of driftwood (m)
L_{wm}	the maximum length of driftwood (m)
P_{24}	24 - hour rainfall (mm)
P_a	average rainfall intensity during the flood concentration time (mm / h)
P_{day}	Daily rainfall (mm)
P_e	effective rainfall intensity (mm / h)
P_p	rainfall of the annual exceedance of probability (mm)
ΣQ	total sediment volume containing in a debris flow (m^3)
Q_p	peak discharge of water without sediment under rainfall with the design exceedance probability (m^3/s)
Q_{sp}	peak discharge of debris flow (m^3/s)
R_w	breast height diameter (m)
R_{wa}	average diameter of driftwood (m)
T_f	flood concentration time (min)
U	flow velocity of debris flow (m/s)
V	design volume of debris flow material and driftwood (m^3)

V_d	design volume of debris flow material (m^3)
V_{dqp}	sediment volume discharged by the largest surge of debris flow (including void) (m^3)
V_{dy1}	volume of sediment entrainable by debris flow and prone to collapse in the target basin (m^3)
V_{dy11}	volume of entrainable channel deposits in the section from the reference point, supplementary reference point, or the point where the volume of debris flow material is to be calculated to the furthest upstream point of the first-order stream (m^3)
V_{dy12}	volume of sediment prone to collapse (m^3)
V_w	design volume of driftwood (m^3)
V_{wc}	actual volume of the driftwood deposited on the depositing area or in the reservoir (m^3)
V_{wy}	volume of driftwood yield (m^3)
V_{wy1}	driftwood yield per unit area of target basin (m^3 / km^2)
V_{wy2}	single tree volume (m^3)
ΣV_{wy2}	tree volume per 100 m^2 in the sampling survey (m^3/100 m^2)
W	design allowable volume of debris flow material and driftwood
W_d	design allowable volume of debris flow material (m^3)
W_w	design allowable volume of driftwood (m^3)
X	design capturing volume of debris flow and driftwood by debris flow and driftwood facilities (m^3)
X_d	design sediment capturing volume (m^3)
X_w	design driftwood retention volume (m^3)
X_{w1}	design driftwood retention volume by Sabo dam (m^3)
X_{w2}	Design driftwood retention volume by a sub-dam (m^3)
Y	design depositing volume of the debris flow and driftwood countermeasure facilities (m^3)
Y_d	design sediment depositing volume (m^3)
Y_w	design driftwood depositing volume (m^3)
Y_{w1}	design driftwood depositing volume of the dam (m^3)
Z	design volume of debris flow and driftwood prevention (m^3)
Z_d	design sediment prevention volume (m^3)
Z_w	design driftwood prevention volume (m^3)
α	ratio of driftwood discharge from Sabo dam (approx. 0.5)
γ_d	debris flow unit weight (kN/m^3)
θ	riverbed surface slope (degrees)
θ_0	riverbed surface slope before the facilities being built (degrees)
θ_n	deposit surface slope in normal times (degrees)
θ_p	design deposit surface slope (degrees)
ρ	density of water (approx. 1,200 kg/m^3)
σ	density of gravel (approx. 2,600 kg/m^3)
ϕ	internal friction angle of sediment deposited on a riverbed (degrees) (approximately 30-40°; 35° is commonly used)

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