Paper:

Design Standard of Control Structures Against Debris Flow in Japan

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Countermeasures to prevent or mitigate sediment-related hazards, debris flow in this paper are classified as structural measures or nonstructural measures. The structural measures are Sabo dams, leading dikes, and channels for debris flow control. The nonstructural measures are the designation of areas prone to debris flow, proper land use in the areas, the reinforcement of houses, the creation of warning systems and the evacuation of the inhabitants in case of emergency. A technical standard on debris flow control structures of Japan was revised in 2007. Major revision is that check dams called Sabo dams constructed near houses are changed from closed type Sabo dams to open type Sabo dams because the occurrence frequency is low as once for longer than one hundred years, natural torrent environment should be conserved in ordinary days and sediment trap capacity should be kept until debris flow occurs. Points changed are explained such as the opening of open type dams is as equal as the maximum stone size.

Keywords: sediment hazard, countermeasures, structural measures, nonstructural measures, technical standard for debris flow control

1. Introduction

Countermeasures to prevent or to mitigate sediment related hazards are classified as structural measures or nonstructural measures. In Japan, the SABO (Erosion and Sediment Control) Department of the Ministry of Construction (present Ministry of Land, Infrastructure, Transport and Tourism) has made some laws and technical guidelines related to debris flows, shallow landslides caused by heavy rainfall, and deep seated landslides. A guideline for debris flow prone streams and areas was made in 1999; 'The guideline for survey of debris – flow-prone streams and survey of debris flow hazard area.' 'Standard Procedures for Investigation of Potential Landslide Sites' has been used for deep seated landslides. For shallow landslides or slope failures, 'Inspection Procedure for Steep Slope Failure Hazard Areas' is applied. As warning and evacuation, Sabo department has made the following guidelines; 'Sediment-related Disaster Warning and Evacuation Guidelines' and 'Guidelines for Development of Warning and Evacuation System Against Sediment Disasters in Developing Countries.'

A law concerning the promotion of sediment-related disaster prevention in sediment related disaster hazard areas ("Sediment-related Disaster Prevention Law") is the first law aimed at proper land use in debris flow and landslide areas in Japan. It was enacted in 2000 after sediment disasters in Hiroshima, Japan, in 1999. It designates dangerous areas, prohibits housing development in those areas, and moves existing houses in the areas to safer areas. The law also orders that houses built be sufficiently strong against debris flow or landslide. However, the law was enacted too late. It should have been enacted 20 or 30 years before, before housing areas were expanded to the foots of hills and on the debris flow fans in the areas that were groves or paddy fields before development. It was impossible, however, to resist the boom in development. The law can be found at the following URL in English: http://www.sabo-int.org/law/index.html

The design standard had not been established in 1982 when Ministry of Construction had been starting the new policy named "Promotion of Comprehensive Measures Against Sediment-related Disaster caused by Debris Flows." For that reason, Ministry of Construction started studies on the phenomena and measures, and compiled the results and issued the "Technical Guideline against Debris Flow" in 1989. However the technical guideline had some theoretical assumptions such as the method for estimating the peak flow rate, velocity and depth of debris flow and so on because all features relating to debris flow were not clarified completely at that time. Ministry of Land, Infrastructure, Transport and Tourism has been collecting and analyzed the detailed reports on sediment-related disasters. By analyzing the details of the both reports and the research results collected until 2007, we found followings; 1) Not only boulders but also woody debris triggered floods by blocked stream, 2) the observed data of peak flow rate of debris flow was often greater than the estimated value by using the methods in the technical guideline, 3) a debris flow flowed to downstream, becoming wider in gullies, and 4) the narrower the open space was made the larger amount of sediment could be trapped by the open type dam. Therefore, Ministry of Land, Infrastructure, Transport and Tourism decided to revise the technical guideline in order to take into account of the above-mentioned findings. The main points of the revision were reported. This report mainly aims to introduce the technical standard for planning and designing structural measures and points out the technical problems that have been still under studies.

2. History of Technical Standards on Debris Flow Control and Woody Debris Control in Japan

The first technical standards for planning facilities against debris flows were drafted by the Overall Technical Study Committee on Countermeasures against Debris Flows from 1982 to 1983. Then, the third subcommittee of the Overall Study Committee on Enhanced Debris-Flow Countermeasures from 1984 to 1987 was established in 1985 and modified the above-mentioned technical standards for planning facilities against debris flows on the basis of the results of its practical application to debris-flow-prone torrents. On October 9, 1989 the director of the Erosion and Sediment Control Department of the River Bureau in the Ministry of Construction, that is now the Ministry of Land, Infrastructure, Transport and Tourism, issued the findings of the study committee nationally as technical guidelines for countermeasures against debris flows.

The draft technical guidelines were then amended on July 13, 2000 and issued nationally. In March, 2004 the planning part of the draft technical standards for the erosion-and-sediment control and river engineering was revised and published. It stipulates that the basic plan for erosion-and-sediment control should consist of the following five areas: erosion-and-sediment control for river systems; countermeasures against debris flows; countermeasures against woody debris; measures for volcanic erosion-and-sediment control; and countermeasures against extraordinary landslide disasters caused by natural landslide dams.

As for countermeasures against debris flows and woody debris, the guidelines for the basic planning of erosion-and-sediment control, that is the part on countermeasures against debris flows and woody debris and set out standard methods for the basic planning of erosion-and-sediment control, and the design technology guidelines for countermeasures against debris flows and woody debris were issued on March 13, 2007. They were issued under the joint names of the Erosion-and-Sediment-Control Planning Section director and the Maintenance Section director of the Erosion-and-Sediment-Control Department of the River Bureau of the Ministry of Land, Infrastructure, Transport and Tourism to supersede the draft technical guidelines for countermeasures against debris flows and the draft guidelines for countermeasures against woody debris. Later, guidance on these two guidelines was compiled primarily by the National Institute for Land and Infrastructure Management and published as the Institute's Materials No. 364 and 365 in March, 2007.

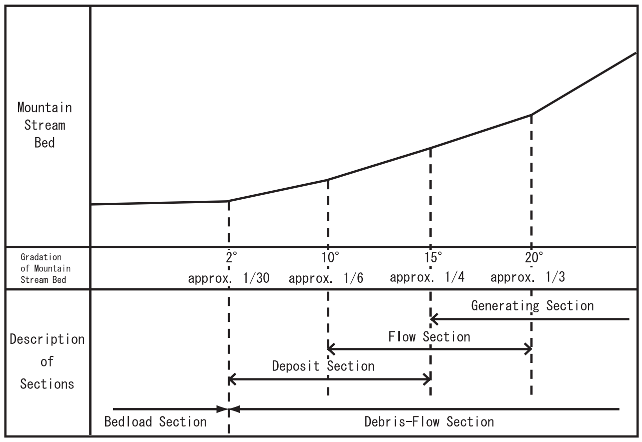

Fig. 1. Gradation of mountain stream bed in sediment displacement morphology (rough standard).

Below is intended to describe the modifications and additions to the draft technical guidelines for countermeasures against debris flows, modifications and additions which were made in the course of compiling the guidance on the guidelines for the basic planning of countermeasures against debris flows and woody debris and the design technology guidelines for countermeasures against debris flows and woody debris.

3. Main Points in the Guidance on the Guidelines for Basic Planning of Countermeasures Against Debris Flows and Woody Debris

3.1. Sediment Transport Modes

Figure 1 shows the sediment transport mode in the basic plan. Basic planning of erosion-and-sediment control shall be based on sediment transport modes. Sediment transport modes are largely divided into the debris-flow and the bed-load sections, depending on the gradient of the mountain stream beds. In the current revision, it is so stipulated that the boundary between the two sections should be the point where the gradient of the mountain stream bed is 2 degrees.

3.2. Control Plan for Debris Flows and Woody Debris

Control plan for debris flows and woody debris can be expressed by Eq. (1):

$$V - W - (X + Y + Z) = 0 \qquad (1)$$

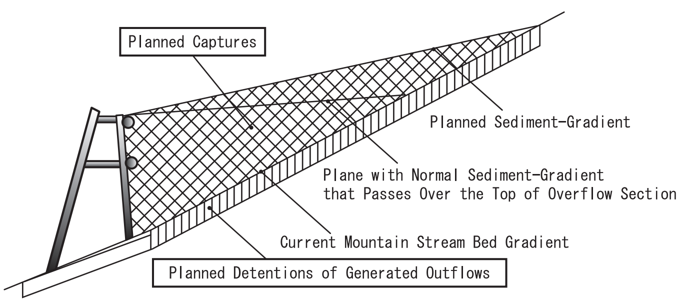

Fig. 2. Sediments to be calculated in control plan for debris flows and woody debris for open-type.

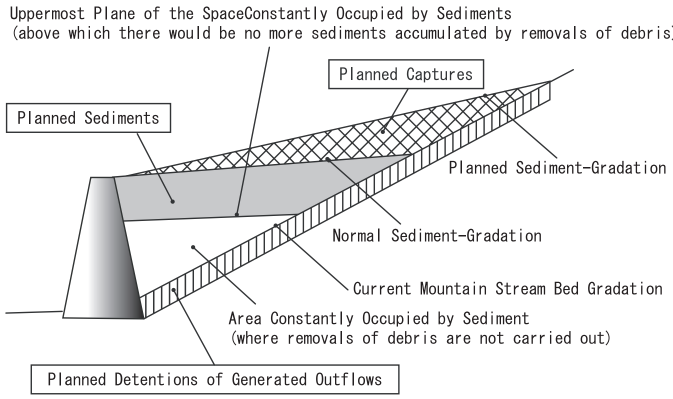

Fig. 3. Sediments to be calculated in control plan for debris flows and woody debris for closed-type.

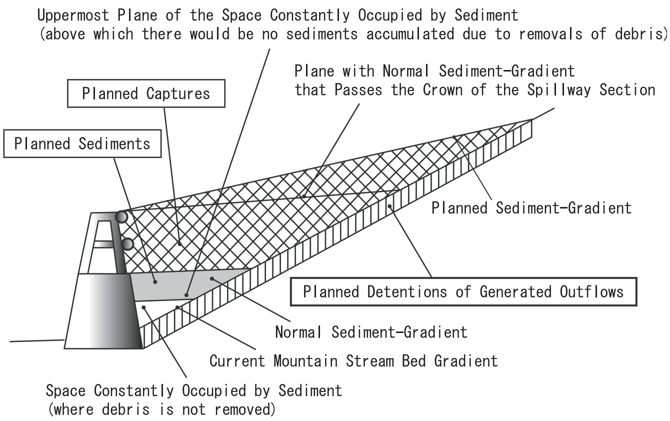

Fig. 4. Sediment to be calculated in control plan for debris flows and woody debris for partially open-type.

where V denotes the total volume of sediment and woody debris carried by a plan size debris flows; W, denotes the planned allowable volume of sediment and woody debris; X, planned captures; Y, planned sediments; and Z, planned retentions of generated flows. V, W, X, Y and Z, each representing a sum of debris flows and woody debris, are expressed in the following expressions (2)–(6):

$$V = V_d + V_W \quad \ldots\ldots\ldots\ldots (2)$$

$$W = W_d + W_W \quad \ldots\ldots\ldots\ldots (3)$$

$$X = X_d + X_W \quad \ldots\ldots\ldots\ldots (4)$$

$$Y = Y_d + Y_W \quad \ldots\ldots\ldots\ldots (5)$$

$$Z = Z_d + Z_W \quad \ldots\ldots\ldots\ldots (6)$$

where V_d denotes planned debris flow volume; V_W, planned woody debris volume; W_d, planned allowable debris flow volume; W_W, planned allowable woody debris volume; X_d, planned detentions of debris flow volume; X_W, planned detentions of woody debris volume; Y_d, planned sediment debris flow volume; Y_W, planned woody debris volume; and Z_d, planned detentions of generated debris flow volume; Z_W, planned detentions of generated woody debris volume.

In order to incorporate planned captures and planned sediments in the control plan for debris flows and woody debris, it is necessary to estimate the volume of X, Y and Z in the Eqs. (4), (5) and (6). **Figs. 2**, **3** and **4** shows the volumes of X, Y, and Z. The slope of the normal sediment-gradation is half of the tangential value of the original bed slope. And the slope of the planned sediment-gradation is two thirds of the tangential value of the original bed slope. These values are derived from the past disasters. It is necessary to establish and implement a debris-removal plan, comprised of periodic removals of debris including woody debris and contingent removals of debris including woody debris.

3.3. Peak Debris Flows Discharge and Depth of Debris Flows

Peak debris flow discharge in all cases are to be calculated by Eq. (7) for peak debris flows based on outflow-sediment volume.

$$Q_{sp} = \frac{0.01 C_* V_{dqp}}{C_d} \quad \ldots\ldots\ldots\ldots (7)$$

where Q_{sp} denotes peak debris-flows; V_{dqp}, outflow-sediments including voids expected from one wave of debris flows; C_d, concentrations of debris flows; C_*, volumetric concentrations of mountain stream bed sediments and the value is usually around 0.6.

V_{dqp} is calculated as follows. First of all, we have to determine the section where debris outflows are expected.

Eq. (7) is derived from the past records of debris flow. As shown in the Eq. (7), it is important and difficult to set the value of V_{dqp} because the computed value of Q_{sp} is proportional to the value of it. At this moment, it is difficult to find out a fact that two or more debris flows start flowing down at the same time according to our experiences in Japan. Therefore we assume that the sediment volume transported by one debris flow affects on the peak debris-flows. **Fig. 5** shows a schematic figure of a course of one debris flow. As shown in **Fig. 5**, the expected debris outflow area is determined to be a section ranging from the upstream point circled in **Fig. 5** between the point where Q_{sp} is calculated and the most downstream point in the flow area of debris flows to the farthest watershed point along the mountain stream, including mountain sides called zero-order basins. If there are branch streams

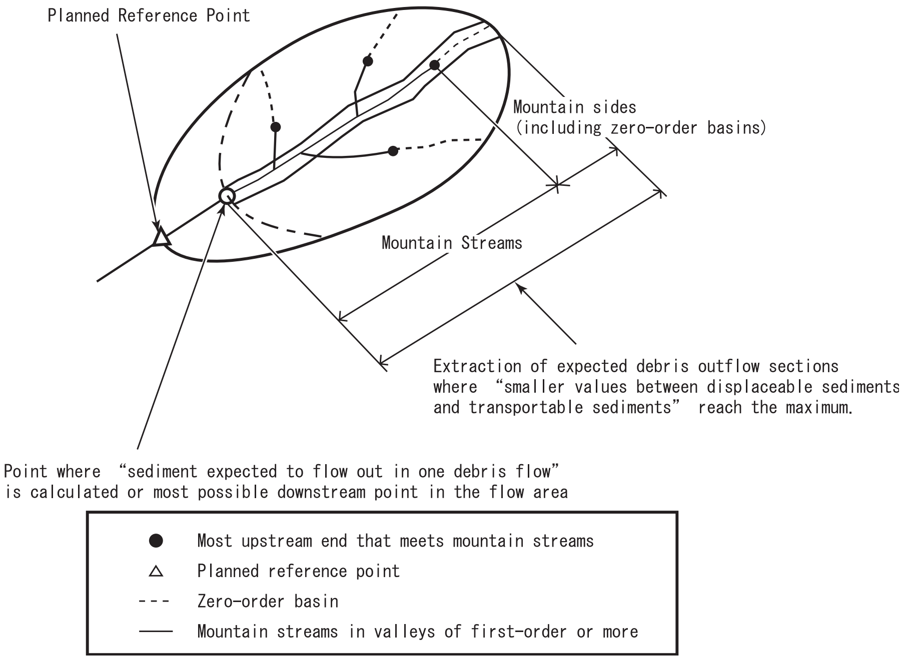

Fig. 5. Schematic drawing of expected debris-outflow sections.

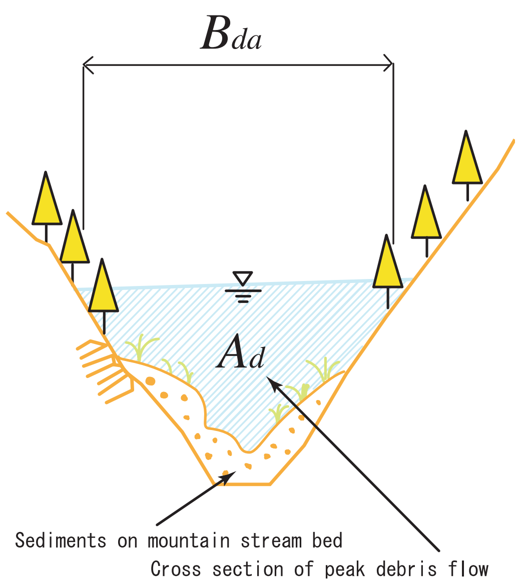

Fig. 6. Cross section of peak debris flows.

in addition to the main mountain stream in the watershed, more than one area where debris outflows are expected have to be set up.

In the next place, we calculate "erodible sediments" for each such section and "transportable sediments by the flow due to rainfalls of a magnitude that will exceed the probabilities assumed in the annual planning" that is same as "erodible sediments" described in Paragraph 2.7.3 of the Guidance on the Basic Planning Guidelines for Countermeasures against Debris Flows and Woody Debris, and we choose the smaller value of these two calculations as "expected sediment outflow volume."

Lastly, we choose the greatest value of the "expected sediment outflows" in these sections as V_{dqp}.

Figure 6 shows a cross sectional view of a debris flow. Originally we assumed that a cross-section of a debris flow was a rectangle shape with the river bed width in the former guideline. However we found that debris flows moved to downstream, becoming wider in gullies in the 2002 debris flow disaster in Mie Prefecture, Japan. Therefore we assume that cross-section of a debris flow is like **Fig. 6**. (Flow discharge rates and depths of the debris flows are obtained from simultaneous equations) The cross-mean velocity and flow depth corresponding to the peak flow discharge are obtained by Eqs. (8)-(10):

$$U = \frac{1}{K_m} D_r^{2/3} (\sin\theta)^{1/2} \quad \cdots\cdots (8)$$

$$Q_{sp} = U A_d \quad \cdots\cdots (9)$$

$$D_d = \frac{A_d}{B_{da}} \quad \cdots\cdots (10)$$

where, as in **Fig. 6**, D_r denotes hydraulic radius of debris flow, and the value is approximated to the depth of debris flow denoted as D_d; θ, mountain stream bed gradient ; K_n, roughness coefficient; and A_d, flow sectional area of peak debris flows; B_{da}, breadth of debris flow.

4. Main Points of Guidance on Design Technology Guidelines for Countermeasures against Debris Flows and Woody Debris

4.1. Openings of Open and Partially Open Type Dams

Mizuyama and Mizuno (1997) reported that one of the key factors that affects whether or not a Sabo dam of the open type and the partially open type was the dimension

Table 1. Dam openings.

Function	Net Width	Net Height	Lowest Level of Opening
Capture of debris flows	D95 × 1.0[*1]	D95 × 1.0[*1]	Below water depth of debris flow[*2]

*1 Net width and height may be expanded to 1.5 times the maximum rock diameter (D95).
*2 Lowest level of opening may be narrowed to 1.5 times the maximum rock diameter (D95).

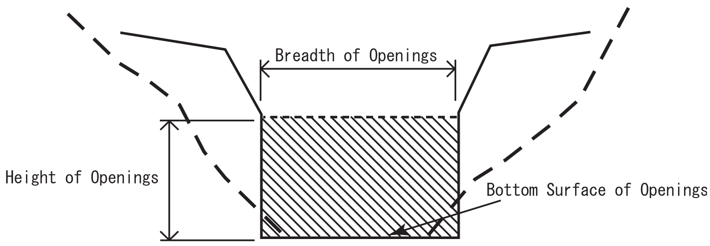

Fig. 7. Openings.

of the openings shown in **Fig. 7** and **Table 1**. **Fig. 7** shows terminologies of the parts of Sabo dam of the open type and the partially open type. The openings described in **Fig. 7** should be as broad as possible, as broad as the width of the valley in principle, so that the functions of the open type can be fully exploited and so that no backwater be created on the upstream side of the Sabo dam before the arrival of debris flows.

4.2. Cross-Section of Opening of Open type and Partially Open Type Dams

Mizuyama and Mizuno (1997) reported that the Sabo dam could capture debris flows if the (ration) ratio of height or width of an opening to a maximum size of boulders, that were transported by debris flows, was less than two. On the other hand, it is very difficult to estimate the maximum boulder size in real cases. Therefore, in order to take consideration of uncertainty, the dimension of opening sets to half of the size that Mizuyama and Mizuno reported as shown **Table 1**. In principle, the openings should have a cross sectional shape as indicated in **Table 1** to ensure the capture of debris flows and to prevent the captured debris flows from escaping and continuing downstream. However, the opening may have a shape other than the one in **Table 1** on the condition that the opening has the function of allowing normal sediments to flow downstream and that those sediments fully meet conditions (a) and (b) below.

(a) The opening shall be closed off, without fail, below the water level of debris flows by large rocks in the debris flows, and this closure must hold during debris flows.

(b) The opening shall be closed off, without fail, above the water level of debris flows by subsequent debris flows, and this closure must hold during these subsequent debris flows.

Table 2. Combination of design external forces for open-type excluding self weight.

	Normal	Debris Flow	Flooding
Height of Dam less than 15m		Sediment Pressure Fluid Force of Debris Flow	
Height of Dam 15m or more		Sediment Pressure Fluid Force of Debris Flow	

4.3. Design of Spillway Section of Open and Partially Open Dams

The opening shall be designed so as to secure stability when conditions such as the design external forces in **Table 2** are acting on the dam, in addition to the self-weights of the Sabo dam in **Fig. 8**. The openings of the partially open-type dams shall be designed so that stability is secured when conditions such as the design external forces in **Table 3** are acting in the way shown in **Fig. 9**, in addition to self-weights of the Sabo dam.

However, the breadth of the top or crown of the dam in the spillway section shall be designed so as to be able to withstand the impact of large rocks and woody debris and, in principle to be able to withstand the impact of boulders with diameters twice or more the design maximum.

As for structural calculations, structural members shall be designed so as to be safe against the design external forces in **Table 4**. Sabo dams shall have a structure with as high a level of fail-safe redundancy as possible, so that any partial breakage of the members will not lead to the collapse of the entire structure.

Out of the members that are provided to block debris flows, members that do not constitute structural members that maintain the shape of the structure may be allowed plastic deformation, because such members can be considered as having served their purpose provided that they have successfully captured the sediments in the flows. And these members are called "functional members."

4.4. Design of Wing Section in case of Open, Closed, and Partially Open Types

Designs for the non-overflow section shall be based on stability calculations in which the following design external forces act on the wing section in addition to the self-weights: for the open type, design external forces shown in **Table 5**; for the closed and partially-open types, design external forces of the overflow section of the closed type.

Figure 10 shows an example of how design external forces act on a dam of less than 15 m in height. The wing section shall meet all of the following four conditions against the three design external forces of "self-weight of the wing," "fluid forces of debris flows," and "greater impact force between rock and woody debris."

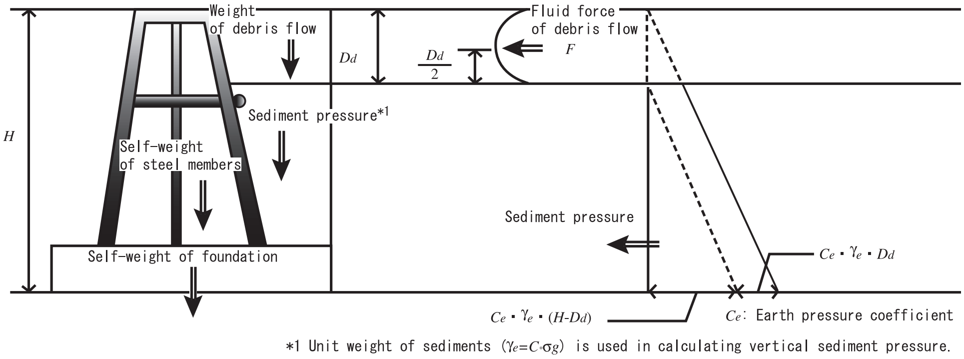

Fig. 8. Acting positions of design external forces for open-type.

Table 3. Combination of design external forces for partially open-type excluding self weights.

	Normal	Debris Flow	Flooding
Height of Dam less than 15m		Static Water Pressure Sediment Pressure Fluid Force of Debris Flow	Static Water Pressure
Height of Dam 15m or more	Static Water Pressure Sediment Pressure Uplift Pressure Seismic Inertia Force Seismic Dynamic Water Pressure	Static Water Pressure Sediment Pressure Uplift Pressure Fluid Force of Debris Flow	Static Water Pressure Sediment Pressure Uplift Pressure

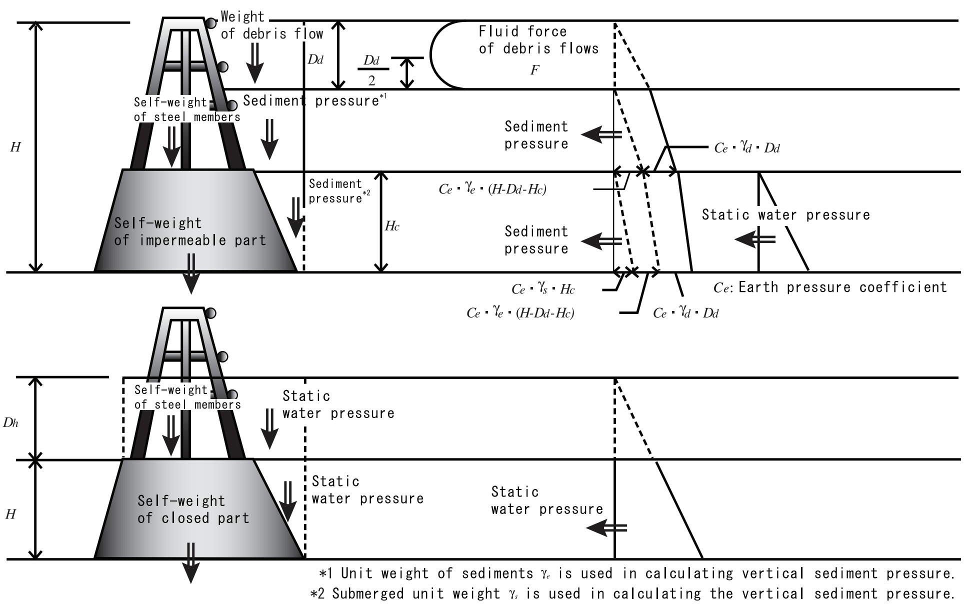

Fig. 9. Acting positions of design external forces for partially open-type: Dam height less than 15 m: Upper figure for debris flows, lower figure for flooding.

Table 4. Combination of design external forces for structural calculations.

Case	Debris Flow	Full Sediments	Changes in Temperature
Self-Weight	○	○	○
Fluid Forces of Debris Flows	○		
Sediment Pressure	○	○	
Temperature Stress			○
Extra Coefficient for Allowable Unit Stress	1.5	1.0	1.15

Table 5. Combination of design external forces for open-type excluding self-weights.

	Normal	Debris Flows	Flooding
Height of Dam less than 15m		Static water pressure Sediment pressure Fluid forces of debris flows	
Height of Dam 15m or more	Seismic inertial forces	Static water pressure Sediment pressure Uplift pressure Fluid forces of debris flows	

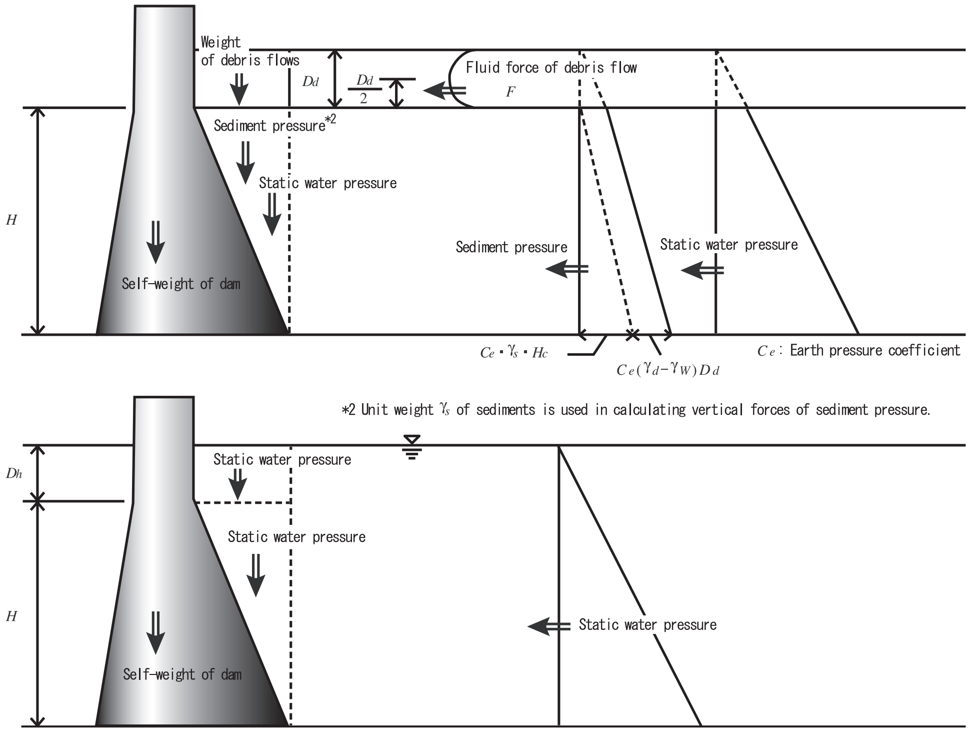

Fig. 10. Acting positions of design external forces for dams of less than 15 m in height: Upper figure for debris flows and lower figure for flooding.

(a) The angle of inclination of the wing on the upstream side shall be in principle vertical.

(b) Slope inclination of the wing on the downstream side shall be either vertical or identical to that of the main body on the downstream side.

(c) If the inclination of the wing on the downstream side is made identical to that of the main body on the downstream side, the breadth crown of the dam at the wing shall be 1.5 m at the minimum.

(d) The safety factor for shear sliding against design external forces shall not be less than four on the boundary surface between the wing and the main body.

After that, tensile stress is to be calculated for the cases in which the above-mentioned three design external forces are acting. In case the calculations should indicate any tensile stress higher than that allowable, such tensile stress shall be undertaken by reinforcing bars or steel frames, which shall be so arranged as to pass the boundary surface between the wing and the main body.

5. Conclusions

The revised technical guideline has still assumptions. For example, the control plan mentioned in 3.2 is established under an assumption that debris flow and woody debris will be transported from the all gullies in the basin. However it is reported that traces of debris flows and woody debris were found in not all gullies in a basin, so that we are planning to find out the tendency and revise the technical guideline in the future.

Recent Sabo facilities are increasingly being expected to take into consideration not only disaster prevention but also environmental or landscape issues, as practiced in comprehensive sediment control activities. Accordingly, more and more attention has come to be paid to open or partially open Sabo dams, which can efficiently control sediment discharges and capture debris-flows/woody-debris, while not affecting the continuity of river-bed levels or water currents or unduly obstructing the passage of animals or fish. As a result, a great number of such dams have been constructed.

We have also come to recognize more and more the true benefits of such dams. Considering the current circumstances, it is reasonably expected that an increasing number of sabo dams will continue to be aggressively planned and constructed in the future, and we expect this will require us to seek further advancements in technical standards and guidelines. Accordingly, we intend to investigate at sites what kinds of effects may be expected of open and partially open dams, so that we may incorporate accumulated or advanced knowledge into subsequent revisions of the technical standards and guidelines.

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More information can be obtained from following web sites;
http://www.sabo-int.org/law/index.html
http://www.sabo-int.org/guideline/index.html

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• International Association of Hydrological Sciences (IAHS)