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土石流・流木対策設計技術指針解説（英訳）

土砂災害研究部　砂防研究室

Technical Guideline for Designing Sabo Facilities 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
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概　要

本資料は、国総研資料第905号「土石流・流木対策設計技術指針解説」を英訳したものである。

キーワード：土石流、砂防設備、設計

Synopsis

This note is the translation of the technical note of NILIM No.905 (Manual of Technical Guideline for Designing Sabo facilities against Debris Flow and Driftwood, originally written in Japanese in April, 2016).

Keywords: Debris flow, Sabo facilities, design

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 change without any prior notice.

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Section 1. General Principles

Debris flow and driftwood facilities shall be designed to have necessary functions and safety based on the Sabo master plan against debris flow and driftwood.

Explanation

The Technical Guideline for Designing Sabo Facilities against Debris Flows and Driftwood (hereafter called "the Guideline") explains the methods of designing debris flow and driftwood facilities stipulated by the Sabo master plan against debris flow and driftwood created based on *the Technical Guideline for Establishing Sabo Master Plan against Debris Flows and Driftwood*.

The characteristics and condition of river varies by zone and changes over time. Thus, the spatial distribution and design of debris flow and driftwood facilities are prepared by clarifying functions suited to these characteristics. Such characteristics and condition are determined by field surveys and collection of documents regarding river characteristics including its changes over time.

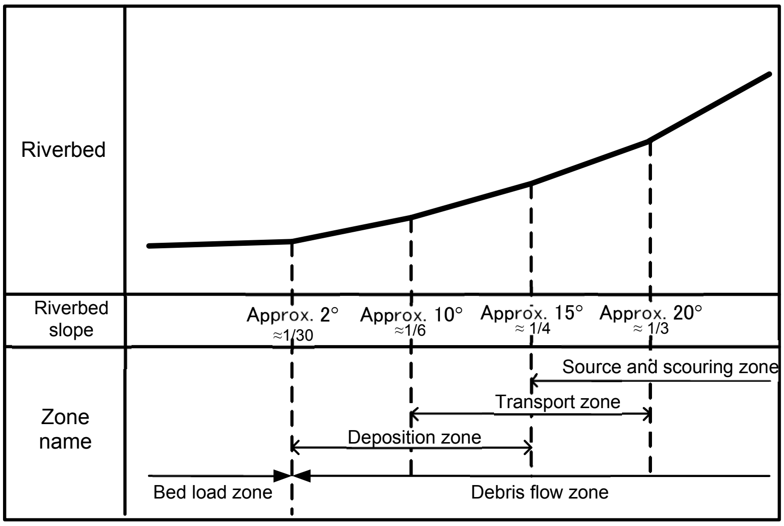

Figure 1 Changes of sediment transport pattern based on the riverbed slope [1)]

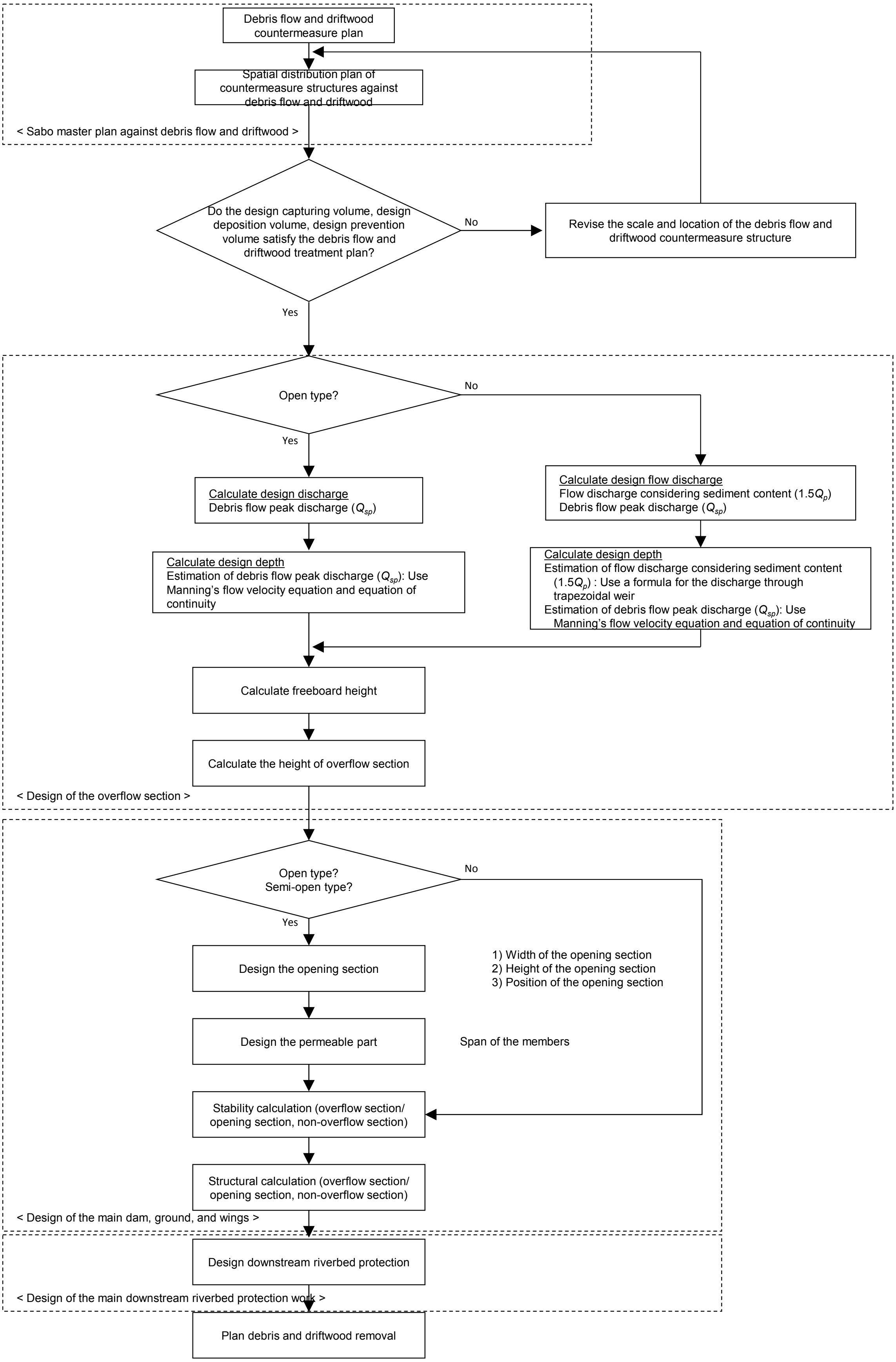

Figure 2 Flow chart of the debris flow and driftwood capturing work design

Section 2. Design of debris flow and driftwood facilities

2.1 Debris flow and driftwood capturing work

2.1.1 Type of debris flow and driftwood capturing work

The types of debris flow and driftwood capturing work include open, semi-open, and closed type.

Explanation

Sabo dams used as debris flow and driftwood capturing work are designed differently according to its type. Concerning functions of each type, see the explanation on *Technical Guideline for Establishing Sabo Master Plan against Debris Flows and Driftwood*, Section 4.3.1.

2.1.2 Dimensioning and positioning of debris flow and driftwood capturing work

> The dimensioning and spatial distribution of a debris flow and driftwood capturing work shall be formulated based on Section 4 of the *Technical Guideline for Establishing Sabo Master Plan against Debris Flows and Driftwood*. However, the decision shall also be determined based on geological, topographical, and other site conditions.

Explanation

The dimensioning and spatial distribution of a debris flow and driftwood capturing work must be set based on the spatial distribution plan of facilities against debris flow and driftwood established under Section 4 of the *Technical Guideline for Establishing Sabo Master Plan against Debris Flows and Driftwood*. When designing the structure, dimensioning and spatial distribution of the debris flow and driftwood capturing work can be reviewed if necessary, and revised accordingly.

The location of debris flow and driftwood capturing work is selected appropriately considering the topography, geology, etc. If a curved section of the river must be selected, direction of the main body axis and protection works for the downstream riverbed shall be examined by considering the flow directions upstream and downstream of the debris flow and driftwood capturing work.

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(Appendix A) Design of Sabo facilities in a small ephemeral river

Sabo dam set in a small ephemeral river which has no branching channel need to be designed properly by fully considering the field conditions such as topography and geology. For the definition of "small ephemeral river", refer to the *Technical Guideline for Establishing Sabo Master Plan against Debris Flows and Driftwood*, Section 2.5.1.1. Note that there are cases[2)] where countermeasures in a small ephemeral river were examined and the following viewpoints may be referred to.

- The crest width shall be determined considering the riverbed materials, patterns of mass movement and sediment transport, target flow rate, etc. at the planned site. The crest width shall be twice the maximum boulder size that collides with the dam, but shall be at least 1.5 m.
- The slope of the top of the dam's wing is basically horizontal or steeper.
- Apron length shall be longer than the nappe distance which is calculated using semi-theoretical equation. This is to secure safety of main dam body from erosion on its downstream due to debris flow.

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2.1.3 Structure of closed type Sabo dam

2.1.3.1 Stability of overflow section

The entire closed type Sabo dam must be stable against overturning, sliding, and sinking. Further, members that configure the dam body must be safe against debris flow and driftwood.

Explanation

Stability of overflow section is calculated based on the method in the Guideline, Section 2.1.3.1(1).

Dam body shall be a safe structure based on the method in the Guideline, Section 2.1.3.2 (2) and (3) and stability of non-overflow section shall be also ensured as stated in Section 2.1.3.3 (1). The dam body shall be designed so that the dam body consisting of several types of members is integrally resisting the design external forces. In addition, when sediment is used as filling material and water flows constantly (e.g., a large basin), the dam should be designed to secure redundancy. For instance, using soil cement to solidify the sediment filling material, hence partial damage may not expand to the whole body.

(1) Stability conditions

A closed type Sabo dam used as a debris flow and driftwood capturing work shall satisfy the following three conditions in order to maintain stability under the external forces in (2). 1. In principle, the resultant force consisting of the dam's self-weight and external forces must work within the range of the middle up to 1/3 of the dam base section. Hence, tensile stress is not generated at the upstream end of the Sabo dam. 2. Sliding shall not occur between the bottom of a Sabo dam and the ground. 3. The maximum stress generated inside the Sabo dam shall not exceed the allowable stress of the material. The maximum pressure received by the ground shall be within the allowable bearing capacity of the ground.

Explanation

For rock ground, the safety factor (N) against sliding is N = 4.0 considering the shear strength (the smaller value between the shear strength in the dam body and in the ground). While for sand and gravel ground, the shear strength is ignored and the safety factor is N = 1.2 for dam height of less than 15 m. While for dam height of 15 m or higher, the safety factor is N = 1.5.

(2) Design external forces

Design external forces considered in designing a closed type Sabo dam are the hydrostatic pressure, earth pressure, uplift pressure, inertia force during earthquakes, hydrodynamic pressure during earthquakes, and "load due to debris flows and driftwood" (hereinafter referred as "load of debris flow").

Load of debris flow includes drag force produced by a debris flow (hereinafter referred as "drag force of debris flow") and the force produced by the collision of boulder and driftwood. The former is considered to affect the entire structure, while the latter is considered to affect locally. Therefore, stability calculations for a Sabo dam shall deal with the drag force of debris flow only, while the force produced by the impact of boulder and driftwood shall be considered for the design of the crest width.

Explanation

In addition to the combinations of design external forces (in normal times and during flooding) presented in the *Technical Criteria for River Works (Tentative)*, Design, II, Chapter 3, Section 2.2.1, the following stability calculations during debris flows are performed and stability conditions must be satisfied by all combinations.

Combinations of design external forces are as shown in Table 1 in addition to the self-weight of a Sabo dam. "Design external forces (in normal times and during flooding)" referred in the Guideline are based on the "Loads used for Stability Calculations" in the *Technical Criteria for River Works (Tentative)*, Design, II, Chapter 3.

However, the design external forces for Sabo dam with height of less than 15 m is calculated by assuming the unit weight of the water as 11.77 kN/m^3.

During a debris flow, the most critical condition for the load of debris flow is assumed, i.e. a debris flow directly hits the main body while sedimentation proceeds until the remaining deposition height is same as the debris flow depth (D_d) (see Figure 3).

The drag force of debris flow acts horizontally at the position of D_d / 2. The deposited earth pressure consists of weight of debris flow as loading load, $C_e(\gamma_d - \gamma_W)D_d$, as well as deposited earth pressure up to the sedimentation surface.

Where,

C_e : coefficient of earth pressure,

D_d : depth of debris flow calculated using the current riverbed gradient (m),

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

γ_s : unit weight of sediment in water (kN/m^3),

γ_W : unit weight of water (γ_W is approximately 11.77 kN/m^3 for Sabo dam height of less than 15 m, and 9.81 kN/m^3 for Sabo dam height of 15 m or more).

$$\gamma_s = C_*(\sigma - \rho)g \quad \text{................................(1)}$$

$\gamma_w = \rho g$ ....(2)

Where,

C_* : volumetric concentration of riverbed sediment,

ρ : water density (kg/m^3),

σ : gravel density (kg/m^3),

g : gravitational acceleration (m/s^2) (9.81 m/s^2).

The hydrostatic pressure during a debris flow acts only below the sedimentation surface because the drag force of debris flow acts above the sedimentation surface.

Table 1 Design external forces used for stability calculations for closed type dam (excluding self-weight)

	Normal time	During debris flow	During flooding
Dam height of less than 15 m		Hydrostatic pressure, earth pressure, drag force of debris flow	Hydrostatic pressure
Dam height of 15 m or more	Hydrostatic pressure, earth pressure, uplift pressure, inertia force during an earthquake, hydrodynamic pressure during an earthquake	Hydrostatic pressure, earth pressure, uplift pressure, drag force of debris flow	Hydrostatic pressure, earth pressure, uplift pressure

* According to the past large earthquakes experiences such as Kobe Earthquake 1995, Sabo dams with height of less than 15 m have never been severely damaged, lost their functions, or cause direct and secondary damages to the surrounding buildings. The results of dynamic analysis have shown that they are safe from tensile stress, compressive stress, and sliding [3].

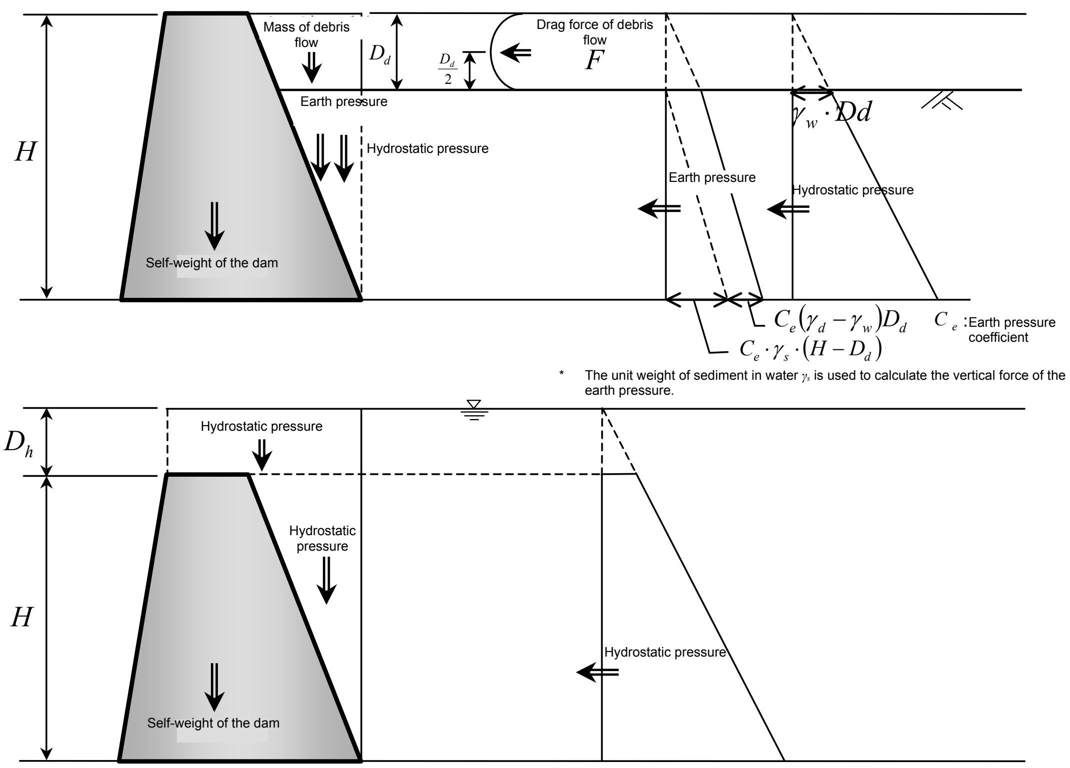


Figure 3 Closed type Sabo dam: design external forces of the overflow section

(H < 15 m, Top: during debris flow, Bottom: during flooding)

(3) Design discharge

The design discharge consists of the "discharge bulked with sediments" (during flood) and the peak discharge of debris flow (during debris flow). The discharge of water containing fine sediments is calculated by taking the larger value out of the design scale's rainfall of annual exceedance probability and the past maximum rainfall.

Explanation

In principle, the "discharge bulked with sediment" is calculated by the method described in the *Technical Guideline for Establishing Sabo Master Plan against Debris Flows and Driftwood*, Section 2.6.4. For the calculation, the larger value of design scale's rainfall of annual exceedance probability and the past maximum rainfall is taken. In addition, 1.5 times of discharge without sediment is applied.

The debris flow peak discharge is calculated based on the method shown in *Technical Guideline for Establishing Sabo Master Plan against Debris Flows and Driftwood*, Section 2.6.3.

(4) Design water depth

Design water depth is defined as the overflow depth of the spillway where the design discharge can flow.

Explanation

The design water depth is the largest of the values from the calculation results of 1) to 3).

1) Value of overflow depth in regards to the discharge bulked with sediments

The overflow depth in regards to discharge of water containing fine sediments is calculated using Equation (3) as presented in the *Technical Criteria for River Works*, Design, II, Chapter 3.

$$Q = \frac{2}{15} C \sqrt{2g} \left(3B_1 + 2B_2\right) D_h^{3/2} \quad \text{.......(3)}$$

Where,

Q : discharge of water containing fine sediments (m^3/s),

C : coefficient of discharge (0.6 to 0.66),

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

B_1 : base width of the spillway (m),

B_2 : width of the overflow (m),

D_h : overflow depth (m),

2) Value of the overflow depth in regards to the debris flow peak discharge.

The overflow depth in regards to the debris flow peak discharge is calculated by the method presented in the *Technical Guideline for Establishing Sabo Master Plan against Debris Flows and Driftwood*, Section 2.6.5 using the design sediment deposition slope.

3) Maximum boulder size

The maximum boulder size is calculated with the method provided in Section 2.6.8 of the *Technical Guideline for Establishing Sabo Master Plan against Debris Flows and Driftwood*.

For the dam in the most downstream of a river that satisfies the debris flow and driftwood sediment and drift wood control plan (100% of control ratio), the design water depth of the spillway should be determined based on the "discharge of water containing fine sediments" (during flood). In such case, the width of the spillway is determined appropriately by considering the current river width and the downstream channel width. However, even in such case, erosion countermeasures in downstream are implemented considering the possibility of flood overflowing the wing.

2.1.3.2 Main body structure

(1) Spillway section

In principle, the spillway section of a Sabo dam is determined by adding the freeboard height to the design water depth. Further, the spillway width shall be set based on the riverbed width before the facilities being built and should be at least 3 m.

Explanation

1) The freeboard is set based on Table 2. However, the freeboard height shall be designed according to the riverbed slope and freeboard height ratio to the design water depth must not be less than the value presented in Table 3. The riverbed slope referred here is the design sediment deposition slope.

Table 2 Freeboard height

Design discharge	Freeboard height
Less than 200 m^3/s	0.6 m
200 – 500 m^3/s	0.8 m
500 m^3/s or more	1.0 m

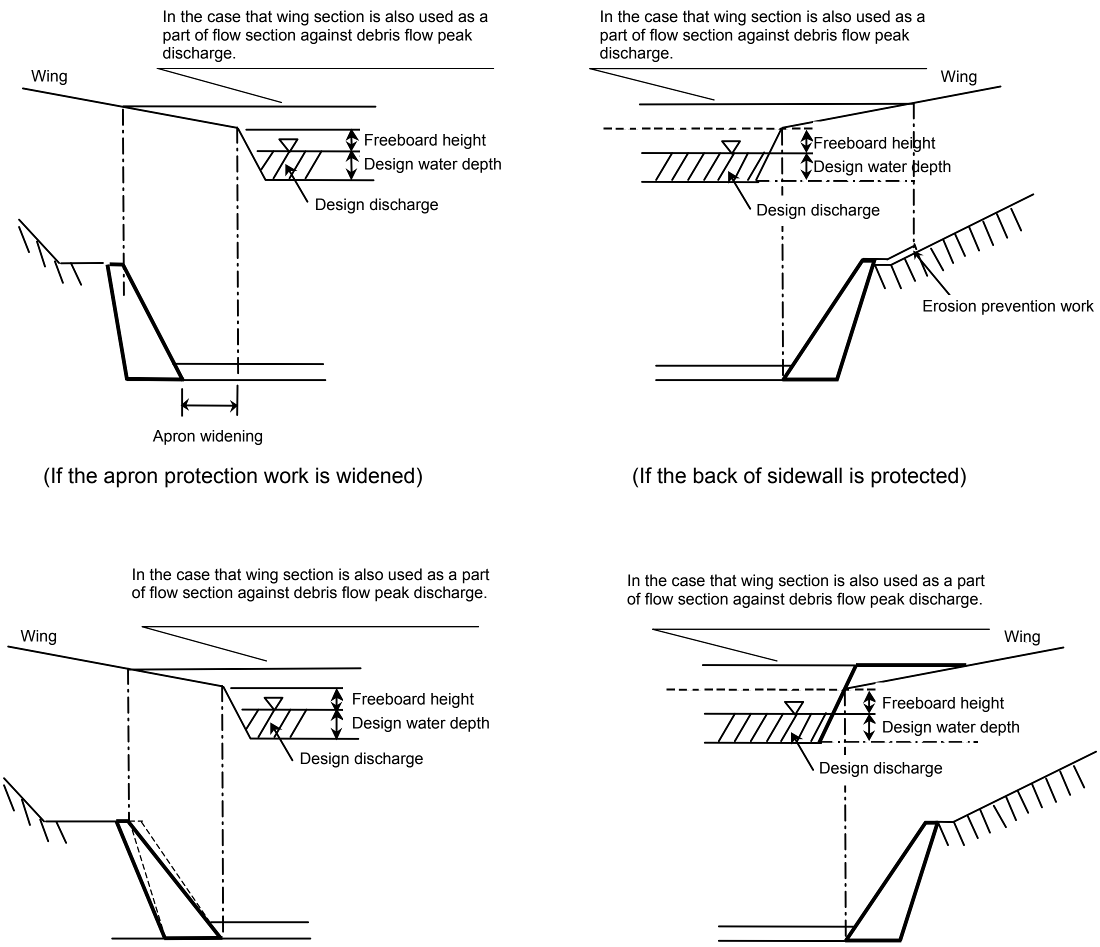
Table 3 Minimum value of the ratio of the freeboard height to the design water depth by riverbed slope

Riverbed slope	(Freeboard height)/(Design water depth)
1/10 or more	0.50
1/10 – 1/30	0.40
1/30 – 1/50	0.30
1/50 – 1/70	0.25

2) When spillway section is designed based on “overflow depth of debris flow peak discharge” or “maximum boulder size”, if sufficient flow area cannot be secured in spillway section due to topography or other factors, wing section can be included as a flow section (see Figure 4). In that case, the design water depth for determining spillway section shall be decided by the overflow depth of discharge of water bulked with sediments.

In addition, considering the stability of the wing section, damage to apron, and prevention of scouring downstream, appropriate measures shall be taken such as widening of apron, protection of backfill soil of sidewall, reducing the slope of sidewall etc.

In particular, if properties exist just immediately on the downstream, the above points must be given particular consideration.



(If the slope gradient of sidewall revetment is reduced)

(If the wing height (height of spillway section) is increased)

Figure 4 Spillway section

(Example of treatment when the wing section is also used as a part of flow section against debris flow peak discharge)

(2) Crest width

The crest width of the dam body shall be determined to prevent its failure by collision of boulder and driftwood.

Explanation

The crest of a Sabo dam body must be wide enough to withstand the collision with the volume of conveyed sediment, while the spillway must be wide enough to withstand the abrasion of passing debris. The crest width shall be twice the diameter of the largest debris colliding with the structure, if the body material is mass concrete. However, if the crest width shall be 3 m or more and if the required crest width exceeds 4 m, additional protection using buffer materials (materials which are expected to have buffering effect), embankments, and reinforcement by reinforcing bars or steel frames shall be provided. The effectiveness of the buffering material is confirmed by testing.

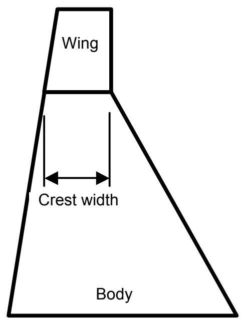


Figure 5 Example of Sabo dam side section and name of the members

(3) Downstream slope

The downstream slope of a Sabo dam shall be highly resistant to damage by overflowing sediment. The gradient of the downstream slope on the overflow section of Sabo dam is generally 1:0.2 (rise : run).

This gradient may be lower for a river with small grain diameter, small volume of conveyed sediment during a small- and medium-sized flood, and hillslope area.

Explanation

The downstream slope shall be equal or steeper than the slope calculated by the following formula even if gentle slope is required. U (m/s) means the flow velocity when volume of conveyed sediment starts increasing and H (m) means the Sabo dam height.

$$\frac{L}{H}=\sqrt{\frac{2}{gH}}U \quad \text{.......} (5)$$

However, its upper limit is 1:1.0.

The flow velocity U (m/s) at which sediment begin to be actively transported shall be about 50% of the flow velocity used by the design external forces (the Guideline, Section 2.1.3.1 (2)). The higher the Sabo dam height, the smaller the value of L / H, but its lower limit is 0.2.

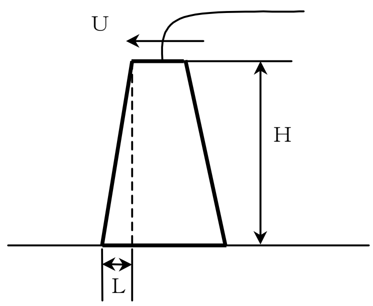


Figure 6 Downstream slope

(4) Ground

The bottom of a Sabo dam should be in contact with rock, but if this is impossible, floating foundation may be used. But in such cases, the dam body height of the Sabo dam shall be less than 15 m.

Explanation

The bottom of a Sabo dam should be in contact with rock to ensure safety. However, if bedrock cannot be found at the Sabo dam location planned based on the debris flow and driftwood countermeasure plan and the debris flow and driftwood countermeasure structure layout plan, floating foundation may be used. In this case, the height of the Sabo dam shall be 15 m or less, in principle.

If the bearing ground is soft or the specified bearing capacity cannot be obtained, ground improvement shall be performed.

(5) Drain hole

The drain hole should be designed to ensure its functions and safety.

Explanation

The drain holes are installed to switch running water during construction, prevent ponding, reduce water pressure after sedimentation, etc. In principle, the drain hole size, shape, quantity, and layout are designed in consideration of sudden discharge of sediment from drain holes, concentration of stress on the drain area, etc.

2.1.3.3 Stability and structure of non-overflow section

(1) Non-overflow section stability calculations

The cross-section of the main body of the non-overflow section shall ensure the same stability as in the overflow section against the design external forces.

Explanation

The cross-section of the main dam body of closed type dam shall be designed uniformly the same for both the overflow and non-overflow sections based on the stability against the design external forces for each section. However, this shall not be applied in special circumstances such as when the ground characteristics of overflow section is different from that of the non-overflow section. In the cross-section where the dam height, *H,* is identical with the overflow section, the stability of non-overflow section is calculated by applying the drag force of debris flow to act horizontally. Such calculation is assuming that sediments are deposited up to the crest of the spillway, including the wings. Stability conditions comply with the Guideline, Section 2.1.3.1(1), while the design external forces comply with the Guideline, Section 2.1.3.1(2), but the acting position complies with Figure 7.

Even though, as described in Explanation 2) of this Guidelines Section 2.1.3.2(1), when debris flow peak discharge is controlled by the cross-section of the spillway and wings, stability should be calculated for multiple cross-sections by assuming the sedimentation surface as in (a) and (b) shown below.

(a) If the depth of debris flow does not exceed the wing height when sedimentation surface is same as crest height of spillway in the cross-section, stability should be calculated with the sediment deposited up to the spillway crest.

(b) If the height of debris flow exceeds the wing height when sedimentation surface is same as crest height of spillway in the cross-section where the stability is calculated,, the sedimentation surface should be lowered so that the debris flow height does not exceed the wing height. The purpose of this arrangement is that the whole drag force of debris flow acts on the dam including wing section.

Furthermore, (i) and (ii) below can be considered as the section where the stability is calculated. However, other positions may be determined considering site conditions, dam size, etc.

(i) Cross-section at the wing edge

(ii) Cross-section where the depth of debris flow matches the wing height

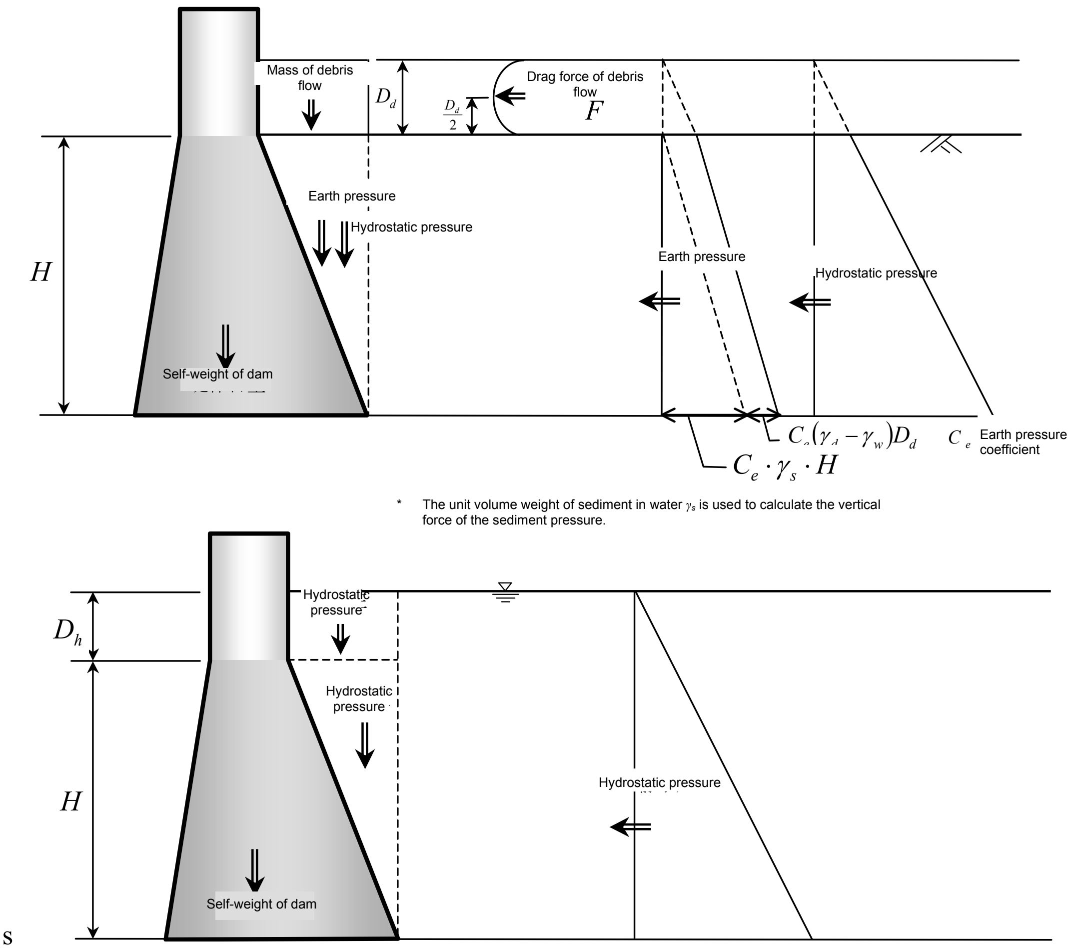


Figure 7 Closed Type Sabo dam: Design external forces of the Non-overflow section (H < 15 m, Top: during debris flow, bottom: during flooding)

(2) Structural calculations for wing failure

The structure of Sabo dam wings shall be safe against the drag force of debris flow and the largest value among the impact loads of boulder and driftwood.

Explanation

The cross-section of the wing must satisfy the following four conditions:

a. In principle, the upstream slope of the wing is vertical.
b. The downstream slope of the wing is either vertical or conforms to the downstream slope of the dam body.
c. If the downstream slope of the wing conforms to the downstream slope of the dam body, the lower limit of the crest width of the wing is 1.5 m.
d. The safety factor against shear friction generated by the design external forces at the boundary of main dam body and the wing shall be equal to or more than four.

The design external forces used for the above study are the following three components, and the locations where these act on the wing are as shown in Figure 9.

- Self-weight of the wing
- Drag force of debris flow
- The larger value between impact load of boulder and impact load of driftwood

If the safety factor against shear friction at the boundary of main dam body and wing is equal or less than 4, it should be increased by enlarging the crest width to the upstream side (Figure 8) or equipping the upstream side of the wing with buffer material to reduce the impact load. When protecting the wing with buffer material, the effectiveness of the buffer material should be confirmed by a test.

Since the impact load that causes wing failure[4),5)] is a short-time loading, tensile stress generated at the boundary of main dam body and wing is principally equal or lower than the allowed tensile stress. In contrast, if the tensile stress is higher than the allowed tensile stress, this tensile stress is resolved by reinforcing bars or a steel frame. These reinforcing bars or steel frame are arranged to connect the main dam body and the wing.

In the calculation of the impact loads of boulder and driftwood, the following assumptions are set: their velocity is equal to that of the debris flow, the diameter of boulder is the maximum boulder diameter (D_{95}), the diameter of driftwood is the maximum driftwood diameter (R_{wm}), and the length of the driftwood is the maximum driftwood length (L_{wm}). The boulder and driftwood are assumed to collide with the wing body at the surface of debris flow height with sediment deposition until the crest of spillway (Figure 9 (b)). If the depth of the debris flow is smaller than the boulder and driftwood diameters, it is assumed that the boulder and driftwood flow down and collide with the structure over the sedimentation surface. The flow velocity and depth of a debris flow are calculated by the method described in the *Technical Guideline for Establishing*

Sabo Master Plan against Debris Flows and Driftwood, Section 2.6.5.

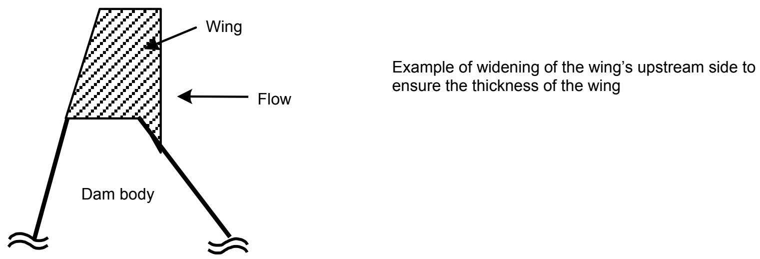


Figure 8 Cross-section of the wing

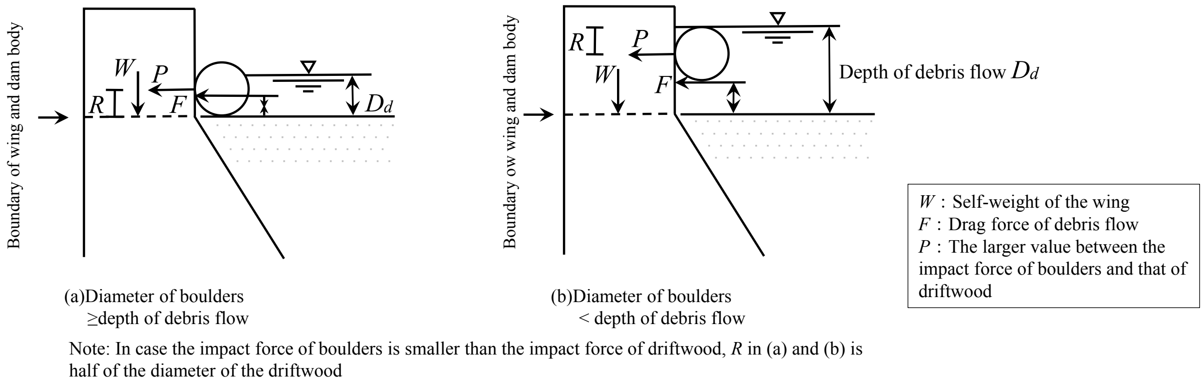


Figure 9 Acting point of design external forces at the boundary between the main dam body and wing

(3) Wing edge

The wing edge of a Sabo dam shall be 1:0.5 or less.

Explanation

The wing edge of the debris flow and driftwood capturing work has a slope of 1:0.5 or less to deal with the failure caused by the impact of a boulder or driftwood.

(4) Slope of the wing crest

In principle, the slope of the wing crest shall be equal to the riverbed slope before the facilities being built (θ_0).

Explanation

In principle, wing crest shall be sloped up to hillslopes. However, if the sloped crest section is too long, it can be shortened to appropriate length according to the site conditions and connected to a horizontal crest section.

2.1.3.4 Downstream riverbed protection work

Downstream riverbed protection work shall be constructed on the downstream of a Sabo dam as necessary to prevent the main body failure due to scouring.

Explanation

Downstream riverbed protection works are designed using the design discharge (discharge used to determine the spillway section). If the debris flow is expected to overflow the wing, its structure should consider the overflow of a debris flow as shown in Figure 4. The overflow depth of debris flow peak discharge is used for the design of thickness and length of apron.

The downstream slope of the sub-dam conforms to the concept in the Guideline, Section 2.1.3.2 (3).

The spillway section of a sub-dam is basically identical to the spillway section of the main dam. However, when installing a driftwood countermeasure structure on a sub-dam, no freeboard shall be planned. Its structure is determined for the design discharge in accordance with the *Technical Criteria for River Works* (Tentative), Design, Chapter 3.

The design criteria of driftwood countermeasure structure in bedload transport zone (see Appendix D p.66) can be applied for the design of it on the sub-dam.

2.1.4 Structure of open type Sabo dam

2.1.4.1 Stability of the overflow section

The entire dam body of an open type Sabo dam shall be stable against sliding, overturning, and sinking capacity. Further, permeable section and other parts of the dam body shall be safe against debris flow and driftwood.

Explanation

An open type Sabo dam shall be designed so that the dam body consisting of several types of members shall be integrally resisting the design external forces. In addition, when sediment is used as filling material and water flows constantly (e.g., a large basin), the dam should be designed to secure redundancy. For instance, using soil cement to solidify the sediment filling material, hence partial damage may not expand to the whole body.

(1) Stability conditions

The stability conditions of the open type Sabo dam are identical to those of a closed type Sabo dam.

Explanation

The concept of the stability conditions of an open type Sabo dam is identical to the closed type Sabo dam (see the Guideline, Section 2.1.3.1 (1)).

(2) Design external forces

The design external forces of an open type Sabo dam almost complies with the closed type Sabo dam, but the design external forces shall act according to the structure of the permeable section.

Explanation

1) The self-weight is calculated without boulder and water on the permeable section.
2) The earth pressure and hydrodynamic force shown in Figure 10 are treated as external forces to examine the stability of the entire dam body and the safety of each member. Since the weight of debris flow can act as a surcharge pressure, the earth pressure is distributed in a trapezoid shape.

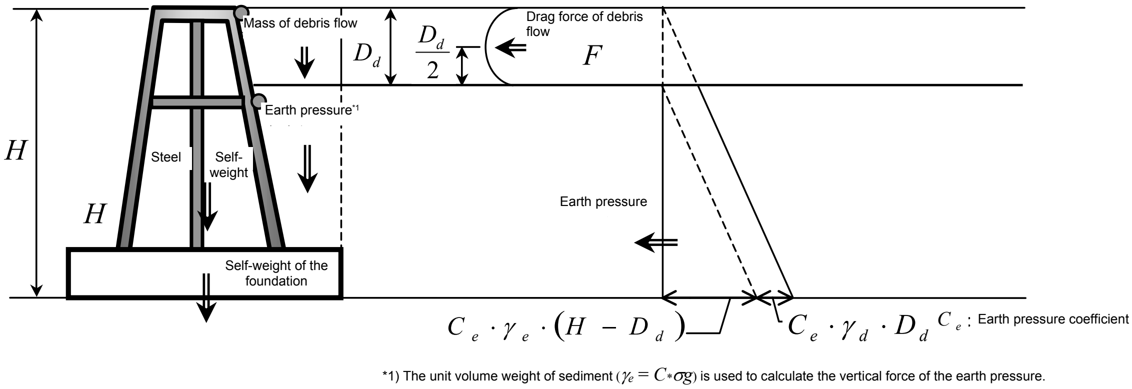


Figure 10 Design external forces (during debris flow)

3) If the permeable part is made of concrete, the self-weight of the dam body is calculated using the dam body block volume (V_c) which is calculated by assuming the overflow section as a closed structure, and the dam body block weight (W_{rc}) which is calculated by assuming the overflow section as an open structure (Figure 11). Further, it is noted that the dam body block refers to the concrete block in the permeable part, not the concrete block used at the time of casting.

$$\gamma_{rc} = W_{rc} / V_C \qquad (6)$$

Where,

γ_{rc} : apparent unit weight of concrete (kN/m^3),

W_{rc} : dam body block weight (kN) calculated by assuming the overflow section as an open structure with concrete,

V_c : dam body block volume (m^3) calculated by assuming the overflow section as a closed structure.

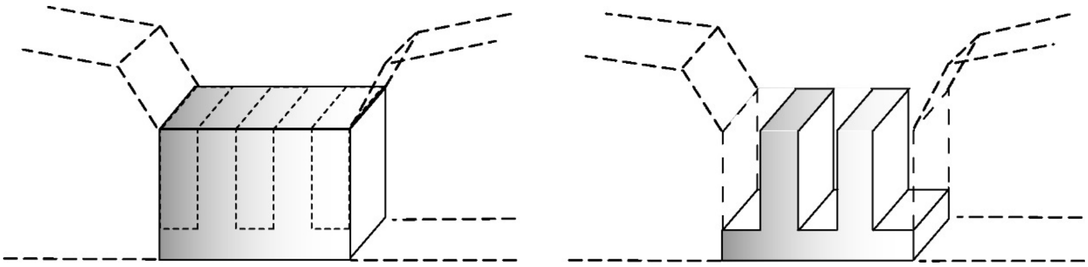


Figure 11 Dam body volume of spillway of the slit part

4) Combinations of design external forces excluding the self-weight of dam body are as shown in Table 4.

Table 4 Design external forces used to calculate stability of an open type Sabo dam (excluding self-weight)

	Normal time	During debris flow	During flood
Dam height less than 15 m		Drag force of debris flow, Earth pressure	
Dam height of 15 m or more		Drag force of debris flow, Earth pressure	

The stability conditions for the permeable section of an open type Sabo dam with height of 15 m or more are identical to those with height of less than 15 m. Besides, since the upstream slope of the non-overflow section is generally steep, the safety factor should be examined in a state where seismic inertia force acts from the downstream side when it is not fully filled with sediment.

(3) Design discharge

> The design discharge shall be the debris flow peak discharge used to design the spillway section.

Explanation

The debris flow peak discharge is calculated based on the method in the *Technical Guideline for Establishing Sabo Master Plan against Debris Flows and Driftwood*, Section 2.6.3.

(4) Design water depth

> The overflow depth of the spillway where the design discharge pass through is defined as the design water depth.

Explanation

Design water depth is the largest of the values of 1) and 2) below. However, if enough flow area cannot be secured in spillway section due to topography or other factors, wing section can be included as flow section.

1) Value of the overflow depth for debris flow peak discharge
   (see the Guideline, Section 2.1.3.1(4))
2) Value of the maximum boulder size
   (see the Guideline, Section 2.1.3.1(4))

For a dam located in the most downstream of a river that satisfies the debris flow and driftwood control plan (with 100% control ratio), the design water depth of the spillway, as in the case of a closed type Sabo dam, should be determined based on the Explanation of Section 2.1.3.1(4) of this Guidelines. However, if the “debris flow peak discharge” is smaller than the “discharge bulking with sediment” (during flood), the design water depth of spillway shall be determined based on the “debris flow peak discharge”.

2.1.4.2 Structural design of the permeable section

(1) Structural design conditions

Members of permeable sections shall be safe against the design external forces. The Sabo dam structure shall be as redundant as possible to achieve fail-safe performance, hence the failure of one member will not cause the failure of entire dam.

Explanation

The safety of the strength of members of the permeable section must be confirmed. To deal with sediment movement phenomena, the structure must have high redundancy so the failure of some members will not cause the failure of the overall structure. This is because sediment movement such as debris flows can cause severe damage, requiring countermeasures that take into account the uncertainty of their scale and the possibility of temporally and spatially complex phenomena. Because sediment movement phenomena such as debris flow has many uncertain elements yet causes severe damage.

The following items must be the part of the structural examination.

1) Examination of the strength of each member against drag force of debris flow and earth pressure
2) Examination of the strength of each member against thermal stress caused by temperature change
3) Examination of the strength of joints against the forces in 1) and 2) above
4) Examination of strength of each member against the impact load of boulder and driftwood.

For the members installed to capture debris flows (functional members) but not to maintain the shape of structure (structural members), plastic deformation is allowed provided that the boulder of debris flow can be captured.

Note that the following points should be additionally considered for a site where the external forces in the target basin are severe.

- In a site with particularly severe external forces, site conditions and target basin characteristics shall be thoroughly investigated and the boulder size should be determined appropriately. If record of volume of conveyed sediment in nearby rivers is available, the boulder size in the record can be used as a reference.
- If extremely large boulder could flow down with particularly severe external force, a dam structure shall be designed to maintain its capturing function as a whole Sabo dam even if such large boulders collide with the dam.

(2) Design external force

Design external forces considered in the structural design are the self-weight, drag force of debris flow, earth pressure, and thermal stress.

Explanation

Combinations of design external forces considered in the structural design are shown in Table 5.

Since the design external forces are short-time loading during debris flow, the allowable stress shall be increased by 1.5 times by considering the past records whereas since the earth pressure acts for a long period after the debris flow is captured, the allowable stress when the Sabo dam got fully filled with sediment is not increased. For the thermal stress, the allowable stress is generally increased by 1.15 times. If the thermal stress is large, the cross-section of the member shall be designed so that it is not determined by the thermal stress, or the length of the member shall be divided.

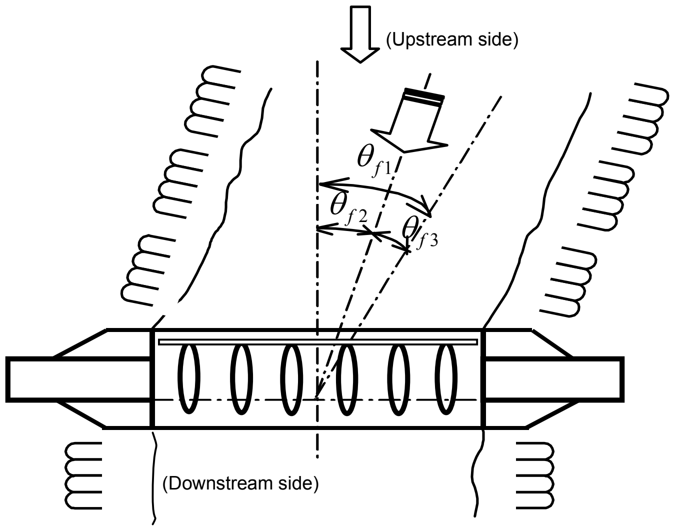
In structural calculations for an open type Sabo dam, the generated stress of members and the strength of joints must be safe against combination of design external forces during debris flow and when the structure is full with sediment. Further, if the facility is a statically indeterminate structure, its safety against combinations of design external forces during temperature change must be confirmed.

Permeable sections are designed so that they are safe from eccentric load, in addition to the loads in Table 4. Such eccentric loads are the drag force of debris flow which acts eccentrically on a structure and the impact load generated by the collision of boulder and driftwood are also considered.

Furthermore, the axis of a Sabo dam on a curve section of a river should be roughly at right angles to the downstream river channel. However, consideration must be given to minimize its eccentricity to the upstream river course to maintain its capturing functions. If the dam is eccentric to the upstream stream axis, the eccentric angle to the Sabo dam (θ_{f1}) is set by hypothesized debris flow longitudinal axis to the dam axis (θ_{f2}) with the allowed angle (θ_{f3}) (See Figure 12). Additionally, when the dam is constructed on a curve section, the risk that the inner side of the curve section may not be blocked by boulders contained in the front part of the debris flow and subsequent flows to pass through must be addressed.

Table 5 Combination of Design external forces Considered in the Structural Design

Cases	During debris flow	When filled with sediment	During temperature change
Self-weight	✓	✓	✓
Drag force of debris flow	✓		
Earth pressure	✓	✓	
Thermal stress			✓
Allowable stress increase factor	1.5	1	1.15



$$\theta_{f1} = \theta_{f2} + \theta_{f3} \quad 6 \; (7)$$

θ_{f1} : eccentric angle to the sabo dam (°)

θ_{f2} : angle of the hypothetical longitudinal axis of the debris flow and the axis perpendicular to the dam axis (°)

θ_{f3} : allowable angle (θ_{f3} = 10°)

Figure 12 Eccentric Loads on Permeable Section
(In case Sabo dam installed on a Curve Section of a River)

2.1.4.3 Main body structure

(1) Spillway section

> The spillway section shall be identical to that of a closed type Sabo dam, but it shall be a section that allows the debris flow peak discharge to pass safely even after the permeable section (slit part) is blocked.

Explanation

The spillway shall have a sufficient cross-section to allow the debris flow peak discharge to pass even after the permeable section has been completely blocked by debris. The freeboard does not need to be considered in this case.

However, if enough flow area cannot be secured in spillway section due to topography or other factors, wing section can be included as flow section.

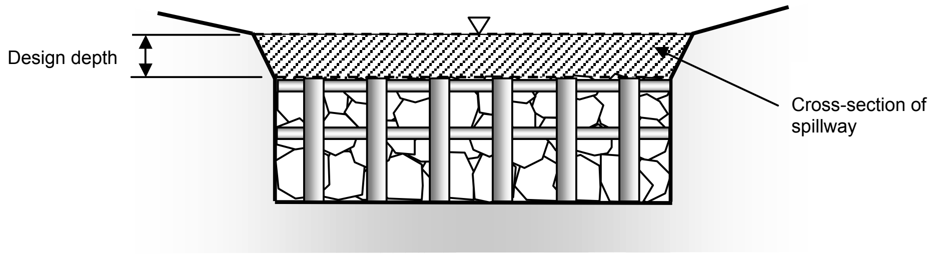


Figure 13 Cross-section of a spillway (the part in diagonal pattern)

(2) Setting of the opening section

> The width, height, and layout of the opening section in an open type Sabo dam shall be determined so that it can effectively capture debris flow and driftwood.

Explanation

The opening section must be wide enough so that the permeable function of an open type Sabo dam is fully achieved.

The height of opening section shall be equal to or greater than the depth of debris flow or of flood discharge bulked with sediment used to obtain the design capturing volume of debris flow and driftwood.

The bottom surface of the opening section shall be designed so that the discharge at normal times can flow downstream without damming up when the structure is not fully filled with sediment.

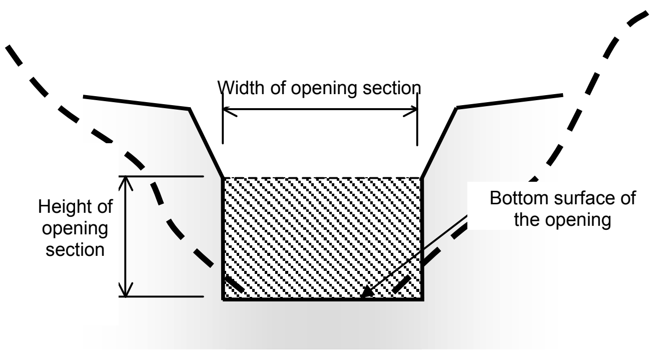


Figure 14 Opening section of an open type Sabo dam (the part in diagonal pattern)

(3) Setting the cross-section of the permeable section

The cross-section of the permeable section of an open type Sabo dam shall be determined based on the maximum boulder size and the purpose of the structure.

Explanation

By optimal setting of spacing of the permeable section, an open type Sabo dam for debris flow capturing can have debris flow capturing function while allowing sediment flow at normal time (see Figure 15). Thus, the flow type of a debris flow, maximum boulder size (D_{95}), layout of existing structures in the target basin, and Sabo dam height shall be fully considered when designing the cross-section of the permeable section.

The horizontal span is set to about 1.0 times of the maximum boulder size (D_{95}). When the height of an open type Sabo dam is planned to be higher than the debris flow depth, the vertical length of each mesh opening is set to 1.0 times of the maximum boulder size (D_{95}) to ensure the debris flow capture. The height of the lowest permeable section (see Figure 15) shall be less than the depth of debris flow but it shall be larger than the heights of upper permeable sections (see Table 6).

According to various experiments (see Figure 16), if the horizontal and vertical length of each mesh opening are smaller than 1.5 times the maximum boulder size (D_{95}), the overflow section may be blocked when the volumetric sediment concentration is high. Therefore, the horizontal and vertical length of each mesh opening can be widened to 1.5 times in the necessary cases. One of the necessary cases is, for example, that when several open type Sabo dams are planned, the design sediment and driftwood discharge volume could be efficiently controlled by designing the upper dam with widened spacing.

If all the following conditions are met as far as sediment discharge at normal time would pass through, permeable section can be designed by a method other than above-mentioned method with considering the conditions of river.

1) The permeable section lower than the debris flow depth is surely blocked by boulders contained in the debris flow and the blockage remains during debris flow.
2) The permeable sections higher than the debris flow depth are surely blocked by the following part of debris flow and the blockage remains during the latter half of debris flow.

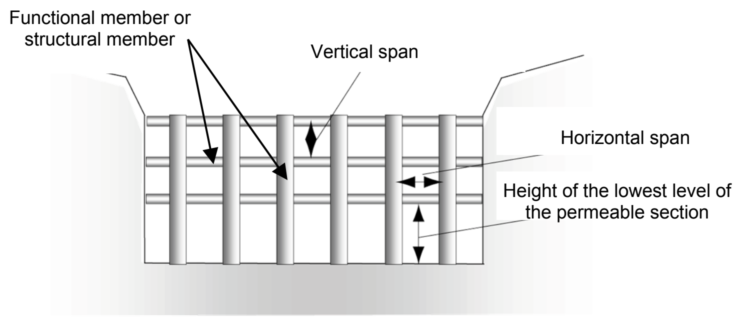


Figure 15 Span of the permeable section

Table 6 Setting of the permeable section of an open type Sabo dam

Function	Horizontal span	Vertical span	Height of the lowest level of permeable section
Capturing debris flows	$D_{95} \times 1.0$ *1	$D_{95} \times 1.0$ *1	Lower than debris flow depth *2

*1 As stated above, the horizontal and vertical span can be widened to 1.5 times the maximum boulder size (D_{95}).

*2 As stated above, it should be noted that the height of the lowest level shall not be smaller than the vertical length of each mesh span of other level

〜〜

(Appendix B) Blockage of the permeable section (experiment results)

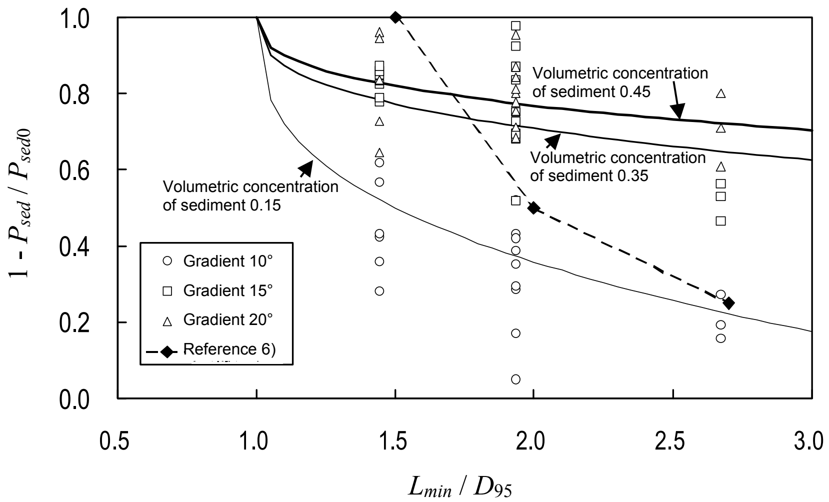


Figure 16 Relationship between the width of the mesh opening (steel pipe spacing) and the decreasing rate of the peak sediment load

Relationship between the width of the mesh opening (steel pipe spacing) and the decreasing rate of the peak sediment load. P_{sed}: peak sediment load at the downstream end of a channel with a structure, P_{sed0}: peak sediment load at the downstream end of a channel without a structure, L_{min}: smaller one[7)] of horizontal span and vertical span in a grid type Sabo dam, the horizontal span[6)] in another Sabo dam without horizontal beams, D_{95}: grain size for which 95% of a material weight is finer[7)], but maximum grain size[6)]. As the volumetric concentration of sediment in a debris flow decreases, $1 - P_{sed} / P_{sed0}$ also decreases, hence the permeable section is not easily blocked.

〜〜

2.1.4.4 Stability and structure of the non-overflow section

> The cross-section of the body of the non-overflow section shall be decided based on the stability calculation.

Explanation

The concepts of stability conditions of the non-overflow section of an open type Sabo dam and design external forces used are identical to those of closed type Sabo dam (this Guidelines, Section 2.1.3.3).

2.1.4.5 Downstream riverbed protection work

Downstream riverbed protection works shall be designed as needed by considering the local geology, topography, and other factors to maintain the stability of the Sabo dam body.

Explanation

In an open type Sabo dam, the water in normal time continues to flow on the riverbed almost identically prior to the dam construction. Therefore, downstream riverbed protection works are often considered to be unnecessary. However, if scouring is predicted to occur due to subsequent flow of the captured debris flow or relatively large gap between the level of the surface of the foundation of the permeable part and that the level of the downstream riverbed exists, downstream riverbed protection works identical to those for a closed type Sabo dam are required. The necessity of water cushion or a sub-dam is carefully examined and planned.

Note that the cross-section of the spillway of a sub-dam is designed by adding freeboard to the cross-section of the spillway of the main dam set in the Guideline, Part 2.1.4.3 (1).

2.1.5 Structure of a semi-open type Sabo dam

2.1.5.1 Stability of the overflow section

The entire dam body of a semi-open type Sabo dam shall be stable against sliding, overturning, and bearing capacity. The permeable section and other members of the dam body shall be safe against debris flow and driftwood.

Explanation

A semi-open type Sabo dam shall be designed so that the dam body consisting of several types of members shall be integrally resisting the design external forces. In addition, when sediment is used as filling material and water flows constantly (e.g., a large basin), the dam should be designed to secure redundancy. For instance, using soil cement to solidify the sediment filling material, hence partial damage may not expand to the whole body.

(1) Stability conditions

The stability conditions of the semi-open type Sabo dam is identical to those of a closed type Sabo dam.

Explanation

The stability conditions of a semi-open type Sabo dam shall conform to the closed type Sabo dam (see the Guideline, Part 2.1.3.1(1).)

(2) Design eternal forces

The design external forces of a semi-open type Sabo dam is basically identical to those of a closed type Sabo dam, but the design external forces which applied for open type Sabo dam is also applied according to the design of open part.

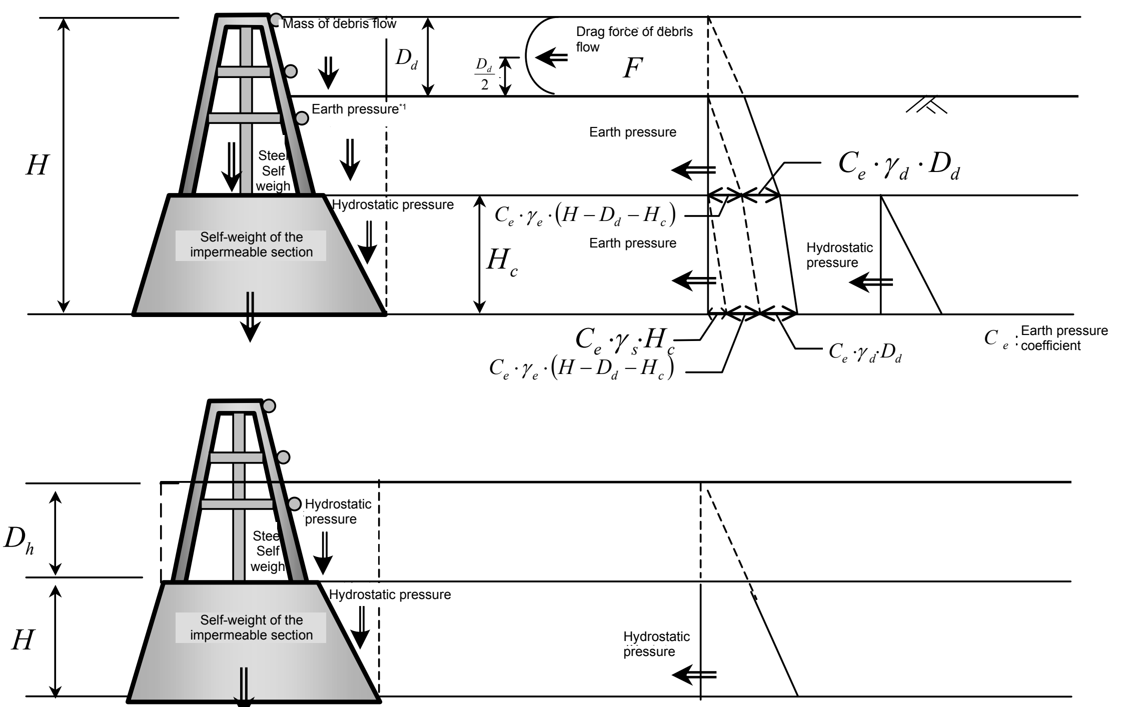
Explanation

1) Table 7 shows the combinations of design external forces used for the stability calculations.

Table 7 Design external forces used for stability calculation of semi-open type Sabo dam (excluding self-weight)

	Normal time	During debris flow	During flood
Dam height less than 15 m		Hydrostatic pressure, earth pressure, drag force of debris flow	Hydrostatic pressure
Dam height of 15 m or more	Hydrostatic pressure, earth pressure, uplift pressure, inertia force during an earthquake, hydrodynamic pressure during an earthquake	Hydrostatic pressure, earth pressure, uplift pressure, drag force of debris flow	Hydrostatic pressure, earth pressure, uplift pressure

2) Design external forces used for stability calculation act both on the permeable section and on the impermeable section as shown in Figure 17.



*1. The unit volume weight of sediment γ_e is used to calculate the vertical force of the earth pressure.
*2. The unit volume weight of sediment in water γ_s is used to calculate the vertical force of the earth pressure.

Figure 17 Design external forces used for stability calculations of a semi-open Sabo dam (H < 15m, Top: during debris flow, bottom: during flood)

3) Self-weight of the permeable section is calculated by assuming that boulder and water do not block the permeable section. Further, the self-weight of water that passes through the permeable section during a flood acts on the impermeable section as hydrostatic pressure.

(3) Design discharge

> The design discharge shall be identical to that of closed type Sabo dam.

Explanation

The concepts of design discharge of a semi-open Sabo dam are identical to that of closed type Sabo dam (see the Guideline, Section 2.1.3.1 (3)).

(4) Design water depth

> The design water depth shall be identical to that of a closed type Sabo dam.

Explanation

The concept of the design water depth of a semi-open Sabo dam is identical to that of a closed type Sabo dam (see the Guideline, Section 2.1.3.1 (4)).

2.1.5.2 Structural examination of the permeable section

> The examination of the structure of the permeable section shall be conducted in the same method as that of an open type Sabo dam.

Explanation

The members and structure of a semi-open Sabo dam are examined in the same method as those of an open type Sabo dam (see the Guideline, Section 2.1.4.2).

2.1.5.3 Main body structure

(1) Spillway section

The spillway section shall be identical to that of an open type Sabo dam.

Explanation

The spillway section of a semi-open Sabo dam is identical to that of an open type Sabo dam (see the Guideline, Part 2.1.4.3(1)).

(2) Setting the opening section

The opening section shall be determined in the same method as that of open type Sabo dam.

Explanation

The opening section of a semi-open Sabo dam is determined in the same method as that of open type Sabo dam (see the Guideline, Section 2.1.4.3 (2)).

(3) Setting the permeable section

The permeable section shall be set in the same method as that of a open type Sabo dam.

Explanation

The permeable section of a semi-open type Sabo dam is designed in the same method as that of a open type Sabo dam (see the Guideline, Part 2.1.4.3 (3)).

(4) Crest width of the impermeable section

The crest width of the impermeable section shall be determined so that it does not fail against the impact load of boulder and driftwood.

Explanation

The crest width of the impermeable section is at least twice the maximum diameter of the colliding boulder (D_{95}). However, considering the safety of the impermeable section according to the closed-type Sabo dam, the crest width shall be at least 3 m.

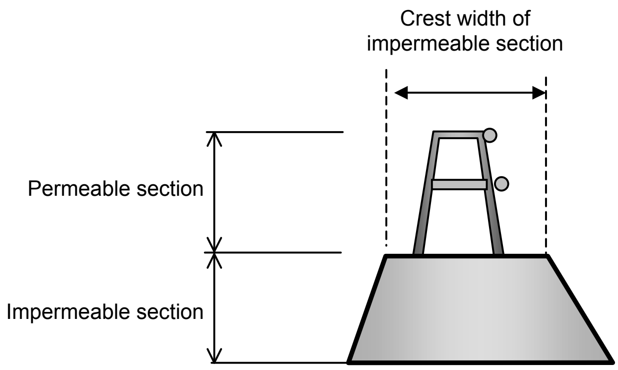


Figure 18 Lateral cross-section of the overflow section of a semi-open Sabo dam (example)

(5) Downstream slope

The downstream slope shall be identical to that of a closed-type Sabo dam.

Explanation

The downstream slope of a semi-open Sabo dam is identical to that of a closed-type Sabo dam (see the Guideline, Section 2.1.3.2 (3)).

(6) Ground

The ground shall be identical to that of a closed type Sabo dam.

Explanation

The ground of a semi-open Sabo dam is identical to that of a closed type Sabo dam (see the Guideline, Section 2.1.3.2 (4)).

(7) Drain hole

> The drain hole shall be identical to that of a closed type Sabo dam.

Explanation

The drain hole of a semi-open Sabo dam is identical to that of a closed type Sabo dam (see the Guideline, Section 2.1.3.2 (5)).

2.1.5.4 Stability and structure of the non-overflow section

The stability and structure of the non-overflow section shall be identical to those of a closed type Sabo dam.

Explanation

The stability and structure of the non-overflow section of a semi-open Sabo dam are identical to those of a closed type Sabo dam (see the Guideline, Section 2.1.3.3).

2.1.5.5 Downstream riverbed protection works

The downstream riverbed protection works of a semi-open Sabo dam shall be identical to that of a closed type Sabo dam.

Explanation

The downstream riverbed protection works of a semi-open Sabo dam is identical to that of a closed type Sabo dam (see the Guideline, Section 2.1.3.4).

Length and thickness of the apron shall be designed considering the more severe conditions between the two: scouring due to flooding and scouring due to the following part of debris flow. The height from the apron crest to the crest of impermeable part is used in the design of "during flood" while the height from the apron crest to the crest of permeable part is used in the design of "during debris flow".

The necessity for water cushion or a sub-dam should be carefully examined and planned. Note that the cross-section of the spillway of a sub-dam is designed by adding freeboard to the cross-section of the spillway of the main dam set in the Guideline, Part 2.1.5.3 (1).

2.1.6 Sediment and driftwood removal

> If the effect of debris flow and driftwood capturing work is estimated by assuming the sediment and driftwood removal, sediment and driftwood removal of captured or deposited sediment and driftwood shall be immediately conducted.

Explanation

Basic concepts of sediment and driftwood removal are based on the Guideline, Section 3.

2.2 Debris flow and driftwood restraint work

2.2.1 Debris flow and driftwood restraint hillside works

Debris flow and driftwood restraint hillside works aim to stabilize hillside slopes by reforestation or other civil engineering structure.

Explanation

Debris flow and driftwood restraint works are mainly hillside conservation works to prevent hillside failure that may trigger debris flows.

2.2.2 Riverbed sediment stabilization work

Riverbed sediment restraint work is a method to prevent the movement of sediment deposited on riverbed such as by groundsill

Explanation

Riverbed sediment restraint work is a method to prevent the movement of sediment deposited on riverbed or riverbanks, mainly by groundsill. In principle, the upstream side of groundsill shall be filled with sediment up to its crest and the structure shall not be directly exposed to the impact load of boulder and driftwood. Further, measures such as sediment accumulation on the upstream side of the wings shall be taken to prevent wing failure due to debris flow. By referring to the Guideline, Section 2.1.3.1(2), the design external forces for this stabilization work is only the hydrostatic pressure, while the load of debris flow is not considered.

The spillway design of groundsill, as the riverbed sediment restraint work, shall follow this Guidelines, Section 2.1.3.2(1). However, the width of spillway shall be as wide as possible considering the topography of site, while if the design water depth is set depending on the debris flow peak discharge, freeboard does not need be considered in the design. Further, for other structures made of concrete, the design must comply with the structure of the closed type Sabo dam as explained in the Guideline, Section 2.1.3.

2.3 Debris flow torrent training work

2.3.1 Cross-section

The cross-section of debris flow torrent training work shall be determined by considering the debris flow discharge and depth, and then a freeboard shall be added. It is noted that the riverbed aggradation in upstream direction shall not cause flooding.

Explanation

Debris flow torrent training works shall be planned after one or more debris flow and driftwood capturing works, such as Sabo dams or debris flow depositing areas in the upstream and be designed to connect to the lower side of them in order to control the debris flow movement to a safe place.

The design discharge is determined by assuming that the debris flow peak discharge decreases by a ratio of the total sediment volume controlled by facilities in the upstream to the design volume of debris flow material. However, it shall not be less than the discharge without sediment (obtained from probable design rainfall) plus 10% of sediment content.

The width of a debris flow torrent training work is at least twice the maximum boulder size of debris flow (D_{95}), or at least 3 m.

If the ratio of the total sediment volume controlled by facilities to the design volume of debris flow material is equal to 1.0, channel work shall be planned instead of debris flow torrent training work. Explanation on the normal channel work is available in Section 3-2 of the Facility Planning Part, *Technical Criteria for River Works*.

The freeboard shall be as follows.

Discharge	Freeboard (ΔD_d)
< 200 m^3/s	0.6 m
200 – 500 m^3/s	0.8 m
500 – 2000 m^3/s	1.0 m

But, it shall not be less than the following values according to the riverbed slope.

Riverbed Slope	$\Delta D_d / D_d$
> 1/10	0.5
1/10 – 1/30	0.4

Where, D_d : water depth (m).

2.3.2 Alignment

The alignment of a debris flow torrent training work shall be as straight as possible.

Explanation

Due to the large inertia of debris flow, the alignment of a debris flow torrent training work should also be straight. If the alignment has to bend due to the topography, land use, or other reason, a circular curve should be inserted. The radius of curvature is obtained by the following equation where its center angle shall be 30° or less[8].

$$\frac{B_r}{R_{(IN)}} \leq 0.1 \quad \cdots\cdots (8)$$

Where, B_r: channel width (m), and $R_{(IN)}$: radius of curvature of the bend (m), as shown in Figure 19.

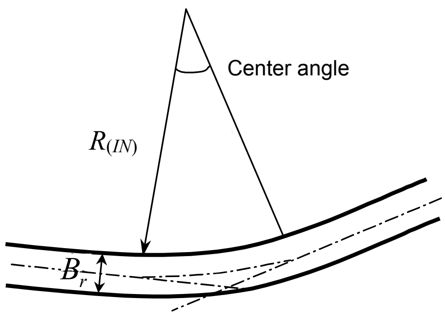


Figure 19 Alignment of a curved debris flow torrent training work

2.3.3 Longitudinal profile

The longitudinal profile of a debris flow torrent training work shall avoid abrupt slope change. If riverbed aggradation in upstream direction is predicted to occur, the debris flow torrent training work structure shall be designed to be safe from it.

Explanation

A debris flow torrent training work shall guide debris flow to a safe place, hence sediment deposition due to abrupt slope change shall be avoided. In addition, if riverbed aggradation in upstream direction is predicted to occur at the end of the river, the debris flow torrent training work structure shall be secured for instance by setting the height of embankment according to the aggradation in upstream direction.

2.3.4 Structure

2.3.4.1 Riverbed

In principle, the debris flow torrent training work shall be an excavated channel.

Explanation

In principle, the debris flow torrent training work shall be an excavated channel to ensure safety.

2.3.4.2 Curved section

On the curved section, the height of the embankment is determined by considering the water level rise on the outer side bank.

Explanation

Water level rise on the outer side bank is estimated based on theoretical values, measured values, and experimental results. The structure of debris flow torrent training work shall allow this water level to pass safely.

In a debris flow, the maximum water level on the outer side bank $D_{d(OUT)max}$ can be as high as $D_{ds} + 10 \cdot \frac{(B_r \cdot U^2)}{(\theta_r \cdot g)}$. However, on an alluvial fan where debris flow torrent training work and channel work are usually constructed, the maximum water level of debris flow and flood are obtained by the following equations respectively [8)].

Debris flow: $$D_{d(OUT)\,max} = D_{ds} + 2\frac{B_r \cdot U^2}{R \cdot g} \quad \text{(9)}$$

Flood (supercritical flow): $$D_{d(OUT)\,max} = D_{ds} + \frac{B_r \cdot U^2}{R \cdot g} \quad \text{(10)}$$

Where:

D_{ds} : depth in the straight section (m),

B_r : channel width (m),

U : average flow velocity (m/s),

R : radius of curvature at the center of the channel (m), and

g : gravitational acceleration (9.81 m/s^2).

2.4 Debris flow depositing area

2.4.1 Debris flow dispersion/depositing area

2.4.1.1 Type

The shape of a debris dispersion/depositing area shall be appropriate based on the flow characteristics of debris flow and topography.

Explanation

The shape of a dispersion/depositing area is determined based on the scale, flow, and inundation characteristics of the past debris flows or if no data of them is available, based on the characteristics of debris flows in similar rivers.

2.4.1.2 Design sedimentation slope

The design sedimentation slope of a debris flow dispersion/depositing area shall be between 1/2 and 2/3 of the original riverbed slope before the facilities being built.

Explanation

The default of the design sedimentation slope of a debris flow dispersion/depositing area is between 1/2 and 2/3 of the riverbed slope before the facilities being built. If an applicable value measured in the past is available, the measured value may be used instead of the default value.

2.4.1.3 Design sediment depositing volume

The design sediment depositing volume of a debris flow dispersion/depositing area is calculated in the condition of sedimentation occurred in design sedimentation slope.

Explanation

The design sediment depositing volume of a debris flow dispersion/depositing area is calculated for a situation where sediment has been deposited on the design sedimentation slope determined by the Guideline, Part 2.4.1.2.

2.4.1.4 Structure

Sabo dams or groundsills shall be constructed at the upstream and downstream ends of a debris flow dispersion/depositing area and revetment work for embankment or groundsill shall be constructed inside the depositing area as necessary.

Explanation

A debris flow dispersion/distribution work consists of Sabo dam (groundsill) at the upstream and downstream ends, dispersion part, deposition part, and downstream end training work. To make gentle slope at the widened part (Figure 20), the part shall be excavated in general. Thus, the upstream end Sabo dam (groundsill) is installed to maintain the gap between the current riverbed upstream and the widened part. The downstream end Sabo dam (groundsill) controls the dispersed flow to smoothly return it to the river course. In some cases, groundsill is constructed in the deposition part to increase its sedimentation capacity.

The width of the deposition part (B_{d2}) should be within about 5 times the width of the upstream channel (B_{d1}).

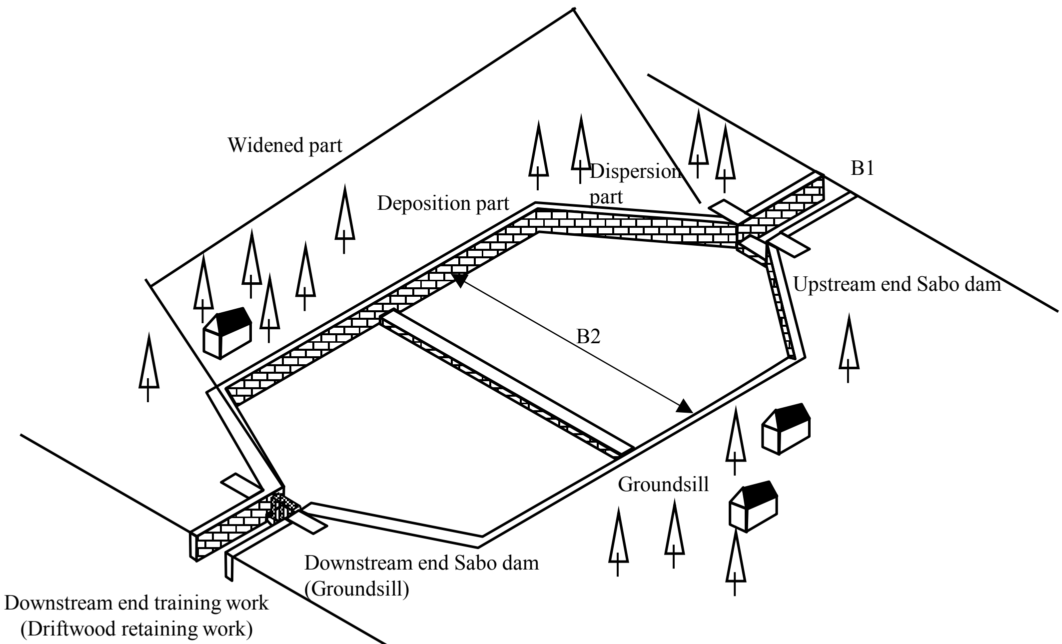


Figure 20 Debris flow dispersion / depositing area

2.4.2 Debris flow depositing channel

Debris flow depositing channel shall actively deposit sediment of debris flow in a channel on an alluvial fan. Further, revetment work for embankment shall be used to prevent riverbank erosion.

Explanation

To actively deposit sediment of debris flow in the channel, the sediment transport capacity is reduced by having the gentle channel bed gradient and widening the channel width. However, if sediment is deposited at the normal discharge prior to debris flow occurrence, the deposition capacity at the time of debris flow will decrease. Thus, assuming the volume of conveyed sediment at normal time (sediment concentration), the channel bed gradient shall be designed so that sedimentation by the normal discharge does not occur.

2.4.3 Sediment and driftwood removal

> If sediment due to debris flow has been deposited in a debris flow depositing works, this debris shall be removed immediately.

Explanation

The basic concept of debris removal is explained in the Guideline, Part 3.

2.5 Erosion control greenbelt

An erosion control greenbelt shall be installed near the downstream end of the debris flow deposition zone to lower the velocity of the debris flow in the deposition zone.

The deposition zone consists of a groundsill at the lower end, low flow channel, debris flow direction-controlling works, trees and supplementary facilities. These facilities shall be constructed by considering current topography.

Explanation

(1) Tree species used

Tree species to be introduced are selected with reference to the indigenous tree species existing in the planned area or in nearby locations with similar conditions.

(2) Density of trees

1) The density of trees is determined by ensuring a minimum interval between trees which is necessary for the growth of the trees, reduction of the flow velocity in the forest area, and obtaining an adequate sediment deposition effect.
2) Trees which does not toppled by hydrodynamic force are selected.

(3) Evaluation of effectiveness

The effect of greenbelt consists of the sediment deposition volume obtained by bed load calculation assuming the roughness coefficient increased by the greenbelt, and the volume of entrainable channel deposits in the planned zone which shall not be eroded out due to the greenbelt.

The default value of the planned average deposition depth is approximately 0.3 to 0.5m [9].

(4) Maintenance of the greenbelt

To maintain the forest function as erosion control greenbelt, tree replantation or weeding shall be conducted as necessary.

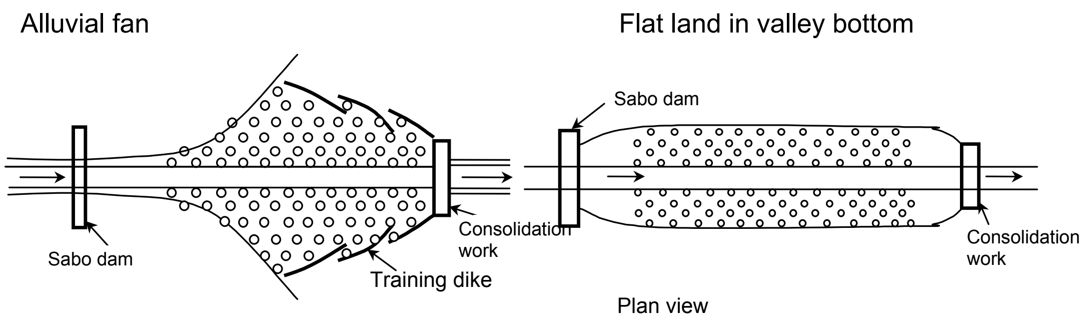


Figure 21 Erosion control greenbelt

2.6 Debris flow direction-controlling work

A debris flow direction-controlling work controls the flow direction of a debris flow. The structure shall be high enough to prevent overflow and scouring at the front slope toe.

Explanation

(1) Alignment of a debris flow direction-controlling work

If a safe location to flow sediment downstream from the reference point is available, and the flowing process would be safe and would not cause any damage to the downstream, the direction of the debris flow can be controlled by debris flow direction-controlling works. To prevent the overflow due to direct impact of debris flow, the alignment of the debris flow direction-controlling work shall be angled to less than 45° (θ_c < 45°). When changing the direction of debris flow by 45 degree or more, more than one debris flow direction-controlling work, open levees in the echelon structure, shall be allocated to change the direction gradually.

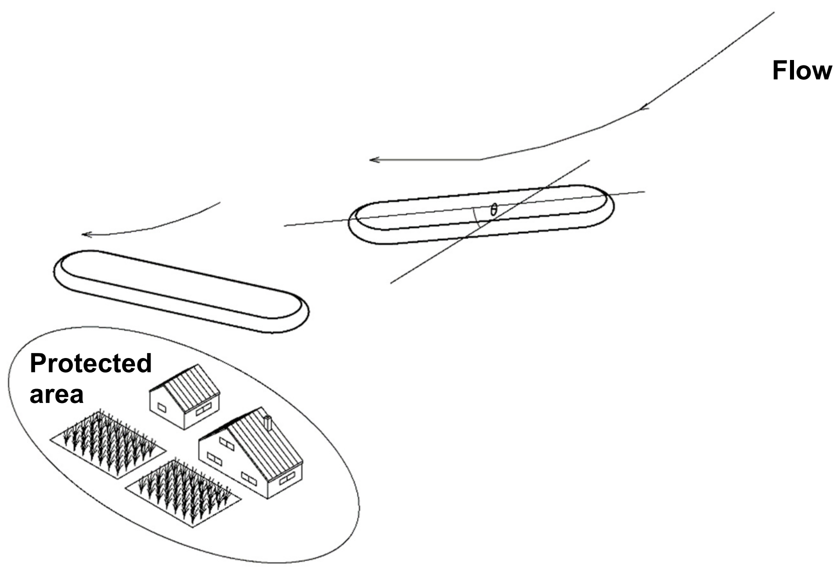


Figure 22 Alignment of a debris flow direction-controlling work

(2) Height of debris flow direction-controlling work

The gradient of the crest of the debris flow direction-controlling work shall be parallel to the current riverbed gradient. The height is the total of the depth of the debris flow and the freeboard (see the Guideline, Part 2.3.1.).

The debris flow velocity and depth are obtained based on the *Manual of Technical Guidelines against Establishing Sabo Master Plan for Debris Flows and Driftwood*, Part 2.6.5.

(3) Slope protection and scouring measures of slope toe of the embankment of a debris flow direction-controlling work

Embankment slope of the debris flow direction-controlling work is protected from debris flow erosion by revetment with concrete, stone masonry, concrete block, steel sheet pile, etc. The toe of the structure is protected against scouring by embedding revetment work, concrete block foot protection work, and foot protection groin work.

(4) Sediment and driftwood removal

Sediment and driftwood removal at a debris flow direction-controlling work is based on the Guideline, Section 3.

Section 3. Sediment and driftwood removal

For the debris flow and driftwood countermeasure structure to fully function, sediment deposition shall be inspected periodically after debris flow occurrence. Then, sediment and driftwood removal shall be conducted as necessary.

Furthermore, if sediment and driftwood removal is required in the debris flow and driftwood treatment plan, transportation method including route for carrying out shall be studied in advance.

Explanation

If sediment and driftwood removal is required in the debris flow and driftwood treatment plan, the transportation method, construction of transportation roads, receiver of transported debris, and frequency of sediment and driftwood removal shall be studied. Further, in principle, sediment and driftwood removal is not carried out for riverbed sediment stabilization work.

In addition, sediment and driftwood removal consists of "emergency sediment and driftwood removal" which is conducted urgently after debris flow occurs, and "periodic sediment and driftwood removal" where deposited sediment and driftwood is removed based on periodic inspection. The basic concept of sediment and driftwood removal is explained in Chapter 5 of the *Manual of Technical Guideline for Establishing Sabo Master Plan against Debris Flows and Driftwood*.

Section 4. Setting design external forces during a debris flow

4.1 Calculation of design external forces during a debris flow (the impact load is excluded)

The debris flow peak discharge, debris flow velocity and depth, unit weight of debris flow, and the drag force of debris flow are necessary to set the design external forces during a debris flow. They shall be calculated by assuming that no debris flow and driftwood facilities exists.

Explanation

The debris flow peak discharge is calculated based on Section 2.6.3, while the debris flow velocity and depth calculation is based on Section 2.6.5, the unit weight is based on Section 2.6.6, and the drag force of debris flow is based on Section 2.6.7 of the *Manual of Technical Guideline for Establishing Sabo Master Plan against Debris Flows and Driftwood*.

4.2 Impact load of boulders

The impact load received by the structure body due to the collision with a boulder varies according to the type and characteristics of structure body material. The impact load due to the collision of a boulder as a design external force is set in consideration of the type of material and characteristics of structure body.

Explanation

For mass concrete, the force (*P)* can be estimated by equation (11) [10), 11)].

$$P = \beta \cdot n\alpha^{3/2}, \qquad n = \sqrt{\frac{16R}{9\pi^2(K_1 + K_2)^2}}$$

$$K_1 = \frac{1 - v_1{}^2}{\pi E_1}, \qquad K_2 = \frac{1 - v_2{}^2}{\pi E_2}$$

$$\alpha = \left(\frac{5U^2}{4n_1 n}\right)^{2/5}, \qquad n_1 = \frac{1}{m_2}$$

$$\beta = (E + 1)^{-0.8}, \qquad E = \frac{m_2}{m_1} U_b^2 \quad \text{(11)}$$

Where,

E_1, E_2 : elastic modulus of concrete and boulder (N/m^2), respectively,

v_1, v_2 : Poisson's ratio of concrete and boulder, respectively,

m_2 : weight of boulder (kg),

R : radius of boulder (m),

π : Pi (= 3.14),

U_b : velocity of boulder (m/s),

α : dent depth (m),

K_1, K_2 : constants,

β : experimental constant

m_1 : weight of concrete block (kg).

The velocity of boulder is considered to be equal to the debris flow velocity, and the boulder size is the maximum boulder diameter (see the Guideline, Section 2.1.3.1 (4)).

〜〜

(Appendix C) Example of physical constants of gravel and concrete [10)]

Elastic modulus of gravel: $E_2 = 5.0 \times 10^9 \times 9.81$ N/m^2, Poisson's ratio: $\nu_2 = 0.23$

Ultimate strength of static elastic modulus※ of concrete:

$E_1 = 0.1 \times 2.6 \times 10^9 \times 9.81$ N/m^2, Poisson's ratio of concrete: $\nu_1 = 0.194$

* Indentations are generated on the concrete surface due to the collision of boulder, hence the average deformation coefficient (ultimate strength of deformation modulus) until failure of concrete is used. This coefficient is approximately 1/10 of the concrete's elastic modulus.

〜〜

4.3 Impact load of driftwood

The impact load received by the structure body due to the collision with driftwood varies according to the type and characteristics of structure body material. The impact load due to the collision of driftwood as a design external force is set in consideration of the type of material and characteristics of structure body.

Explanation

When a driftwood capturing work with a concrete structure such as wings is installed in the debris flow zone and when calculating the impact load received by the structure body due to the collision of driftwood for examining the stability of the structure and members such as wings, the formula for calculating the impact load received by the structure body due to the collision of a boulder shall be applied.

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2) K. Kawabe, S. Sakamoto, T. Uchida, and R. Itou(2014): Design of countermeasures for small rivers in Ohmachi, western Hiroshima Mountains, Journal of the Japan Society of Erosion Control Engineering, Vol. 67, No. 2, p. 42-46
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5) Y. Shimoda, S. Suzuki, N. Ishikawa, and K. Furukawa (1993): Impact failure analysis of concrete check dam by distinct element method, Journal of the Japan Society of Civil Engineering, No. 480, p. 97 - 106
6) M. Watanabe, T. Mizuyama, and S. Uehara (1980): Study of debris flow countermeasure Sabo structures, Journal of the Japan Society of Erosion Control Engineering, No. 115, p. 40
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Appendix D Design of driftwood facilities in the bedload transport zone

Appendix 1.1 Scale of flood and sediment

When a driftwood countermeasure structure is constructed inside or near the river channel of a bedload transport zone, the structure shall be designed considering the scale of flood and immature debris flow so that those can be discharged safely.

Explanation

As a general rule, the scales of flood (peak discharge, flow velocity, depth and sediment content) produced by heavy rainfall are decided based on the *Technical Criteria for River Works (Tentative)*; Practical Guide for Planning, the *Technical Criteria for River Works (Tentative)*; Surveying, Chapter 3, and the *Technical Criteria for River Works (Tentative)*; Design, Chapter 3.

The flow velocity and depth of a flood or of an immature debris flow are calculated based on Manning's equation using the discharge that includes sediment. Meanwhile, driftwood is not considered in the velocity and depth calculation. Further, the flow velocity of driftwood is assumed to be almost equal to the velocity of flow surface of a flood flow or of an immature debris flow, and it is calculated as about 1.2 times the average flow velocity.

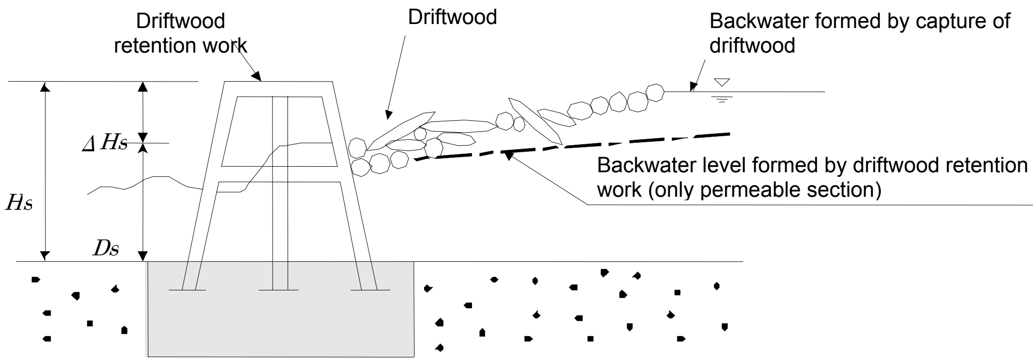
Appendix 1.2　　Design of driftwood retention work

Appendix 1.2.1　　Height of permeable section

The height of permeable section of a driftwood retention work shall be equal to or higher than the total of the water level after the occurrence of backwater effect formed by the driftwood retention work plus the additional height necessary to capture driftwood.

Explanation

The permeable section is designed so that it is not blocked by boulders, and the height of permeable section of a driftwood retention work shall be equal to or higher than the total of the water level after the occurrence of backwater effect formed by the driftwood retention work plus the additional height necessary to capture driftwood (see Appendix Figure 1 for the outline). The symbols in the figure are D_s: water level considering the backwater caused by the driftwood retention work (m), ΔH_s: height necessary to retain driftwood (m), and H_s: height of the driftwood retention work (permeable section). The procedure to determine the height of the permeable section and others is explained as follows.



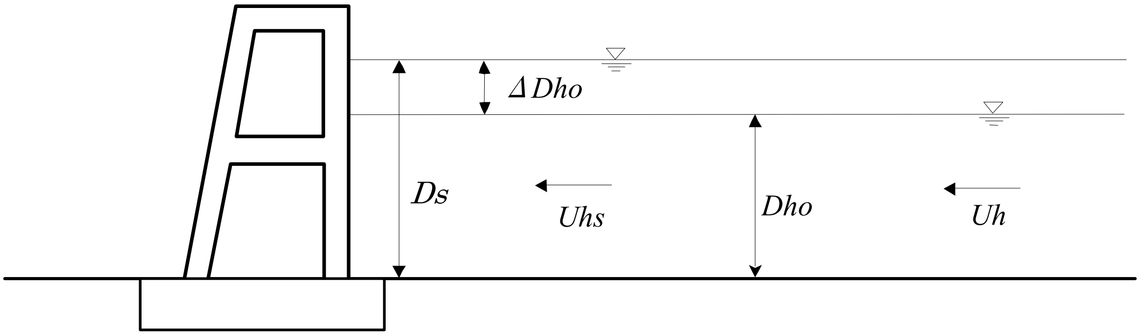
Appendix Figure 1 Schematic diagram of the height (H_s) of the permeable section of driftwood retention work installed in bedload zone

(1) Calculating the water level after the occurrence of backwater effect (D_s)

1) Depth before backwater D_{h0} and average flow velocity U_h are

At the channel section with weir : obtained by weir formula of weir using discharge of water containing fine sediments.

Otherwise: obtained by Manning's equation using discharge of water containing fine sediments.



Appendix Figure 2 Water level after the occurrence of backwater effect caused by a driftwood retention work

2) Water level rise due to backwater caused by a driftwood retention work

When driftwood retention work is installed in a fluvial descending zone, most driftwood will flow on the surface of flood and immature debris flow. Therefore, the height of the driftwood retention work must be higher than the flood and immature debris flow by considering the backwater caused by members consisting of the permeable section of the driftwood retention work.

The water level after the occurrence of backwater effect caused only by vertical members is calculated by the following equation [App. 1)].

$$\Delta D_{h0} = k_m \cdot \sin\theta_m \cdot \left(\frac{R_m}{B_p}\right)^{4/3} \cdot \frac{U_h{}^2}{2g} \quad \text{(App. 1)}$$

Where,

ΔD_{h0} : backwater height by the vertical members of the driftwood retention work (m),

k_m : coefficient depending on the shape of the cross-section of the vertical members (steel pipe $k_m \approx 2.0$, hollow square tube $k_m \approx 2.5$, and H-shaped beam $k_m \approx 3.0$),

θ_m : angle of the vertical members to the downstream river bed surface (degrees),

R_m : Projection width of vertical member (m),

B_p : spacing of the vertical members (m), and

U_h : flow velocity on the upstream side (m/s).

3) Water depth, D_s and average flow velocity U_{hs} after the occurrence of the backwater are shown below.

$$D_s = D_{h0} + \Delta D_{h0} \quad \text{(App. 2)}$$

$$U_{hs} = \frac{Q}{D_s \cdot B_s} \quad \text{(App. 3)}$$

Where,

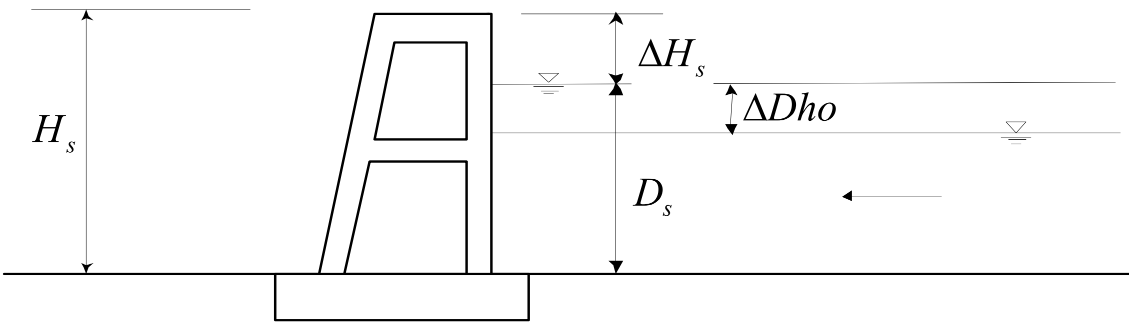
Q : design discharge (m^3/s),

U_{hs} : average flow velocity of backwater (m/s), and

B_s : flow width (m).

(2) Height of driftwood retention work (H_s)

The height of driftwood retention work is the total of the depth including the water depth after the occurrence of the backwater D_s plus the additional height necessary to capture driftwood ΔH_s, assuming that the driftwood retention work is not blocked by sediment and gravel. ΔH_s shall be set at least twice the maximum driftwood diameter considering the situation in which driftwood rides over each other when it is captured.



Appendix Figure 3 Height of the permeable section

Appendix 1.2.2 Spacing of members in the permeable section

The spacing of members on the permeable section of driftwood capturing works shall satisfy two conditions, i.e. the permeable section is not blocked by boulders and it captures driftwood.

Explanation

(1) Maximum boulder size transported by bed load

The maximum boulder size that flows in bedload zone is calculated by the following manner referring to the maximum movable boulder size by critical tractive force.

1) Square of the critical friction velocity to the average grain size: ${U_{*cm}}^2$

It is obtained by the following equation [App. 4].

$$ {U_{*cm}}^2 = 0.05 \cdot \left(\frac{\sigma}{\rho} - 1\right) \cdot g \cdot d_m \quad \text{(App. 4)} $$

Where,

d_m : average diameter of riverbed material (m),

σ : density of boulder, generally from 2,600 to 2,650 kg/m^3,

ρ : density of muddy water, generally 1,000 to 1,200 kg/m^3, and

g : gravitational acceleration (m/s^2).

2) Square of the friction velocity: ${U_*}^2$

It is obtained by the following equation.

$$ {U_*}^2 = g \cdot D_{h0} \cdot I \quad \text{(App. 5)} $$

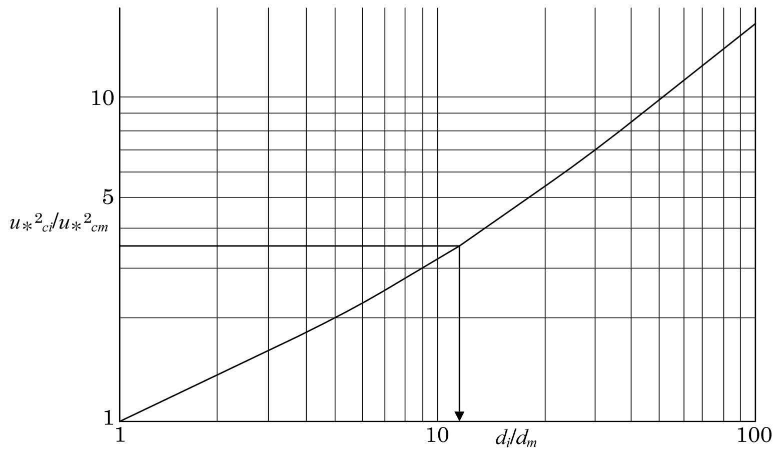
Where, D_{h0} : depth (m), I : riverbed gradient

3) Square of the shear velocity ratio: ${U_*}^2/{U_{*cm}}^2$

It is obtained using the values in 1) and 2).

4) Find the d_i/d_m for the point where the vertical axis ${U_*}^2/{U_{*cm}}^2$ in the figure is equal to ${U_*}^2/{U_{*cm}}^2$ in 3)

$$ \frac{d_i}{d_m} > 0.4: \ \frac{{U_{*ci}}^2}{{U_{*cm}}^2} = \left(\frac{log_{10}19}{log_{10}\left(19\frac{d_i}{d_m}\right)}\right)^2 \left(\frac{d_i}{d_m}\right) \quad \text{(App. 6)} $$



Appendix Figure 4 Critical tractive force by diameter

5) The maximum size is the smaller value between the calculated value above and the maximum size on site.

(2) Spacing of members on the permeable section

To avoid blockage of the permeable section by the boulders, the spacing of members is determined so that the maximum boulder size obtained above satisfies the following condition.

$$B_{wp} \geq 2d_i \quad \text{(App. 7)}$$

Where, B_{wp}: spacing of the permeable section (m), d_i: diameter of class *i* particles (m).

The spacing of the permeable section is also necessary to satisfy the following condition.

$$\frac{1}{2}L_{wm} \geq B_{wp} \quad \text{(App. 8)}$$

Where, L_{wm}: maximum driftwood length (m)

The spacing of members for capturing driftwood shall be the value that satisfies both of the conditions shown above.

Attention should be paid not to let the broken driftwood pass through the driftwood retention work.

Appendix 1.2.3 Examination of overall safety

> The stability of driftwood retention work shall be examined so that the designed structure is stable, even when it is fully blocked by driftwood.

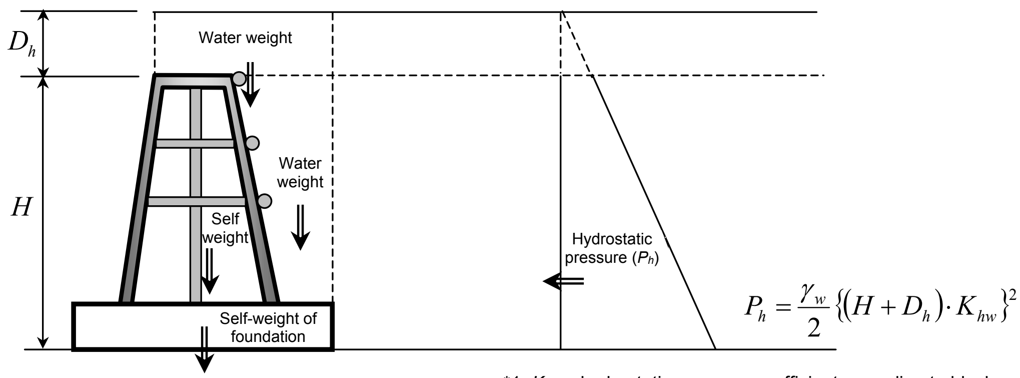
Explanation

The stability of a driftwood retention work in a bed load zone is examined based on the *Technical Criteria for River Works*: Practical Guide for Planning, the *Technical Criteria for River Works (Tentative)*, Design, Chapter 3.

The height of the driftwood retention work including the bottom concrete slab which is installed independently shall be 5 m or less (same as the height of a groundsill). However, if the height exceeds 5 m, stability of the structure shall be examined by considering the following points:

- Widen the spillway and reduce the water depth to minimize the height of the permeable section of driftwood retention work.
- If the bottom concrete slab is thick and a large gap is formed between top of the bottom concrete slab and the downstream riverbed surface, or if the driftwood retention work is high and a large gap is formed at the overflow section, downstream riverbed protection work shall be considered to ensure stability.

In bedload zone, if the driftwood retention work is blocked by driftwood, hydrostatic pressure acts as shown in Appendix Figure 5. The magnitude of hydrostatic pressure is affected by the blockage ratio (K_{hw}) of the permeable section. Further, if the permeable section is completely blocked, the hydrostatic pressure coefficient is assumed to be K_{hw} = 1.0 (unit weight of water γ_w = 11.77 kN/m^3). For a permeable type driftwood retention work in the bedload zone, sediment pressure is not considered because boulders are not designed to be captured.



*1. K_{hw}: hydrostatic pressure coefficient according to blockage ratio of the permeable section (K_{hw} =1.0)

Appendix Figure 5 Blockage of driftwood retention work in a bedload zone

Reference Table 1 Design external forces (excluding self-weight) of a driftwood countermeasure structure (Bedload zone)

	Normal time	During debris flow	During flood
Dam height of 5 m or less (including bottom concrete slab)			Hydrostatic pressure

Appendix 1.2.4 Examination of stability of members of permeable section

Members of the permeable section of driftwood retention work in bedload zone shall be examined to verify their stability against water pressure and against the impact load of driftwood and boulder.

Explanation

Similar to driftwood retention work in a debris flow zone, the cross-section composing the permeable section is small and not a gravity type structure. Thus, structural calculations of the members are conducted to verify their safety.

The impact load due to collision of driftwood and boulder shall comply with the *Manual of Technical Guideline for designing Sabo Facilities against Debris flow and Driftwood*, Section 4.2 and 4.3.

For calculating the impact load of driftwood as design external force which used for structural calculations of permeable members in a bedload zone, the surface flow velocity is applied as shown in the equation below while the average flow velocity is applied for calculating the impact load of boulders. The impact load is calculated assuming that the long axis of the driftwood flows down parallel to the water flow direction and collides with the driftwood retention work.

$$U_{ss} = 1.2U_s \quad \text{(App. 9)}$$

Where, U_{ss}: surface flow velocity (m/s) and U_s: average flow velocity (m/s).

Appendix 1.2.5 Design of parts other than the permeable section

The structure of all members of a driftwood retention work shall be designed so that the driftwood retention work is stable even when it is blocked with driftwood. Its stability against the impact load due to collision of driftwood also need to be examined.

Explanation

The structures of members (spillway section, crest width, downstream slope, ground, structure of wings, downstream riverbed protection work (apron)) of driftwood retention work are examined based on the *Technical Criteria for River Works*: Practical Guide for Planning, the *Technical Criteria for River Works (Tentative)*, Design, Chapter 3. This implies that examination of the structures of driftwood retention work is conducted by assuming that the upstream side of the driftwood retention work (permeable section) is completely blocked by driftwood and water cannot pass through. Thus, the driftwood retention work is considered as an impermeable type Sabo dam when designing the spillway section, crest width, downstream slope, ground, and downstream riverbed protection work. In addition, constructing the driftwood retention work as a sub-dam to the Sabo dam is also possible.

The spillway section of a driftwood retention work is constructed above the permeable section to prepare for any overflow of sediment flow and flood due to blockage of the permeable sections by driftwood. Freeboard is not required, since water can penetrate from the crest of the permeable structure.

Appendix 1.3 Design of driftwood restraint work

Driftwood restraint work in bedload zone shall be designed so that it efficiently prevents erosion of riverbanks and is safe against floods.

Explanation

Driftwood restraint work in bedload zone is constructed to functions similarly and at the same locations as revetment works for embankment and channel works. The design is based on the *Technical Criteria for River Works (Tentative)*, Design, Chapter 3.

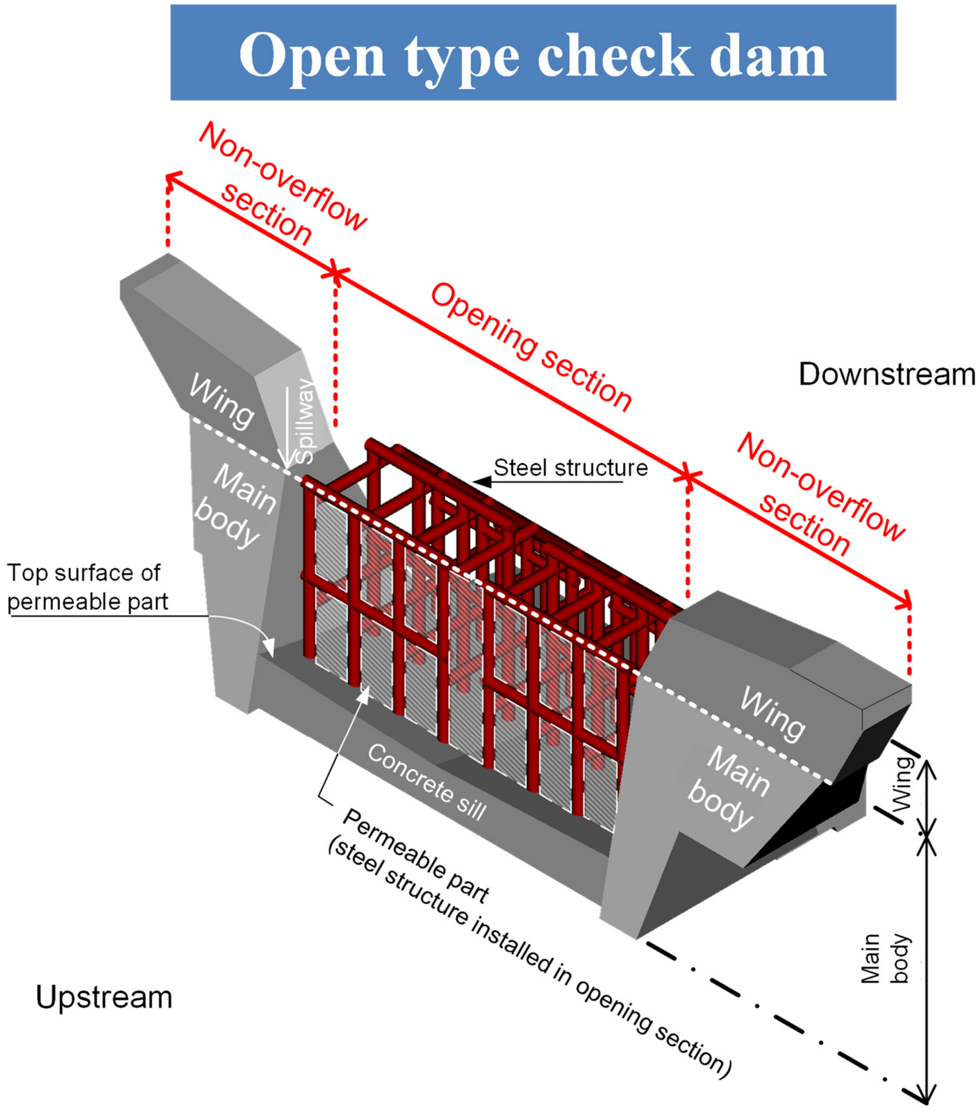
References of Appendix D

Reference 1) Japan Society of Civil Engineering (1971): Hydraulic Equations, 1971 Revised Edition, Japan Society of Civil Engineering, p. 252

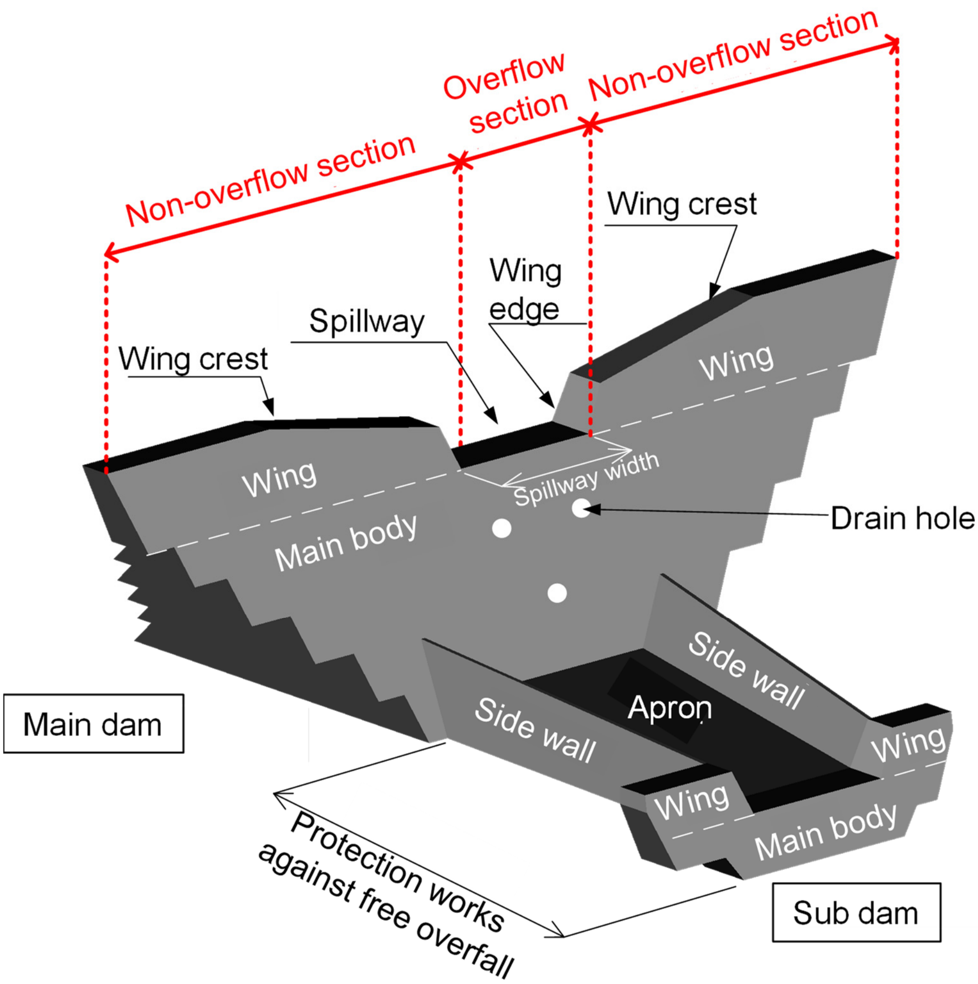
Reference 2) Japan Society of Civil Engineering (1999): Hydraulic Equations, 1999 Revised Edition, Japan Society of Civil Engineering, p. 158

Appendix E Parts names of check dams

Courtesy of Public Works Research Institute



Closed check dam



Appendix F List of symbols

B	channel width (m)
B_1	base width of the spillway (m)
B_2	width of the overflow (m)
B_{d1}	width of the upstream channel of debris flow depositing area (m)
B_{d2}	width of the depositing area of debris flow depositing area (m)
B_p	spacing of the permeable section of open type Sabo dam (m)
B_r	channel width (m)
B_s	flow width (m)
B_{wp}	spacing of the vertical members of driftwood retention work (m)
C	coefficient of discharge (0.6 to 0.66)
C_*	volumetric concentration of riverbed sediment
C_e	coefficient of earth pressure
D_d	depth of debris flow (m)
ΔD_d	freeboard height (m)
D_{ds}	depth in the straight section (m)
D_h	overflow depth (m)
D_{h0}	water depth before backwater (m)
ΔD_{h0}	backwater height by the vertical members of the driftwood retention work (m)
d_i	diameter of class i particles (m)
d_m	average diameter of riverbed material (m)
D_s	water level considering the backwater caused by the driftwood retention work (m)
D_{95}	grain size for which 95% of the material weight is finer (treated as the maximum boulder size) (m)
E_1, E_2	elastic modulus of concrete and boulder (N/m^2)
F	drag force of debris flow
g	gravitational acceleration (9.81 m/s^2)
H	Sabo dam height (m)
H_c	height of impermeable part of semi-open type Sabo dam (m)
H_s	height of driftwood retention work (m)
ΔH_s	height necessary to retain driftwood (m)
I	riverbed gradient
K_1, K_2	constants for P
K_{hw}	blockage ratio of the permeable section
k_m	coefficient depending on the shape of the cross-section of the vertical members
L	horizontal length of downstream slope of closed type Sabo dam

L_{min}	smaller one of horizontal span and vertical span in a grid type Sabo dam (m)
L_{wm}	the maximum driftwood length (m)
m_1	weight of concrete block (kg)
m_2	weight of boulder (kg)
P	Impact force of boulder or driftwood (kN)
P_{sed}	peak sediment load at the downstream end of a channel with a structure (m^3 / sec)
P_{sed0}	peak sediment load at the downstream end of a channel without a structure (m^3 / sec)
Q	discharge of water containing fine sediments (m^3/s)
Q	design discharge (m^3/s)
R	radius of boulder (m)
R	radius of curvature at the center of the channel (m)
$R_{(IN)}$	radius of curvature of the bend (m)
R_m	Projection width of vertical member (m)
U	average flow velocity (m/s)
U_*	shear velocity (m/s)
U_b	velocity of boulder (m/s)
U_{*cm}	velocity corresponding to the beginning of motion of average diameter (m/s)
U_h	flow velocity on the upstream side (m/s)
U_{hs}	average flow velocity of backwater (m/s)
U_s	average flow velocity (m/s)
U_{ss}	surface flow velocity (m/s)
v_1, v_2	Poisson's ratio of concrete and boulder
V_c	dam body block volume (m^3) calculated by assuming the overflow section as a closed structure
W	Self-weight of the wing (kg)
W_{rc}	dam body block weight (kN) calculated by assuming the overflow section as an open structure with concrete
α	dent depth (m)
β	experimental constant for P
γ_d	unit weight of the debris flow (kN/m^3)
γ_{rc}	apparent unit weight of concrete (kN/m^3)
γ_s	unit weight of sediment in water (kN/m^3)
γ_W	unit weight of water
π	pi (=3.14)
θ_c	slope of the debris flow direction-controlling work to flow direction (degrees)
θ_m	angle of the vertical members to the downstream riverbed surface (degrees)
θ_{f1}	eccentric angle to the sabo dam (degrees)
θ_{f2}	angle of the hypothetical stream axis of the debris flow and the axis perpendicular to the dam axis (degrees)

θ_{f3} allowable angle (degrees)

ρ allowable angle (degrees)

TECHNICAL NOTE of NILIM

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