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TECHNICAL STANDARD FOR THE MEASURES AGAINST DEBRIS FLOW (DRAFT)

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**TECHNICAL STANDARD FOR THE MEASURES
AGAINST DEBRIS FLOW (DRAFT)**

by

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Synopsis:

This pamphlet relates the tentative technical standard concerning the plan of various measures against debris flow. It is translated from the original Japanese version which was prepared by the Sabo (Erosion Control) Division, Public Works Research Institute for the technical committee organized by the Erosion Control Department, Ministry of Construction in March, 1987.

Key Words: Debris flow, measures against debris flow, plan, tentative technical standard

土石流対策指針(案)

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要 旨

本資料は土石流対策および土石流対策施設についての計画手法を述べたものであり、建設省河川局長の諮問を受けて設置された「総合土石流対策強化手法検討会」の第三部会において土木研究所砂防部砂防研究室が主務となって、1987年3月にまとめた「土石流対策指針(案)」の英語版である。

キーワード：土石流，土石流対策，計画，土石流対策施設指針(案)

P R E F A C E

This booklet is translated from the original Japanese version which was prepared by the Sabo (Erosion Control) Division, Public Works Research Institute for the technical committee organized by the Erosion Control Department, Ministry of Construction in March, 1987. The translation was done by Mrs. Edith P.H. Li. We would like to express our sincere thanks to her.

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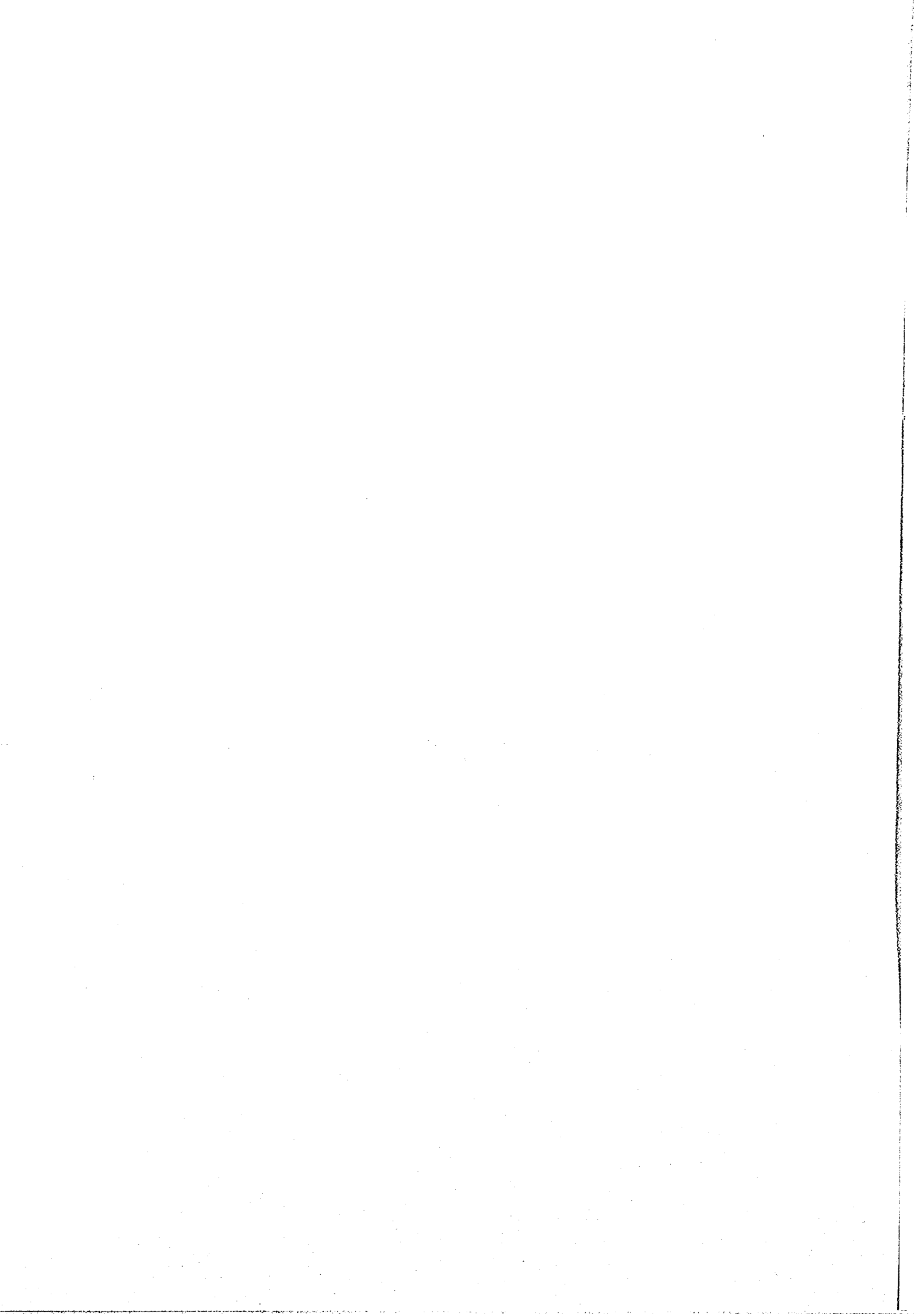
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BASIS OF DEBRIS-FLOW COUNTERMEASURE PLAN



Section 1. General

The debris-flow countermeasure plan shall be formulated to protect human lives and property, living environment and natural environment from sediment-related disasters due to the direct hit of debris flows, on hazard torrents prone to debris flows.

[Comment]

The debris-flow countermeasure plan comprises the arrangement plan of debris-flow countermeasure facilities, which deals with harmful sediment by debris-flow capturing works, and the maintenance plan of a warning and evacuation system, which protects the inhabitants' lives from debris flows without the use of structures. Details of the maintenance of a warning and evacuation system for debris flows are shown on 'The Essentials of the Maintenance of a Warning and Evacuation System for Debris Flow (Draft)' and on 'The Establishment of the Standard for Warning and Evacuation on the Environs of Debris-flow Hazard Torrents' issued by the Sabo Department, River Bureau, Ministry of Construction on June 20, 1984. Therefore, the arrangement plan of debris-flow countermeasure facilities by means of structures shall be exclusively explained here.

Section 2. Basis of Debris-flow Countermeasure Plan

2.1 Basic Policies for Formulating Plan

The debris-flow countermeasure plan shall be formulated rationally and effectively to cope with debris flows in order to prevent the damage they may incur.

[Comment]

The object of the measures against debris flow is attained by the completion of projects which are formulated on the basis of the debris-flow countermeasure plan such as the debris-flow capturing works on hazard torrents and within the areas to be conserved. Nevertheless, in view of the destructive power of debris flows which occur to threaten a great deal the safety of human lives, it is necessary to work out the plan (warning and evacuation system) which protects human lives at least before the completion of the projects.

Moreover, debris flows of a scale larger than the ordinary designed scope may also occur. Therefore, the cancellation of the warning and evacuation system based on the maintenance plan has to be dealt with prudently even after the countermeasure facilities have been established to a certain extent.

2.2 Reference Point of Design

The reference point of design is the spot which determines the sediment yield to be dealt with by the debris-flow countermeasure plan. It shall be located at the upstream of the areas to be conserved.

[Comment]

Generally, the exit of valleys where debris flows start to deposit shall be the reference point of design.

2.3 Scale of Plan

The scale of the debris-flow countermeasure plan shall be evaluated by the basin characteristics, usually by the volume of debris flow or the return period of rainfall.

[Comment]

In principle, the scale of debris flow is to be predicted when their probability of occurrence accompanied by the 24-hr. (or daily) rainfall of the proposed return period (generally 100 years) is judged to be high both in experience and in theory. The countermeasure facilities plan is then formulated to deal with the debris flow of a predicted scale

In torrents where the frequency of debris-flow occurrence is high, the scale of plan can be determined on the basis of the data of their discharge.

2.4 Revision of Debris-flow Countermeasure Plan

When the conditions of the the catchment area have been greatly altered due to natural factors like the instabilization of slopes caused by new collapses, occurrences of debris flow and earthquakes, and artificial factors like human exploitation, it is necessary to re-consider the proposed sediment discharge and revise the debris-flow countermeasure plan as required.

2.5 Ledger for Debris-flow Countermeasure Plan

The debris-flow countermeasure plan together with its various necessary quantities of design and their bases of calculation shall be recorded in the ledger.

[Comment]

A debris-flow countermeasure plan shall be formulated for each torrent in principle. Various quantities of design like the proposed sediment discharge and their bases of calculation according to the

surveys of hazard torrents prone to debris-flow occurrence shall be recorded in the ledger. It is desirable to file and record the conditions of sedimentation in debris-flow capturing works, and the maintenance of the facilities as well.

2.6 Volume of Sediment to be Handled by the Project

2.6.1 Proposed Sediment Discharge

The proposed sediment discharge is comprehensively determined on the basis of topographic maps, field surveys and records of past debris flows.

[Comment]

The proposed sediment discharge shall be the volume of sediment transportable by the debris flow of an estimated scale or the movable sediment volume within the catchment area, whichever is smaller.

Methods of calculating the movable sediment volume within the catchment area are as follows:

- (a) The movable sediment volume (volume of unstable sediment) for the rainfall of an estimated scale on each torrent shall be the sum of deposits on torrent bed and the collapsible sediment.

$$V_e = V_1 \text{ (deposits on torrent bed)} + V_2 \text{ (collapsible sediment)}$$

where V_e : sediment discharge (m^3), $V_1 = A_1 \times L_1$ (A_1 : cross-sectional area of deposits on torrent bed (m^2), $A_1 = B \times D_e$, B : mean width (m) of torrent bed where erosion is predicted when debris flow occurs, D_e : mean depth (m) of deposits on torrent bed, B and D_e is presumed by referring to field surveys and the scouring conditions of nearby torrents. When the deposits are thick, 5m shall be taken as the maximum limit. L_1 : distance (m) measured along the torrent from the outlet of valley or from the spot which is thought to be the downstream

edge of the eroded section when a debris flow occurs to the spot where water issues at ordinary time); V_2 : predicted collapsible sediment volume on the 0-order valley (valley where there is no running water at ordinary times) or on the hillside of torrent. The site of occurrence and the scale shall be concretely predicted.

- (b) When it is difficult to predict precisely the volume of collapsible sediment, the movable sediment volume for debris flow is predicted by the following equation which included the collapse of the 0-order stream.

$$V_e = A_e \times L_e$$

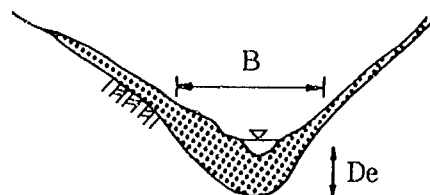
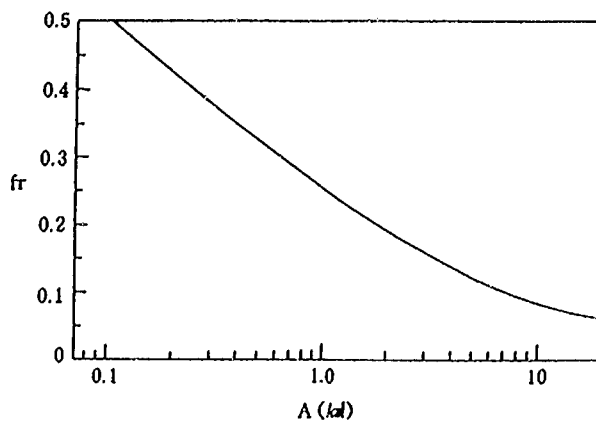
where V_e : sediment discharge (m^3), A_e : mean cross-sectional area of deposits on torrent bed ($= B \times D_e$ where B : mean width (m) of torrent bed where erosion is predicted when debris flow occurs, D_e : mean depth (m) of deposits on torrent bed), L_e : distance (m) measured along the torrent from the outlet of valley to the furthestmost point of the catchment area. The length of branch torrents shall also be added if they are present.

Even if the present movable sediment volume right after the occurrence of debris flow is small, when it is expected to increase in the near future since the sediment yield is intensive on hillside and banks of torrent, it should be estimated and then added to the proposed sediment discharge.

The volume of sediment transportable by the debris flow of an estimated scale (V_{ec}) is calculated by multiplying the sediment concentration of debris flow (C_d) to the total volume of water which is obtained by multiplying the catchment area (A (km^2)) to the daily rainfall of an estimated scale (R_{24} (mm)). The runoff correction rate (f_r) is then considered.

$$V_{ec} = \frac{10^3 \cdot R_{24} \cdot A}{1 - \lambda} \left(\frac{C_d}{1 - C_{d1}} \right) f_r$$

where λ is the void ratio which shall be about 0.4, f_r is the runoff correction rate and is given to the catchment area by the figure on the right.



Reference: Examples of surveys on the mean depth of scouring

Honsawa Valley (Saiko Lake Disaster, Yamanashi Pref.)	: 3.02m
Misawa River (" " ")	: 2.49m
Obama River (Owase Disaster, Mie Pref.)	: 2.0 m
Toishi River (Amakusa Disaster, Kumamoto Pref.)	: 1.7 m
Shodoshima Disaster (Kagawa Pref.)	: 0.5 ~ 1.8 m

2.6.2 Peak Discharge of Debris Flow

The peak discharge of debris flow is obtained as stated below,

$$Q_{sp} = \alpha Q_p$$

where, Q_{sp} : peak discharge of debris flow, Q_p : discharge of water alone corresponding to the rainfall of an estimated probability, α : a coefficient. If there is a measured value or if the peak discharge can be estimated by other methods, the measured value or the estimated value may be used.

[Comment]

During an occurrence process of debris flow, 1) the deposits on torrent bed are greatly eroded by running water and turn into a debris flow; 2) the sediments of hillside collapse become a debris flow; and 3) the sediments of hillside collapse check the flow and become a landslide dam which is then broken and turns into a debris flow. Since there is no way to estimate the peak discharge for 2) and 3), a design value is established only for 1) as stated below.

The peak discharge of debris flow Q_{sp} (m^3/s) can be obtained from its relation with the discharge of water alone Q_p (m^3/s).¹⁾

$$Q_{sp} = \frac{C^*}{C^* - C_d} Q_p$$

where, C^* : volumetric sediment concentration of deposited sediment (about 0.6), C_d : volumetric sediment concentration of debris flow in motion, about 0.9 C^* when the riverbed gradient is greater than 20° . When the gradient is below 20° , the concentration of debris flow can be estimated by the following equation.

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

The above equation is Takahashi's equation²⁾ for the gradient between $10^\circ \sim 20^\circ$, which can also be applied to areas of a more gentle gradient. Moreover, if the calculating value (C_d) becomes larger than 0.9 C^* , C_d shall be regarded as 0.9 C^* , and if it becomes smaller than 0.3, it shall be regarded as 0.30.

Where, σ : density of gravels (about 2.6 t/m^3), ρ : density of water (about 1.2 t/m^3), ϕ : angle of internal friction of deposited sediments (about $30^\circ \sim 40^\circ$), θ : riverbed gradient (degree).

For example, if $C^* = 0.6$, $C_d = 0.54$, Q_{sp} shall become 10 Q_p . Besides the object discharge of water alone (Q_p) is obtained by

$$Q_p = 1/3.6 f \cdot r \cdot A$$

where, f : coefficient of peak runoff, r : mean rainfall intensity (mm/hr) within time of flood concentration, A : catchment area (km²).

The time of flood concentration shall be obtained by the following equation as a rule.³⁾

$$t_p = CA^{0.22} \cdot r_o^{-0.35}$$

where, t_p : time of flood concentration (min.), A : catchment area (km²), r_o : effective rainfall intensity (mm/hr), C : a coefficient, 120.

For example, if the coefficient K is 1/2, using the equation

$$r_t = r_{24} \cdot \left(\frac{t}{24} \right)^K$$

as the rainfall intensity equation, the effective rainfall intensity becomes

$$r_o = \left(\frac{r_{24}}{24} \right)^{1.21} \cdot \left(\frac{24f^2}{\frac{C}{60} A^{0.22}} \right)^{0.606}$$

where, r_{24} : daily precipitation (mm/day), r_t : precipitation during t -hr (mm).

Reference:

According to the observation results of Mt. Yakedake, River Name and Sakurajima, the discharge of water alone is about 70 m³/s, and Q_{sp}/Q_p is distributed widely from 1 to 20.

Besides, a fairly good correlation exists between the total discharge of debris flow Q_T (m³) and the peak discharge of debris flow Q_{sp} (m³/s), which is expressed by the equation below.

$$Q_{sp} = 2 \times 10^{-3} Q_T$$

The data which revealed that the total discharge of debris flow Q_T is approximately equal to the total water volume (found by multiplying the total rainfall to the catchment area) was obtained.

2.6.3 Velocity and Water Depth of Debris Flow

The velocity and the water depth of debris flow are estimated by theoretical formulae, empirical formulae and measured values.

[Comment]

The velocity of debris flow U (m/s) is reported to be expressible by Manning's formula,

$$U = \frac{1}{n} R^{2/3} (\sin \theta)^{1/2}$$

after the observation data of Mt. Yakedake, River Name and Sakurajima have been analyzed, where R : depth of debris flow (m), and R shall be equal to h (water depth of debris flow); θ : riverbed gradient (degree), the average gradient 100m upstream of the spot where the velocity is calculated shall be used; n : coefficient of roughness. However, the coefficient of roughness is much larger than that in the case of clear water. In a natural river channel, 0.10 for the front portion, 0.06 for the subsequent flow and 0.03 for a channel work whose bed is covered with concrete shall be used.

The water depth of debris flow h (m) is given by the width of flow B (m), the peak discharge of debris flow Q_{sp} (m³/s) and the velocity of debris flow U (m/s) as shown below.

$$h = \frac{Q_{sp}}{B \cdot U} = \left\{ \frac{n \cdot Q_{sp}}{B (\sin \theta)^{0.5}} \right\}^{3/5}$$

This value should be compared with the maximum grain size expected to be discharged as a debris flow, and the water depth of debris flow shall be the larger value of the two, provided that the above-mentioned calculated value is used as the velocity. The maximum grain size of debris flow is given by finding the frequency distribution of about more

than 100 huge boulders inside the sediments expected to be discharged as a debris flow, to get the accumulation curve of 95%. The width of flow B (m) shall be the width of valley where the debris flow is expected to run off.

2.6.4 Unit Capacity Weight of Debris Flow

The unit capacity weight of debris flow is predicted by the measured values, experimental and theoretical studies.

[Comment]

The unit capacity weight of debris flow ρ_d (t/m³) is obtained by:

$$\rho_d = \sigma C_d + \rho (1 - C_d)$$

Reference:

Although the precise value of the unit capacity weight of debris flow has not been available, the following measured values have been reported.

Measured values of Mt. Yakedake: 1.77, 2.11, 1.87, 1.81, 1.94, 1.63

Sakurajima, River Nojiri : max. 2.04, min. 1.12, average 1.79

Section 3. Preparation of Debris-flow Countermeasure Facilities Arrangement Plan

3.1 Basic Composition of Debris-flow Countermeasure Facilities Arrangement Plan

A debris-flow countermeasure facilities arrangement plan is formulated for each hazard torrent, which copes with debris flows rationally and effectively by considering the occurrence frequency and the scale of debris flows.

[Comment]

The debris-flow countermeasure facilities arrangement plan is prepared by referring to the following classification.

{ Ordinary (non-volcanic) measures against debris flows	{ (1) Torrents with a high frequency of debris-flow occurrence
	{ (2) Torrents with a low frequency of debris-flow occurrence
{ Measures against debris flows at the foot of volcanoes	{ (1) Torrents with a high frequency of debris-flow occurrence
	{ (2) Torrents with a low frequency of debris-flow occurrence

Torrents with a high frequency of debris-flow occurrence refer to the torrents where debris flows have occurred more than once within the past 50 years. They also include those with a high probability of debris-flow occurrence in the near future due to the change in catchment conditions after an earthquake has occurred.

3.2 Basis for Preparing the Debris-flow Countermeasure Facilities Arrangement Plan

The debris-flow countermeasure facilities arrangement plan is a plan which copes with the proposed sediment discharge of debris flow

by debris-flow capturing works, debris-flow depositing works and the works for restricting the occurrence of debris flow.

In formulating the plan, various types of countermeasure works shall be rationally arranged in consideration of the occurrence frequency, volume, flowing characteristics of debris flow, topography and the areas to be conserved etc. Moreover, sediments (the allowable sediment discharge) which do not cause disasters on the lower reaches can be discharged by debris-flow training dykes. It is possible to determine the sediment volume to be dealt with by subtracting this volume (the allowable sediment discharge) from the proposed sediment discharge. In this case, the grain size and its time distribution have to be examined thoroughly so that depositions do not occur inside the training dykes to remarkably impede the discharge.

[Comment]

The debris-flow countermeasure facilities arrangement plan is prepared to satisfy the following equation which indicates the proposed sediment discharge of debris flow (Q), the design allowable sediment discharge (E), the design capturing volume (C), the design sedimentation volume (D) and the design volume for restricting the occurrence of debris flow (B).

$$Q - E - (C + D + B) = 0$$

The design allowable sediment discharge used here means the sediment volume which flows from the reference point of design of debris-flow hazard torrents without causing disasters on the lower reaches. It indicates the volume other than the designed depositing volume which is dealt with by the debris-flow depositing works. If the proposed sediment discharge is to be estimated for the design sedimentation area of the debris-flow capturing works, it is estimated as the design volume for restricting the occurrence of debris flow at the time when the debris-flow capturing works are completed. The design capturing volume is the design volume for capturing the

debris flow effectively and it is equal to the storage volume of the capturing works where the removal of stones is completely fulfilled.

The facilities arrangement plan for torrents with a high frequency of debris-flow occurrence shall be carried out in the following order in principle.

- ① Calculate the proposed sediment discharge under the consideration of the actual sediment discharge of debris flow. (Refer to 2.6.1)
- ② Determine the location and scale of facilities with the combination of debris-flow capturing works, debris-flow depositing works, debris-flow training dykes and works for restricting the occurrence of debris flow.
- ③ Carry out the removal of stones in the capturing works and depositing works as the situations of sediment runoff required.

The facilities arrangement plan for torrents with a low frequency of debris-flow occurrence shall be carried out in the following order in principle.

- ① Calculate the proposed sediment discharge from the surveys of deposits on torrent bed. (Refer to 2.6.1)
- ② Set up debris-flow capturing works, debris-flow depositing works and debris-flow training dykes near the exit of valleys.
- ③ Carry out regular inspection of the conditions of sedimentation, and promptly after heavy downpours as well, to ensure the sediment trap capacity by the removal of stones if necessary.

The above procedures are applicable to both ordinary (non-volcanic) and volcanic districts. However, they differ in the following ways when the volcanoes are active ones. i) It is necessary to reconsider the proposed sediment discharge according to the conditions of volcanic activities and the changing conditions of the catchment, and ii) countermeasures at the source section are often difficult. The countermeasure plan must also be formulated in consideration of the occurrences of relatively big collapses and that of high-speed mudflows.

When the proposed sediment discharge cannot be dealt with in the upper reaches due to topographic conditions, plan to cope with it by means of debris-flow training dykes along with debris-flow dispersing forest belts and debris-flow direction controlling works in consideration of the situations of land use.

On torrents where large quantities of driftwood are expected to run-off with the debris flow, it shall be put into account while selecting the types of debris-flow countermeasure facilities.

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BASIS OF DEBRIS-FLOW COUNTERMEASURE FACILITIES PLAN

Section 1. General

1.1 Basis of Planning

The debris-flow countermeasure facilities plan shall be set up rationally on the basis of the debris-flow countermeasure facilities arrangement plan. It shall be well-matched technically and effectively in consideration of the situations of debris-flow hazard torrents. In implementing the debris-flow countermeasure facilities plan, it is necessary to consider the order which brings about the best effect.

[Comment]

In planning countermeasure facilities against debris flows, it shall be basically intended to decrease the sediment discharge by setting up debris-flow capturing works at the outlets of valleys and to safely discharge the subsequent flows by means of debris-flow training dykes (including sabo channel works). If the sedimentation capacity of the debris-flow capturing works is smaller than the proposed sediment discharge, such facilities shall be set up further upstream or the debris-flow depositing works shall be set up in the lower reaches. In addition, works for restricting the occurrence of debris flows shall be provided. If the sediment load cannot be handled by the measures stated above or if there is an urgent need to protect the objects to be conserved, then debris-flow direction controlling works shall be set up. In order to further increase the degree of safety, a debris-flow dispersing forest zone shall be provided at the end of the debris-flow deposition area.

Although the debris-flow countermeasure plan indicated here is intended for debris-flow hazard torrents, it can also be applied to the design of sabo facilities on torrents which are not prone to the occurrence of debris flows.

1.2 Kinds of Debris-flow Countermeasure Facilities

Principal countermeasure facilities against debris flows are:

- 1) debris-flow capturing works, 2) debris-flow depositing works,
- 3) debris-flow training dykes, 4) debris-flow dispersing forest zones,
- 5) debris-flow direction controlling works, and 6) works for restricting the occurrence of debris flows.

[Comment]

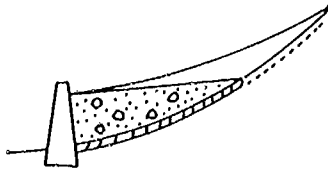
(1) Debris-flow Capturing Works

Dams are the typical structures of this kind of works at present, which can be classified into either the impermeable or the permeable type. Functions common to both types are:

- ① To capture debris flows so as to reduce the volume of sediment discharge.
- ② To lengthen the period of time from the occurrence of debris flow to its outflow onto alluvial fans.
- ③ To prevent the movement of deposits on torrent beds. (It is expected to be accomplished at the foundation section of permeable dams.)
- ④ To capture the boulders and driftwoods at the front of debris flows.
- ⑤ To turn the debris flow into sediment flow.
- ⑥ To reduce the peak discharge of debris flow.

In addition to the above functions, permeable dams are expected to maintain a sedimentation capacity required for the next debris flow by having no sedimentation when small and medium freshets occur. The effect of a culvert boom to stop the driftwood which is predicted to run out can also be anticipated. Mass concrete, steel and reinforced concrete may be used as the material for the dam body. Separating dams (drainage screens) can be considered as debris-flow capturing works. As for the planned sedimentation area, the effect of checking sediment by capturing

works is evaluated as the proposed volume of restricting debris-flow occurrence only when the proposed sediment discharge is evaluated within that area.



(2) Debris-flow Training Dykes

They are used to guide the debris flows to a safe place.



(3) Debris-flow Depositing Works

They include the debris-flow depositing channels (Fig. 1) and the debris-flow dispersing and depositing area (Fig. 2) to be used for reducing and depositing the debris flows.



Fig. 1 Design sedimentation volume

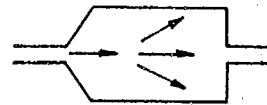


Fig. 2

(4) Debris-flow Dispersing Forest Zones

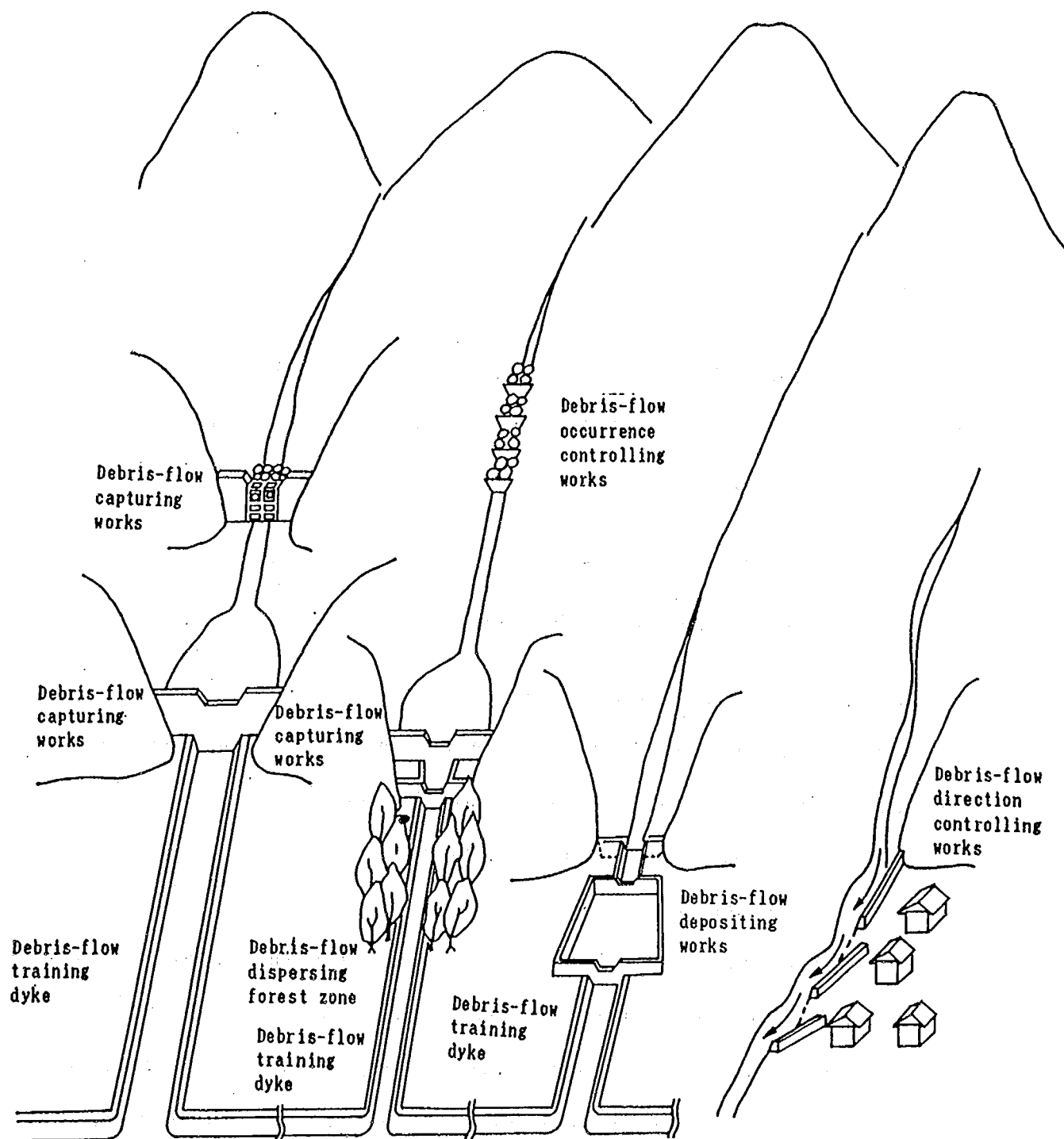
They are used to control the direction of debris flows on alluvial fans and also to restrict the limit of the deposition area by means of trees as they establish a buffer zone between debris flows and the objects to be conserved.

(Remark) The cushioning effect of trees against the impact force of debris flows is uncertain. It is therefore recommendable either to combine strengthening works of engineering structures or to locate the forest zone in an area like the inundation zone where the velocity of debris flow has become fairly low.

(5) Debris-flow Direction Controlling Works

The direction of debris flow is controlled by means of levees and so forth.

(Reference) A typical example of debris-flow countermeasure facilities



Section 2. Debris-flow Capturing Works

2.1 Kinds of Debris-flow Capturing Works

Debris-flow capturing works can be roughly classified into either the impermeable or the permeable type.

[Comment]

Impermeable dams include gravity concrete dams and steel-framed dams, while permeable dams include steel-pipe dams and slit dams. For their respective functions, see Comment (1) in Section 1.2.

2.2 Scale and Arrangement of Debris-flow Capturing Works

The scale and the arrangement of debris-flow capturing works shall be determined according to the debris-flow countermeasure facilities plan (Basis for Planning Measures against Debris Flows 3.2).

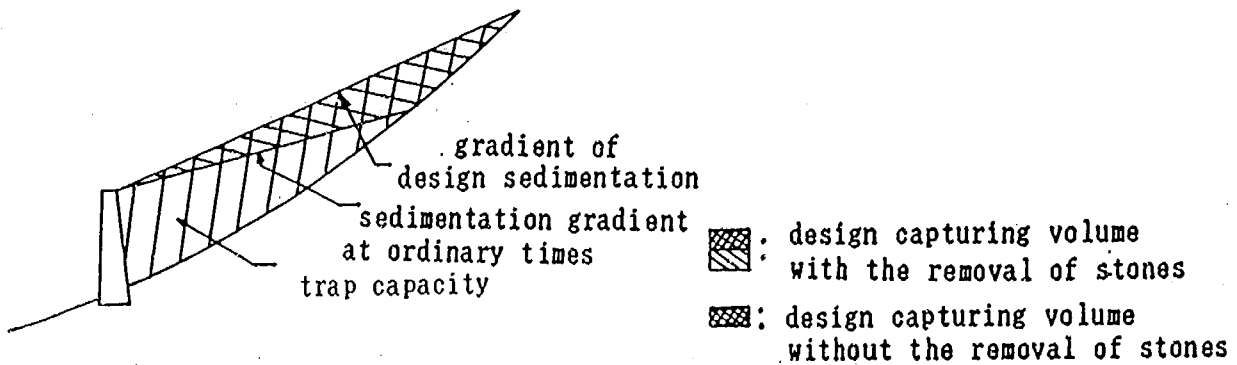
2.3 Gradient of Design Sedimentation

The gradient of sedimentation on dams varies between an almost horizontal gradient to about the present riverbed gradient. The gradient of design sedimentation is defined as the gradient which can reliably capture the debris flow when it occurs.

[Comment]

The gradient of design sedimentation shall range from $1/2$ to $2/3$ of the present riverbed gradient of the dam site, provided that $1/6$ of the gradient ($\tan \theta$) is the maximum. If the sedimentation gradient is known to

become gentle due to geological conditions, the gradient of design sedimentation shall be determined regionally according to past records.



2.4 Design Capturing Volume

The design capturing volume is calculated to show the sedimentation condition at the gradient of design sedimentation.

[Comment]

The design capturing volume on dams without the removal of stones shall be the difference between the sediment storage volume of the gradient of sedimentation in ordinary times based on surveys and that of the gradient of design sedimentation. The gradient of sedimentation in ordinary times shall be from horizontal to $1/2$ the present riverbed gradient by referring to past records.

2.5 Construction of Impermeable Dams

(1) Design Discharge

The design discharge of dams is determined by considering the sediment content ratio, using the return period of about 1:100 years of daily rainfall or the previous maximum rainfall, whichever is larger.

[Comment]

The sediment content ratio shall be 50% in principle and the design discharge shall be 1.5 times the discharge of water alone.

(2) Design Water Depth

The overflow depth of the spillway section which allows the design discharge to flow out is determined as the design water depth.

(3) Design Water Depth of Debris Flow

The design water depth of debris flow on dams is obtained from the Basis of Planning 2.6.3 after the width of debris flow at the dam site for the peak discharge of debris flow is presumed.

[Comment]

The width of debris flow at the dam site is the width of valley on the upstream and the gradient of the present riverbed is used as the gradient of debris flow.

(4) Design External Forces

The design external forces to be considered in the design of dams are hydrostatic pressure, silt pressure, uplift force, inertial force and dynamic water pressure during an earthquake, and the load of debris flow.

The load of debris flow comprises the force due to the collision of gravels and the hydro force. The former affects a portion of the structure while the latter affects the entire structure. Therefore, in calcu-

lating the stability of dam, only the hydro force is dealt with and the force due to the collision of cobbles is considered in the design of material if necessary.

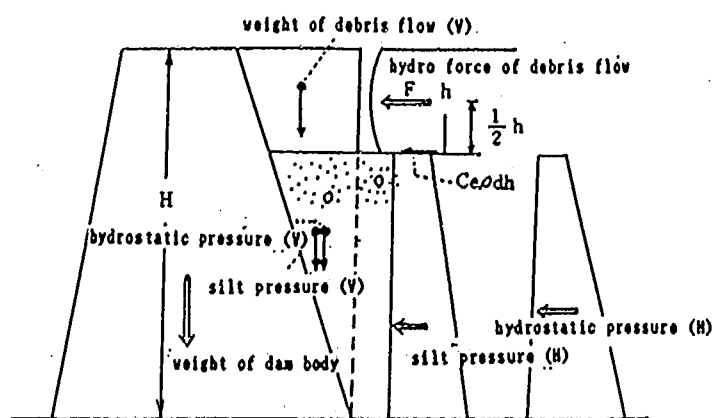
[Comment]

It is necessary to examine both the review on the combination of external forces according to Chapter 3 of the 'River Sabo Technical Standard (Proposal)' on design- 'The Design of Sabo Facilities' and the case in which the following-mentioned hydro force of debris flow is considered, and safety must be guaranteed for both.

Combination of loads to be used for the stability calculations of the dam section for gravity concrete dams with the debris-flow hydro force taken into account should be as shown in the following table. However, the unit capacity weight of water in the calculation of the hydrostatic pressure in a debris flow shall be 1.2 t/m because the impulse force is not considered.

	During Ordinary Times	When debris flow occurs	During Flood
Height of Dam < 15m		Hydrostatic pressure, silt pressure, debris-flow hydro force	Hydrostatic pressure
Height of Dam > 15m		Hydrostatic pressure, silt pressure, uplift force, debris-flow hydro force	Hydrostatic pressure, silt pressure, uplift force

The height of sedimentation surface is set up at the position below the dam height after subtracting the height of the design water depth of debris flow from it. The force exerted by fluid on dams should be examined by adding the hydrostatic pressure and silt



External forces when debris flows occur

pressure below the sedimentation surface to the debris-flow hydro force above the sedimentation surface. (refer to the figure on the right)

The force exerted by fluid is obtained by:

$$F = \alpha \frac{\rho_d}{g} h U^2$$

where F : debris-flow hydro force per unit width (tf/m), U : average velocity of debris flow at dam site (m/s), h : design water depth (m) of debris flow in the debris-flow countermeasure facilities plan 2.5 (3), g : gravity of acceleration (9.8 m/s^2), α : a coefficient ($=1.0$), ρ_d : unit capacity weight of debris flow (tf/m³).

The hydro force of debris flow operates horizontally at the position of $h/2$.

Inertial force and dynamic water pressure during earthquakes, and uplift force are based on Chapter 3 of the 'River Sabo Technical Standard (Draft)' on Design: 'The Design of Sabo Facilities'.

As for dams intended for moderating the gradient of torrent beds, which are not supposed to be directly subject to the impact force of debris flow (including the dams for preventing the movement of sediment deposited in torrents), even if they are inside the hazard torrents prone to debris flows, the impact force of debris flow may be neglected.

(5) Conditions for Stability

Impermeable dams for capturing debris flows must satisfy the following three conditions in order to ensure stability for the external forces shown in (3).

1. That the acting line of the resultant force of the weight of dam and the external forces should fall within the central $1/3$ of the bottom plane of the dam so that tensile stress will not occur at the upstream end of the dam.
2. That sliding will not occur between the bottom of dam and the foundation base.
3. That the maximum stress appeared inside the dams will not exceed the allowable stress of materials, and that the maximum pressure to which the foundation is exposed is within the allowable bearing capacity of the foundation.

[Comment]

The safety factor N for sliding shall be equal to 1.2 in neglecting the shear strength if the dam height is less than 15m. If the dam height is over 15m, N shall be 4.0 for a rock foundation in consideration of the shear strength and 1.5 for a gravel foundation in neglecting the shear strength.

(6) Spillway

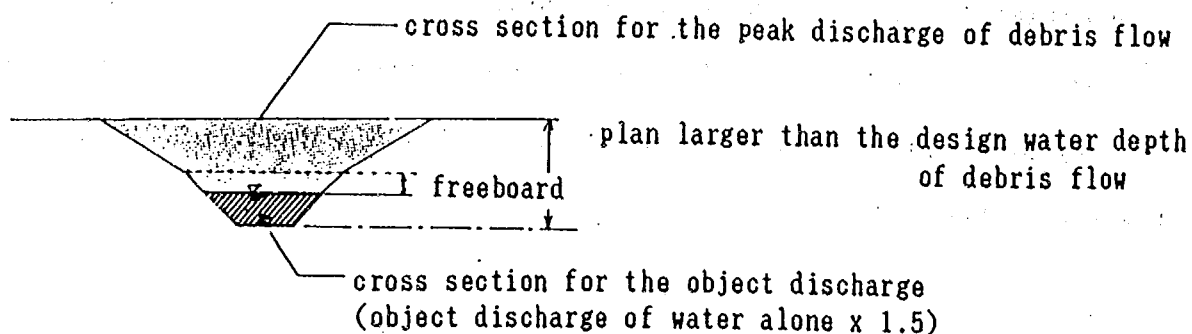
The spillway section of dam is determined by finding the water depth of overflow with the dam formula plus the freeboard. The water depth of overflow corresponds to the estimated discharge of water alone (Q_p) obtained from the precipitation at the dam site and the object discharge of sediment which is 50% of Q_p . The width of spillway shall be larger than 3m in principle.

In torrents with a high frequency of debris-flow occurrence, the spillway section may be determined by corresponding to the peak discharge of debris flow.

[Comment]

In the case where the debris flow runs over the dam, the peak discharge of debris flow shall be dealt with by the spillway section which has a cant (slanting portion). (Refer to the figure below) The freeboard is based on the 'River Sabo Technical Standard (Draft)' on Design.

The water depth of debris-flow overflow is obtained as the flow under the condition where the sediment deposits parallelly to the design sedimentation gradient up to the crown of dam according to the basis of debris-flow countermeasure plan 2.6.3.



(7) Width of Crown

The width and the construction of the crown of dam are determined in such a way that it will not be damaged by the collision of gravels.

[Comment]

For mass concrete, a width of twice the maximum grain size of colliding gravels shall be used as a rule. If the required crown width exceeds 4m, the crown should be protected by cushioning materials or embankment, and be reinforced by iron bars and steel frames. The effect of the cushioning materials should be confirmed by tests.

The impact force (P) received by the dam body due to the collision of boulder varies according to the types and characteristics of the materials of the dam body. The force (P(kg f)) can be presumed by the following formula for mass concrete.¹⁾

$$P = n \alpha^{1/2}, \quad n = \sqrt{\frac{16 R}{9 \pi^2 (K_1 + K_2)^2}}$$

$$K_1 = \frac{1 - \nu_1^2}{\pi E_1}, \quad K_2 = \frac{1 - \nu_2^2}{\pi E_2}$$

$$\alpha = \left(\frac{5 v^2}{4 n_1 n} \right)^{2/3}, \quad n_1 = \frac{1}{m_2}$$

where, E_1, E_2 : modulus of elasticity of concrete and boulder(kg f/m²),
 ν_1, ν_2 :Poisson ratio of concrete and boulder, m : mass of boulder(kg/m/sec²)
 R : radius of boulder(m), π : the ratio of the circumference of a circle to its diameter (=3.14), v : velocity of boulder(m/sec), α : volume of depression (m), K_1, K_2 : constants. The velocity of boulder shall be equal to the velocity of debris flow and the grain size shall be regarded as the maximum diameter of boulder.

(Reference) Example of the physical constant of boulder and concrete¹⁾

Modulus of elasticity of granite

$$E_2 = 5.0 \times 10^9 \text{ kg f/m}^2, \text{ Poisson ratio } \nu_2 = 0.23$$

Modulus of elasticity of the ultimate strength of concrete

$$E_1 = 0.1 \times 2.6 \times 10^9 \text{ kg f/m}^2$$

Poisson ratio of concrete $\nu_1 = 0.194$

(8) Downstream slope

The downstream slope of dam is made in such a way that it will not be damaged by the overflowing sediment as much as possible. The gradient of downstream slope of the overflowing section of dam shall be 1:0.2 in general.

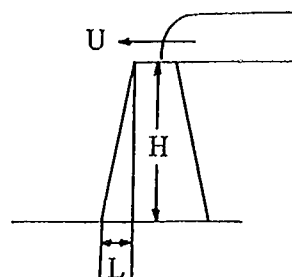
In torrents of a small catchment area with few sediment runoff even during medium to small freshets, the gradient can be made more gentle than that.

[Comment]

If the gradient of downstream slope is to be made gentle, it should be steeper than the gradient given by the velocity of sediment U (m/s) as it starts to move actively and by the height of dam (H) indicated below,

$$\frac{L}{H} = \sqrt{\frac{2}{gH}} U, \text{ with } 1:0.6 \text{ being the maximum limit.}$$

The velocity U (m/s) shall be about 50% of the velocity used in the design external forces of dam (2.5(3)). If the height of dam increases, the value of L/H decreases but 0.2 shall be the minimum.



(9) Foundation

The foundation of dam is expected to be placed over rocks. The height of a floating dam is less than 15m as a rule.

(10) Wing

(10-1) Design

Calculations for stability are carried out for the wing portion.

[Comment]

Calculations for stability are carried out to find the allowable stress of materials against the bending and shear which the hydro force of debris flow operates horizontally on it, in consideration of the sedimentation

condition at the design sedimentation gradient up to the crown of spillway.

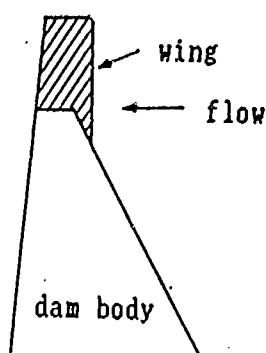
(10-2) Cross Section of Wing Portion

The wing portion of dam should be a safe structure for the load of debris flow and so forth.

[Comment]

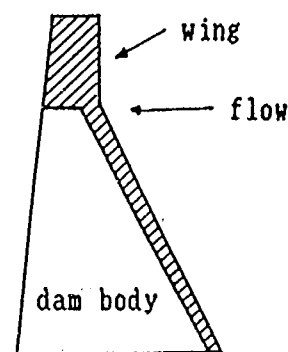
The gradient of downstream slope of the wing portion should either coincide with that of the crown of the main dam, or it should be reinforced by steel frames against the hydro force of debris flow using 1.5m as the minimum width. As for the collision of gravels, it should be

reinforced safely against the forces indicated in the Comment of 2.5(7) or protected by shock absorbing materials or embankment.



thrust out on the upstream side so as to thicken the wing portion

or



vertical at the upstream side of spillway, strengthen the wing portion if necessary

(10-3) End of Wing

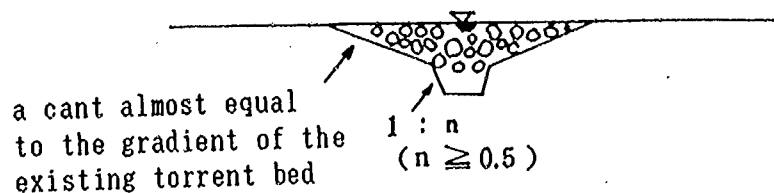
The gradient of the end of wing shall be 1:0.5 or gentler as a rule.

(10-4) Gradient of Wing

It is generally a rule to make the gradient of the wing equal to that of the existing torrent bed.

[Comment]

In case the debris flow runs over the dam, the wing portion shall have a cant almost equal to the gradient of the existing torrent bed for the section which copes with the peak discharge of debris flow.



(11) Apron Protecting Works

Apron protecting works are provided at the apron of dam as the need arises and the damage of the main body of dam due to scouring must be prevented.

[Comment]

Apron protecting works are designed for the object discharge. It shall be a structure which can withstand the case in which the debris flow is expected to run over the wing portion.

The gradient of downstream slope of the counter dam complies with the concept of the downstream slope in Section 2.5(8). The spillway section of the counter dam is determined by considering the freeboard for the object discharge and its structure is determined according to the design of sabo facilities in the 'River Sabo Technical Standard (Draft)' on Design. The width of spillway is decided in consideration of the width of the existing torrent bed. The width of crown shall be 2.0m in principle. If debris flows are expected to pass through the spillway section of the counter dam, it should be planned for dealing with the peak discharge of debris flow, and the width of crown shall be the same as that of the main dam.

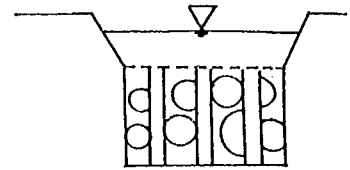
2.6 Construction of Permeable Dams

(1) Spillway Section

The design discharge and so forth are depended on Section 2.5 (1)~(2) in principle. The spillway shall be the section which will safely let pass the debris flow even after the permeable portion is blocked.

[Comment]

Permeable dams shall be structures having a sufficient spillway section which can let pass the peak discharge of debris flow when the permeable portion of dam is completely blocked. The freeboard is determined similarly as that of the impermeable dams.

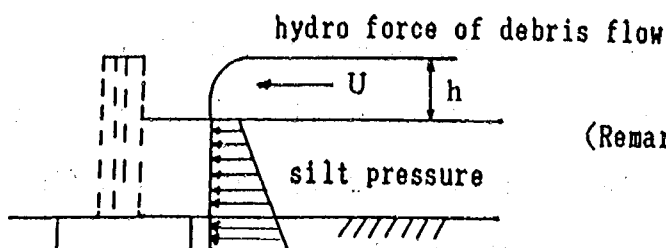


(2) Design External Forces

The design external forces for permeable dams are basically the same as those for impermeable dams. However, because the structure is permeable, instead of hydrostatic pressure, silt pressure is given below the sedimentation surface and the debris-flow hydro force above it.

[Comment]²⁾

The silt pressure is given by the shape of a trapezium as the debris flow overrides on it. The dead load is calculated under the condition that gravels and water are not clogged in the permeable portion. (slit portion)



(Remark) Assume the load of debris flow as the overriding load

In the case of steel-made permeable dams, the design external forces are calculated with the following design load I and design load II according to the dam height and shall satisfy the specific safety factor.

Height of Dam	Design Load I	Design Load II
Less than 8m	Hydro force of debris flow, silt pressure, dead load	—
8~less than 15m	Ditto	Silt pressure during an earthquake with full deposition, weight of deposition on dam and the inertial force which operates on it during earthquake, weight of dam itself and the inertial force which operates on dam during earthquake.
Safety factor for sliding	1.2	1.0

Moreover, the temperature load may also have to be considered. And the design external forces shown in the table above have to be studied also for permeable dams over 15m.

(3) Stability calculations

They are carried out in accordance with the impermeable dams.

[Comment]

For sliding conditions, calculations are carried out by means of the frictional force at the contact surface of the dam body and the foundation ground in principle. The safety factor shall be more than 1.2 for design load I and more than 1.0 for design load II.

In the calculation for the structure of steel-made permeable dams, the stability calculations compute the stresses acted on the steel members and the strength of their joints by the ordinary allowable stress method on the basis of elastic mechanics. The safety of dams must be confirmed beforehand.

Besides the loads used in the stability calculations, the temperature change may also affect the frame to become a statically indeterminate structure. In this case, only the effect of temperature change is examined without adding in the other loads. A suitable value is used for the scope of temperature change according to the situations of the site.

The examination on the collision of boulder shall be depended on the method which assures that the deformation of structure lies within the acceptable magnitude of deformation. The kinetic energy of boulder is supposed to be 100% transmitted to and absorbed by the deformation of structure according to the analysis method on the basis of plastic mechanics.

The determination of a certain magnitude of deformation depends on the form of the frame structure of permeable dams and on the possibility of exchanging the members. It is therefore difficult to prescribe it indiscriminately. However, permeable dams shall function at least in a state where they can resist the silt pressure after the debris flow is trapped even if a relatively big plastic deformation has occurred, or in a state where the structure as a whole does not lose its load resistancy even if some portions of the members have greatly deformed.

Loading conditions and energy absorptivity can be considered as in follows:

- ① The largest boulder is assumed to hit at the most danger point with the

velocity used at calculating the design external forces. The energy loss together with the collision is neglected.

- ② The energy absorptivity of the structure shall be the sum of the partial deformation near the point of collision and the deformation of the entire structure.
- ③ Ensure that the sum of slit pressure and the elastic deformation due to hydro force lies within a certain magnitude of deformation when boulder collide.
- ④ Calculate the energy absorptivity as the accumulated deformation when it exceeds the elastic limit for the collision of many gravels of an average grain size.

(Reference) The following shows the possible allowable value for deformation under trial at present.

- ① For a permeable dam of an A-frame structure whose steel pipes are filled with concrete, the maximum allowable magnitude of deformation for the structure shall be 2% of the height of frame.

- ② For a partial deformation of vacuum steel pipes,

$$\text{when } D/t \leq 40, \delta < 20 \delta_E$$

where D: outer diameter of steel pipe, t: thickness of steel sheet, δ : deflection or a partial deformation of the structure at the rotational angle, δ_E : deflection at the yielding time of members or the rotational angle.

The kinetic energy of boulder is obtained by the following formula:

$$E = \frac{1}{2} m U^2$$

where E: kinetic energy of boulder, m: mass of boulder, U: velocity of debris flow.

(4) Size of Openings

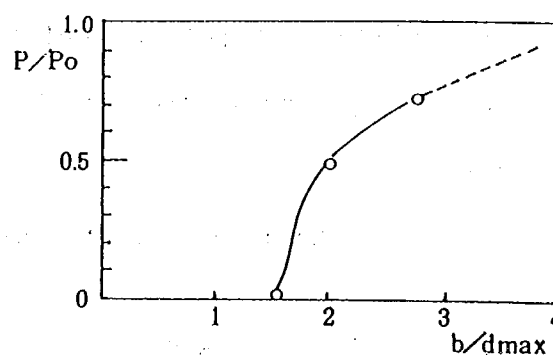
The size of the openings of permeable dam is determined by the maximum grain size of debris flow and by the purposes of the facilities.

[Comment]

Field surveys on the grain size of sediments predicted to run off as a debris flow are conducted on the torrent bed upstream of the project dam site as well as on each torrent bed 200m downstream of the dam site. The grain size frequency distribution of approximately over 100 boulders is studied and the maximum grain size of debris flow shall be the accumulative curve of about 95%.

If the size of the openings of permeable dam is smaller than 1.5 times the maximum diameter of gravels, the dam will certainly be clogged when debris flows occur. But if it is bigger than 2 times the maximum diameter of gravels, the dam will not be clogged. As a result, in an attempt to trap the debris flow surely, the size of the openings is to be less than the diameter of the largest boulder inside a debris flow. When it aims at trapping only the boulders or at reducing the peak volume of sediment only, the size of the openings is to be about twice the diameter of the largest boulders inside a debris flow.

(Reference) Experiment on the rate of decrease in peak discharge of sediment³⁾



The relationship between the size of openings (beam interval) and decrease rate of peak discharge of sediment (P: peak discharge of sediment, P_o : peak discharge of sediment where there is no facilities, b: size of openings, d_{max} : maximum grain size)

(5) Members and Construction

Since permeable dams (including dams having large conduits) are likely to be repeatedly hit by sand and gravel for a long period of time the steel members and structure shall be selected in a such a way that wear or partial damage will not critically affect the entire structure.

[Comment]

Shock absorbing materials shall be put to use if necessary for steel members which are constantly hit by gravels.

(6) Apron Protecting Works

The apron protecting works of permeable dams are planned as required so as to maintain the stability of the dam body for the design object discharge under the state in which the permeable sections are clogged.

[Comment]

The apron protecting works suitable for impermeable dams shall be necessary if 1) scouring due to the subsequent flow of the trapped debris flow is predicted, 2) a difference in height exists between the lower end of the permeable section and the surface of torrent bed, and 3) the ratio of permeable area is small. Energy dissipators or counter dams are planned after their necessity has been fully examined.

(7) Wing

The wing of permeable dam may also be permeable, provided that the bank erosion on the downstream of dam is thoroughly considered.

2.7 Removal of Stones

If the removal of stones after the completion of debris-flow capturing works is deemed necessary, the method of removal is then examined.

Section 3. Debris-flow Training Dykes

3.1 Cross Section

In planning the cross section of debris-flow training dykes, the discharge and water depth of debris flow (refer to the Basis of Debris-flow Countermeasure Plan 2.6.2, 2.6.3) are taken into account and the freeboard shall be added on top of these.

Inundation due to the moving upstream of deposition which started at confluences downstream has to be prevented.

[Comment]

After multiple dams of debris-flow capturing works or the debris-flow depositing works have been built, the debris-flow training dykes are planned to be connected to these dams in order to guide the debris flow to a safe place.

The design discharge is determined on the assumption that the peak discharge of sediment will decrease by the ratio of the design sedimentation volume to the design sediment discharge which is dealt with in the design of the facilities arrangement plan of the entire torrent. However, it should not be less than the discharge of water alone obtained from precipitation plus its 10% of sediment content.

The width of the training dyke should be larger than twice the diameter of the largest boulder inside the debris flow or more than 3m in principle. In addition, ordinary channel works (River Sabo Technical Standard (Draft), Chapter 12, Section 6) shall be planned if the design debris flow is sufficiently coped with in the upper reaches.

The freeboard shall be as follows:

<u>Discharge</u>	<u>Freeboard (ΔH)</u>
Less than 200 m ³ /s	0.6 m
200 to 500 m ³ /s	0.8 m

However, values greater than those shown below should be maintained depending upon the gradient of riverbed.

<u>Gradient</u>	<u>$\Delta H/H$</u>
More than 1/10	0.5
1/10 to 1/30	0.4
1/30 to 1/50	0.3

3.2 Shape of Alignment

The alignment of debris-flow training dykes shall be as straight as possible.

[Comment]

The width of the channel (b) and the radius of curvature of the bend portion (r) shall have the following relationship.⁴⁾

$$b/r \leq 0.1, \text{ central angle of less than } 30^\circ$$

3.3 Longitudinal Alignment

Acute changes in the gradient of the longitudinal alignment of debris-flow training dykes should be avoided whenever possible. It shall be a reliable structure for the case in which the upstream movement of deposit from a confluence with the main river or from a point of change in gradient is expected.

3.4 Construction

(1) Torrent bed

The channel shall be formed by excavation in principle.

(2) Bent portion

The height of revetment is determined for the bent portion by taking into account the rise in water level at the outer bent side.

[Comment]

It shall be a structure which can safely let flow the rise of water level predicted by theoretical values, measured values and the test results. In a debris flow, the maximum water level $h(\text{out})_{\text{max}}$ at the outer bent side will exceed $h_0 + 10 \frac{bu^2}{rg}$. The maximum water level at the outer bent side in alluvial fan where an ordinary channel is built shall be obtained by the following formulae:

For sediment flows:

$$h(\text{out})_{\text{max}} = h_0 + 2 \frac{bu^2}{rg}$$

For fresh water (hypercritical flow):

$$h(\text{out})_{\text{max}} = h_0 + \frac{bu^2}{rg}$$

where h_0 : water depth at straight portion (m), b : width of channel, u : mean velocity (m/s), r : radius of curvature in the center of channel (m), g : acceleration due to gravity (9.8 m/sec²).

Section 4. Debris-flow Depositing Works

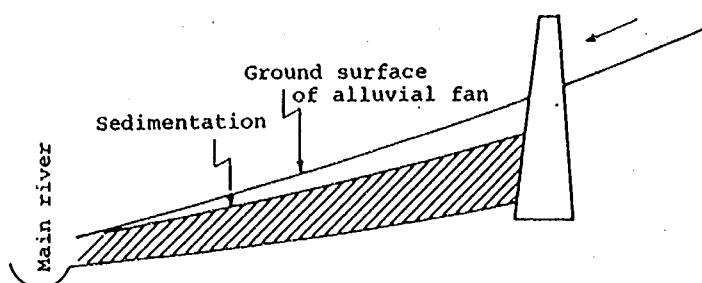
4.1 Debris-flow Depositing Channels

(1) Debris-flow Depositing Channels

The channels in alluvial fans for depositing big quantity of sediment may have a gentle gradient that will not cause the deposition of sediment during ordinary discharge.

[Comment]

Refer to figure.



(2) Removal of Stones

If sediment is deposited due to debris flows within the debris-flow depositing channels, the deposited sediment shall be immediately removed.

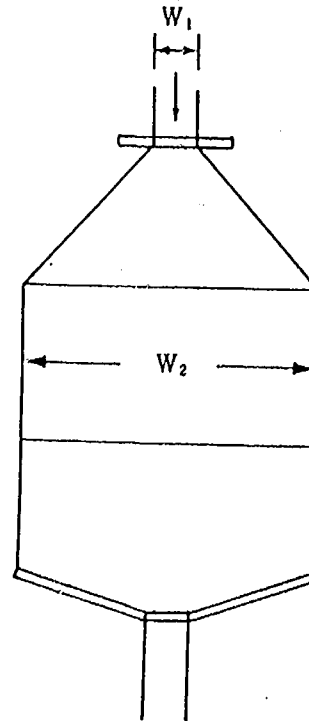
4.2 Debris-flow Dispersing and Depositing Areas

(1) Shape

Debris-flow dispersing and depositing areas shall be properly designed by fully recognizing the topographic characteristics.

(2) Design Sedimentation Gradient

1/2 to 2/3 the gradient of the present torrent bed shall be the standard for the design sedimentation gradient of the debris-flow dispersing and depositing areas.



(3) Design Sedimentation Volume

The design sedimentation volume is obtained from the condition of sedimentation at the gradient of design of sedimentation.

(4) Construction

Dams or groundseils are installed upstream or downstream of debris-flow dispersing and depositing areas, and revetment works or groundseils are provided as required.

[Comment]

The width of the debris-flow dispersing and depositing areas (W_2) shall be about 5 times the width of the channel upstream (W_1) as a rule.

(5) Removal of Stones

The removing method is examined beforehand for the removal of stones after sedimentation has occurred.

(6) Works for Restricting the Occurrence of debris flows

It is a method of restricting the occurrence of debris flows. Dams, terraced dam works, ground sills, hillside works can be used.

New kinds of facilities and methods are likely to be proposed in future but they should be employed after they have been thoroughly examined through laboratory and field tests and so forth.

Section 5. Debris-flow Dispersing Forest Zones

The debris-flow dispersing forest zone is located near the end of a debris-flow depositing area for the purpose of checking the debris flow.

Tree species and the growing density should be thoroughly examined.

When the volume of sedimentation and the grain size are big, it is desirable to combine the structures of public works to fully utilize their effects.

Section 6. Debris-flow Direction Controlling Works

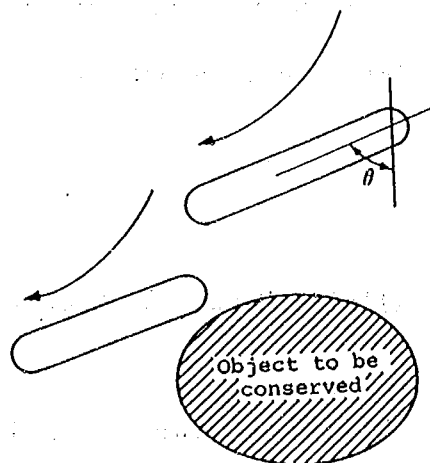
These are employed for controlling the direction of debris flows by means of levees, for which a sufficient height not causing overflow is provided and the scouring of the waterside slope should be prevented.

[Comment]

The height shall be the water depth of debris flow plus the freeboard.

(refer to 3.1)

The levee crown of the direction controlling works shall be parallel to the gradient of the present torrent bed. The angle (θ) of the direction controlling works shall be less than 45° .



Section 7. Works for Restricting the Occurrence of Debris Flows

7.1 Works for Preventing the Movement of Sediment Deposited on Torrent Beds

A method which prevents the movement of sediment deposited on torrent bed by low dams.

[Comment]

In principle, it shall be a structure which will not be hit directly by the impact force of debris flow with back filling up to the crown of the upstream side of dam. It shall avoid the damages incurred by debris flows whenever possible by the embankment of sediment on the upstream side of the wing section as well. The object of design shall be the hydrostatic pressure alone without considering the impact force of debris flow.

It can be made of concrete or steel crib. The spillway section is based on the Debris-flow Countermeasure Facilities Plan 2.5(6). The width of the spillway is made as wide as possible, taking the topography into account. The freeboard for the peak discharge of debris flow may be neglected in principle. Other concrete-made design shall be in accordance with the impermeable dams in Section 2.5 of the Debris-flow Countermeasure Facilities Plan.

7.2 Hillside Works for Restricting the Occurrence of Debris Flows

Hillside slopes shall be stabilized by means of vegetation or structures of public works.

[Comment]

Methods of drainage, sheathing and cultivation are employed to prevent hillside collapses which may turn into a debris flow.

Section 8. Maintenance

It is necessary to inspect the conditions of sedimentation on dams regularly and after freshets in order to obtain the best functions of the countermeasure facilities against debris flows.

[Comment]

The debris-flow capturing works become more effective as the sediment trap capacity increases. Therefore, the conditions of sedimentation on dams should be inspected regularly or after freshets.

Permeable dams shall be so maintained as to prevent the clogging by driftwood etc.

After the occurrence of debris flows, the damages on the facilities should be surveyed and the necessary measures should be carried out.

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TECHNICAL STANDARD
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