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MEASURES AGAINST DEBRIS FLOW ON ROADS

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**SABO (EROSION CONTROL) DIVISION
SABO DEPARTMENT
PUBLIC WORKS RESEARCH INSTITUTE
MINISTRY OF CONSTRUCTION**

Asahi 1—banchi, Tsukuba-city, Ibaraki-ken, 305 Japan.

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MEASURES AGAINST DEBRIS FLOW ON ROADS

by

Akio YAZAWA

Takahisa MIZUYAMA

Synopsis:

Mountainous areas occupy much of the land in Japan. This morphological feature inevitably leads to frequent constructions of roads on a steep topography. Since debris flow easily occurs in the mountains due to heavy rainfall, and damages are often incurred on roads, it is an important task to protect the roads from debris flows and to guarantee the safety of road traffic.

This pamphlet relates the general technical guideline concerning the survey, design and construction, and maintenance management of various measures against debris flow on roads. These sections are excerpted from the "Manual for Slope Protection of the Highway Earthwork Series" published by the Japan Road Association.

Key Words: Debris flow, debris-flow disasters on roads, survey, design, construction, maintenance management, measures against debris flow.

PREFACE

This pamphlet is a translation of the section of 'Measures against Debris Flow' excerpted from the "Manual for Slope Protection of the Highway Earthwork Series" published by Japan Road Association in 1986. Thanks are extended to Mrs. Edith Li for her translation.

SABO (EROSION CONTROL) DIVISION

Former Division Head: Akio YAZAWA

Division Head: Takahisa MIZUYAMA

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1. INTRODUCTION

1.1 An Explanation of Terms

1- Debris Flow

A phenomenon in which sediments and boulders in mountain torrents being fluidized by surface or subterranean water start to flow down usually with great energy and destructive power.

Easy to occur in steeply-sloped torrents where there is an accumulation of big volume of gravels as well as when there is great danger of slope collapse accompanying heavy downpours.

2- Debris Flow Countermeasure Works

A general term for the improvement of roads in order to mitigate or prevent road damage confronting a debris flow, and the countermeasure works in areas where debris flows occur, in transportation and deposition zones when the improvement of the road itself as an answer becomes difficult.

1.2 Related Ordinance

1- Erosion Control Law

As an aim to prevent such happenings as when the production and discharge of sediments mainly from torrent and slopes that range out from it exert a bad influence on flood control. For this reason, erosion and flood control facilities are required. Besides, as lands which need prohibition or restriction of certain actions, some specified erosion control areas are being set up. It is necessary to receive permission in order to carry out road construction on the specified erosion control areas.

1.3 The Forms of Occurrence of Collapses, Landslides and Debris Flows

Collapses, landslides and debris flows etc. are so-called sediment disasters as a general term. They are classified as shown in Fig. 1.1. However, when cutting becomes the direct cause and induction of landslide and slope failure, it is difficult to make a clear division between deep cutting collapse in (B) and slope failure, as well as between collapse that extends to a deep and wide scope in (C) and landslide respectively.

Besides, when filling was done on the head of an old landslide site, it often gives rise to filling slope collapse. Nevertheless, in the case of such collapse, it is common to include it into landslide rather than considering it as collapse including ground foundation in (F).

Collapse (in a broad sense)	Collapse of the face of slope	cutting slope	— shallow cutting collapse — deep cutting collapse — collapse that extends to a deep and wide scope
		filling slope	— shallow filling collapse — deep filling collapse — collapse including ground foundation
	slope failure	— surface slope failure — deep slope failure	
	rockfall	— slip-off type (boulder type) rockfall — exfoliation type (floatstone type) rockfall	
Landslide	— rockbed landslide — weathered rock landslide — colluvial deposit soil landslide — cohesive soil landslide		
Debris Flow	— debris flow triggered by the mobilization of soil and gravel deposition on the bed of torrent — debris flow triggered by the mobilization of earth and sand of hillside collapse — debris flow triggered by the collapse of landslide dams — debris flow triggered by the mobilization of earthlump from landslide		

Furthermore, even among surface slope failure in (G) which is a small-scale slope failure, the type that contains mainly rock resembles a rockfall. And there is no definite division between the two. And rockfall does not only occur on the face of slope but also on cutting slope.

Moreover, the model map and explanation by classification of debris flows are shown on the reference table 1.1 at the end of Chapter 1.

1.4 The Forms of Debris Flow Occurrence

Debris flow is the soil from the bottom of valley and from its upstream section which flows out from the valley after being triggered by downpours, thaw and earthquake. Its forms of occurrence in connection with roads are mainly four types as follows:

- ① Debris flow that is triggered by the mobilization of soil and gravel deposition on the bed of torrent. (O)

Debris flow that runs as water is supplied to the soil and gravel depositing on steeply-sloped torrent bed by downpour, abrupt thaw and so on.

- ② Debris flow that is triggered by the mobilization of earth and sand of hillside collapse. (P)

While the soil of hillside collapse falls down from the face of slope, its structure comes to pieces, gets mixed with water and becomes fluidized. In this case, it is difficult to distinguish such type of debris flow from slope failure.

- ③ Debris flow that is triggered by the collapse of landslide dams. (Q)

Collapsed debris dams up the torrent for a while and builds a landslide dam. Water runs over and erodes the landslide dam, or the landslide dam collapses and becomes a debris flow.

- ④ Debris flow that is triggered by the mobilization of earthlump of landslide. (R)

Mainly the viscous earthlump of landslide with high moisture ratio fluidizes and becomes a debris flow.

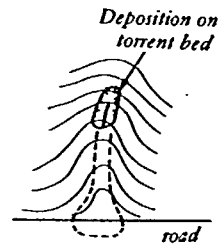
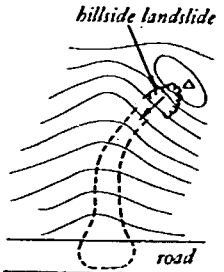
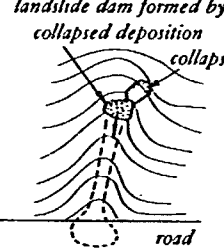
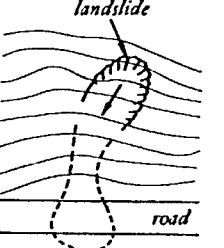
For an occurrence of a debris flow, it is necessary to satisfy the three factors of steep gradient, sufficient water and movable soil. Most debris flows occur on the bed of torrent of over 15° in grade. Nearly all stop and deposit on the section of below 10° to over 3° in grade. However, fine-grained sediments may further reach up to the section of gentle gradient.

Debris flow mostly contains boulders, great quantity of tree trunks, branches and leaves other than water and soil. When boulders are contained, they tend to center on the front part of the debris flow. This is called the phenomenon of coarsenization. Before

the debris flow arrives, the torrent generally has a fairly small discharge. Discharge increases abruptly along with the arrival of the debris flow.

For debris flow with high proportion of gravel (the gravel-type debris flow), its velocity ranges from a few meters per second to the extent of 10 meters per second. For debris flow in volcanic regions, depending upon the moisture ratio, its velocity ranges from fairly slow to even 15 - 20 m/sec. Moreover, the wave height of debris flow is generally below 3 meters.

Table 1-1: Forms of Debris flow Occurrence.

Types of Debris Flow	Explanation	Model Map
(O) Debris flow triggered by the mobilization of soil & gravel deposition on the bed of torrent.	Debris flow that runs as water is supplied to the soil and gravel depositing on steeply-sloped torrent bed by heavy rainfall, abrupt thaw and so on.	
(P) Debris flow triggered by the mobilization of earth & sand of hillside landslide.	While the soil of hillside landslide falls down from the face of slope, its structure comes to pieces, gets mixed with water & becomes fluidized.	
(Q) Debris flow triggered by the collapse of landslide dams.	Collapsed soil dams up the torrent for a while and builds a landslide dam. Water runs over and erodes the landslide dam, or the landslide dam collapses to become a debris flow.	
(R) Debris flow triggered by the mobilization of earthlump of landslide.	The viscous earthlump of landslide with high moisture ratio fluidizes.	

2. SURVEY

2.1 Reading of topographical maps and aerial photos

On the track of debris flow, generally on the section of a torrent, a continuous distribution of vegetation discharge, crop up of bedrock and eroded cliffs can be seen. Besides, at the exit of the torrent where there is much deposition of rocks and gravels, a gently-sloped alluvial fan of 10 to 15 degrees in gradient can be found. On the upper reaches of the torrent, collapses which supply sediments to or trigger the debris flow, and landslides mostly occur. When there is a gently-sloped section on the torrent, sediment deposits temporarily. Since there is the danger of sediment discharge in the future, it is necessary to take precaution.

The above characteristics are comparatively obvious on the new track of debris flow. However, along with the passing of time, they become obscure due to the regrowth of vegetation and the weathering and erosion of soil. Since debris flow tends to re-occur, it is necessary to pay sufficient attention to the old track of debris flow as well.

Table 2.1: Topographical conditions of debris flow and its characteristics on aerial photos

Explanation of topography	Landform produced by the materials of slope failure which gather on the bottom of valley, run down with water and then deposit on the gently-sloped middle or lower reaches.
Location	On torrents.
Approximate inclination	Source of occurrence: over 15° Deposition zone: 3° ~ 10°
Composition of materials	Disorderly deposition of rocklumps of various sizes, pebbles, gravels, sand and mud.
Color tone on photos	Although new debris flow appears whitish on photos, sometimes it is difficult to distinguish it from the ordinary depositions on the bed of torrent.
Gist of reading	Pay attention to the debris flow deposition seen on the exit of torrent where debris flow occurred in the past.

2.2 Field Survey

The occurrence of debris flow is complicated by the conditions of slope, torrent and rainfall. And when compared with landslides and collapses, debris flows mostly extend to a longer territory. Points of attention of the field survey concerning debris flow are as follows:

① The entire topographical condition

The relationship of position between the occurrence, movement, scope of deposition of debris flow, gradient of slope and torrent and the planned route etc.

② The source of occurrence

The state of collapses, landslides and so forth on the source of occurrence of debris flow, the thickness-distribution-gradient of weathered layer, unconsolidated layer, deposition of collapsed soil, talus cone on banks and bed of torrent.

③ Transportation reach

The gradient, width of torrent, state of bank erosion of torrent, distribution of rocklumps, vegetation etc.

④ Deposition area

Thickness and distribution of debris flow deposition, grain-size distribution of rock and gravels, rock type, condition of vegetation growth etc. on the exit of and along the torrent.

2.3 Application of the Results of Preliminary Survey

Debris flow is easy to occur on the bed of torrent of more than 15° in gradient with over 5ha of water catchment area where there is movable depositional gravels, or where there is danger of comparatively big hillside collapse on the upper reach. The danger of debris flow occurrence may be thought high especially on torrents with a record of debris flow occurrence in the past and on torrents with existing identifiable sediment of old debris flow.

When there are torrents with the danger of debris flow occurrence on the planned route, the ways to cope with them by traffic regulations according to the degree of importance of roads and by the countermeasure on road structures (section scale-up of bridges and culverts, strengthening of road structures and so on) are examined.

2.4 Survey of Debris Flow

1- Points of Observation

The surveys of debris flow include:

- ① Survey to distinguish the places which have the possibility of debris flow occurrences.
- ② Survey to presume the frequency of debris flow occurrences.
- ③ Survey to presume the conditions of rainfall that cause debris flow occurrences.
- ④ Survey to presume the scale and nature of debris flow to occur.
- ⑤ Survey to presume the flood area of debris flow.
- ⑥ Survey concerning items like the presence of existing erosion and flood control facilities.

2- Survey concerning debris flow occurrences

(i) Survey of predicted places of debris flow occurrences along the route.

In a depressed topography where rain water collects, a torrent where running water exists at least when rain falls, with a gradient of over 15° on the torrent bed, and a catchment area of over 5 ha on the upstream from the point where the torrent bed has a gradient of 15° , when there are depositions that may become a debris flow on the torrent bed, all these conditions are used as a yardstick in the survey of predicted places of debris flow occurrences. Debris flow occurs from about once in several scores of years to once in every 200 to 300 years on a general torrent. Especially if it is not a place that has been greatly changed artificially, there is almost no torrent where debris flow will occur for the first time in the future, and usually there was sediment runoff in the past. Therefore, if a survey is conducted near the valley exit of the area concerned, the scale of the debris flow, the grain size of the gravels it contained, the extent of sediment runoff and deposition can be known.

Besides, even if the catchment area is less than 5 ha on the upstream from the point where the gradient of torrent bed is 15° , judging from the geology, spring water and collapse record of the area concerned, when there is probable occurrence of comparatively large hillside collapse, the area may be considered as a predicted place of debris flow occurrences. The above work is expected to be rectified by field survey after a general examination of topographical maps and aerial photos.

(ii) Survey of the frequency of debris flow occurrences

The time and frequency of recent debris flow occurrences on the torrent in question are found out from data of past disasters, information obtained by inquiry and field survey.

(iii) Survey to presume the conditions of rainfall that bring about debris flow occurrences

Divide areas by considering the similarity of rainfall conditions. Collect data concerning rainfall that caused debris flow occurrence in the past and downpour which did not lead to such. Find out the conditions of rainfall for the boundary between the presence and absence of debris flow occurrences.

When there is no rainfall which caused debris flow occurrence inside the area concerned, the maximum rainfall is to be taken as the provisional rainfall condition for debris flow occurrence. On the other hand, make use of information of other areas which have similar topography and geology.

As methods of arranging the data of rainfall, for rainfall which caused debris flow occurrence, plot on the graph the relationship between total precipitation until the time of debris flow occurrence and the most intensive precipitation (per 30 minutes or per hour) corresponded to debris flow occurrence, and for rainfall which did not cause such, plot that between total precipitation and the most intensive precipitation. Draw the curve which separates the zones of occurrence and of no occurrence, and take it as the boundary line of debris flow occurrence. (Fig. 2-1)

When sufficient data of the area in question cannot be gathered, it is desirable to carry out temporary analyses of neighboring data and improve on them up to the stage when appropriate data are collected.

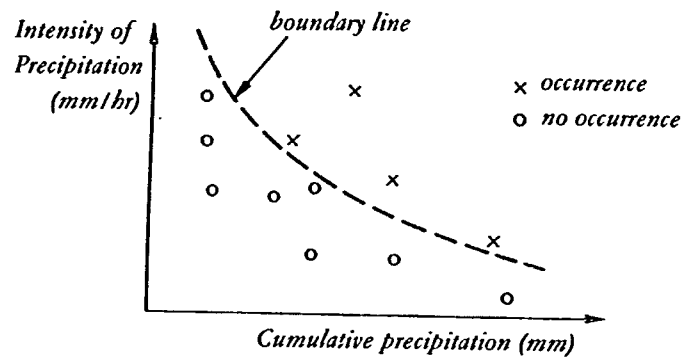


Fig. 2-1: Rainfall conditions for debris flow occurrence (conception map).

Note 1) For cumulative precipitation ($\Xi \sum_{i=0}^n \alpha_i \gamma_i$, where γ_i : hourly precipitation before i hours, α_i : coefficient, n : beginning time period of rainfall in regard to debris flow occurrence) may be used.

3- Survey concerning the presumption of scope and nature of debris flow

It is necessary to presume the scope (sediment yield), peak discharge and velocity of debris flow etc. in order to review the scale and arrangement of debris flow countermeasure works.

It is possible to presume the sediment yield of debris flow and the maximum grain size by field survey. However, the peak discharge, velocity and unit volume weight of debris studies of the average debris flow and on-the-spot observation. If there are records of a debris flow occurred near the torrent in question, it is good to refer to them when making presumption after the topographical and geological similarities are confirmed.

(i) Sediment yield

For the sediment yield as a debris flow, it is as a rule to presume the volume of sediment on torrent bed from the watershed to the valley exit by field survey. Since the thickness of sediment on torrent bed of most debris flows is about 1.5 - 2.0m, length of the valley is read from topographical map and sediment yield can be estimated by multiplying the presumed width of torrent bed by the above thickness of deposition. Further, carry out seismic prospecting and test boring when necessary.

(ii) Maximum grain size of debris flow

For the maximum grain size of debris flow, carry out field survey of sediment on torrent bed predicted to flow out as a debris flow, study the grain size frequency distribution of approximately over 100 gravels and take the cumulative curve of 95% as the maximum grain size.

4- Presumption of debris flow flood area

On the lower reaches of predicted place of debris flow occurrences, presume the transportation zone and flood zone of debris flow.

Debris flow is assumed to deposit on the flat valley bottom and fan-shaped land of the present topography. Though the valley exit is generally taken as the starting point of deposition, depositions sometimes occur on the section of gradient of below 15° on the torrent bed where the width of the channel suddenly widens or narrows and where the slope suddenly becomes gentle.

5- Preparation of an inspection map of predicted places of debris flow occurrences

It is desirable to draw up an inspection map of predicted places of debris flow occurrences with predicted flood zone jotted down. Put down also the established erosion and flood control facilities and as for the existing roads, it is good to study and enter the places necessary to be improved beforehand.

3. DESIGN AND CONSTRUCTION METHODS

3.1 Basic concept of measures against debris flow

Forms of disaster on roads stricken by debris flow are as follows:

(i) Occurrence zone of debris flow.

Part of the road collapses along with the occurrence of debris flow. However, this case is generally the same as collapses of face of slope, slope failure or landslides.

(ii) Transportation and deposition zones of debris flow.

① Because of the insufficient width of culvert and bridge, gravels and driftwood inside the debris flow are trapped. As culvert and bridge are blocked, a portion of the debris flow stops and deposits. Flood occurs there as the starting point. As a result, sediment deposits on road and then collapses due to the water flowing on it.

② Bridges are washed away by the debris flow.

(iii) Others.

Debris flow that once passed through the road safely starts to deposit on the downstream. Such depositions upwash toward the upper reaches. As a result, the road is flooded and buried under sediment. When the road passes through certain places of predictable debris flow occurrence, it is as a rule to set up routes outside the debris flow flood zone. When it is unavoidable to pass through it, bridges with sufficient clearance are expected to do so. When there is high frequency of debris flow occurrences or in case when debris flow did occur, it takes long time to repair, the road function is impeded considerably (when the mountain road has no alternative route), and great damage is incurred on adjacent structures, appropriate measures like submergence roads, debris flow shed and culverts with sufficient width for the passage of debris flow are carried out. As for the other roads, it is common to employ only traffic regulations according to needs.

When the change of route or improvement of the road itself cannot be the answer, it is necessary to control the debris flow by dams and so on. However, in this case, adjustment with other projects such as erosion and flood control works is carried out in full. Further, as for areas including certain places of predictable debris flow occurrence, it is as a rule to carry out traffic regulations when rainfall which causes the occurrence of debris flow is predicted and when road which will be damaged by debris flow is predicted. Moreover, in torrents where the frequency of debris flow occurrence is high, when the

occurrence of disasters on road along with the occurrence of debris flow is predicted, traffic regulations are sometimes carried out by debris flow occurrence sensor such as wire sensor.

3.2 Presumption of the scale of debris flow

Presumption of the scale of debris flow is carried out in order to determine the types, scale, arrangement and design conditions of debris flow countermeasure works based on debris flow surveys on each torrent.

(i) Volume of sediment runoff

Volume of sediment runoff as a debris flow can be found out by multiplying the specific volume of sediment runoff (Table 3-1) classified by geology on drainage area to obtain an approximate numerical value besides from the survey concerning presumption of scale and nature of debris flow in 2.3 'Survey of debris flow' (3).

Table 3-1: Reference value of proposed sediment discharge concerning debris flow.
(when standard drainage area is 1km²)

GEOLOGY	REFERENCE VALUE OF PROPOSED SEDIMENT DISCHARGE
The granite zone	50,000 m ³ /km ²
The volcanic eruptions zone	80,000 "
The Tertiary formation zone	40,000 "
The broken belt zone	100,000 "
Other zones	30,000 "

When the drainage area is 10 times the standard, numerical value is 0.5 time, when it is 1/10 of the standard, about 3 times the numerical value can be used.

(ii) Peak discharge

In determining the height of bridges and the cross section of culverts, it is necessary to find out the peak discharge of debris flow. However, there are various forms of debris flow occurrence. It is difficult to presume the peak discharge when the debris flow occurs as the landslide dams collapse after forming from collapsed soil on the upper reach of torrent, or when collapses on hillside occur continuously to become a debris flow.

As for the case of debris flow occurrence where sediment deposited on riverbed becomes unstable, peak discharge is presumed by the following equation.

$$Q_{sp} = \frac{C_*}{C_* - C_d} Q_p \dots\dots\dots (3-1)$$

Where Q_{sp} : peak discharge of debris flow (m³/sec), Q_p : peak discharge of water alone (m³/sec), C_* : concentration of sediment deposited on riverbed, C_d : concentration of debris flow in motion.

Sediment concentration in the balanced state of debris flow is given by the following equation.

$$C_d = \frac{\gamma_w \tan \theta}{(\gamma_s - \gamma_w)(\tan \phi - \tan \theta)} \dots\dots\dots (3-2)$$

Where γ_s : density of debris (tf/m³), γ_w : density of water (tf/m³), ϕ : internal friction angle of debris deposit on riverbed, (degree), θ : gradient of riverbed (degree).

Besides, the peak discharge Q_p of water alone is obtained by the following equation about the limit of rainfall which causes a debris flow.

$$Q_p = \frac{1}{3.6} f \cdot r \cdot A \dots\dots\dots (3-3)$$

Where f : peak discharge coefficient, r : average rainfall intensity during the flood travelling time (mm/hr), A : drainage area (km²). According to the survey of the Debris Flow Observatory of the Ministry of Construction in Sakurajima, the peak discharge Q_p of water alone is 70 m³/sec, Q_{sp}/Q_p is distributing widely from 1 to 20. Also, there is a fairly good correlation between the total volume of debris flow Q_T (m³) and the peak discharge Q_{sp} of debris flow (m³/sec). The correlation is shown by,

$$Q_{sp} = 2 \times 10^{-3} Q_T \dots\dots\dots (3-4)$$

The total volume of debris flow Q_T can also be obtained as the data of the total volume of water found by multiplying the total precipitation by the drainage area.

(iii) Flow velocity and maximum height of water level (wave height)

The movement of debris flow is tentatively explained by applying the models of dilatant fluid and of bingham fluid, though still on the stage of research. Thereupon, the equation of flow by Manning et al. based on the results of the Debris Flow Observatory of the Ministry of Construction in Mt. Yake-dake and Sakurajima is applied correspondingly.

$$V = \frac{1}{n} h^{2/3} (\sin \theta)^{1/2} \dots\dots\dots (3-5)$$

Where V : average velocity of debris flow (m/sec), h : wave height of debris flow (m).

Coefficient of coarseness n is to be 0.03 on fixed channel and about 0.1 on movable bed.

The maximum height of water level on the transportation zone of debris flow is obtained by the equation of peak discharge, velocity and wave height, and from the width of riverbed.

As for the deposition zone of debris flow, same method for the transportation zone is used. However, it is necessary to consider also the phenomenon in which depositions that started on the downstream upwash till the upper reach.

Rises of water level occur on the outer side of the curve where the channel bends. The maximum height of the rise in water level Δh_{max} (m) is presumed to be:

$$\Delta h_{max} = \alpha \frac{b \cdot v^2}{r \cdot g} \dots\dots\dots (3-6)$$

Where b : width of channel (m), v : average velocity (m/sec), r : radius of curvature (m) of bended portion, g : acceleration of gravity (9.8 m/sec²), α : a coefficient, 0.5 for normal stream of clear water, 1.0 for hypercritical flow, but 2.0 for channel on alluvial fan, also up to 10.0 for transportation zone of debris flow along the torrent.

(iv) Unit weight of debris flow

Sediment concentration of debris flow is given by equation 3-2 from which the unit weight of debris flow can be obtained. For the design of structures, when the approximate value of the unit weight of debris flow is needed, 1.8 tf/m may be used.

(v) Maximum grain size of debris flow

The maximum grain size of gravels inside a debris flow is obtained from the results of field survey of past debris flow sediment and of riverbed deposition on upper reach. (refer to survey concerning the presumption of scale and nature of debris flow 3 in section 2.4 'Survey of Debris Flow')

3.3 Selection of debris flow countermeasure works

Measures against debris flow differ according to the types of debris flow (whether a high speed debris flow of mudflow type or that of gravel type) and the frequency of debris flow occurrence. It is as a rule to cross by bridges with sufficient clearance or by debris flow shed and tunnels in debris flow occurrence and transportation zones of torrents where the occurrence of high speed debris flow of mudflow type is predicted as at the foot of a volcano, and where the frequency of debris flow occurrence is high (at least once in every few years' time).

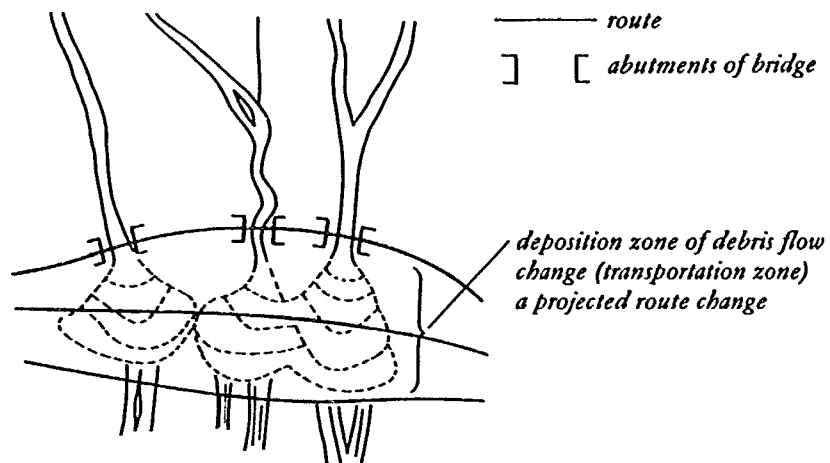


Fig. 3-1: A small shift on the deposition zone of debris flow.

It is as a rule to cross the debris flow occurrence and transportation zones by culverts with sufficient section area and by bridges with sufficient clearance on a general torrent of predictable debris flow occurrence. Since the riverbed change caused by debris flow occurrence is severe on the upper reaches of debris flow deposition zone (over 3° in gradient), it is as a rule to shift the route upstream or downstream and then cross by bridges with sufficient clearance. (Fig. 3-1)

- (a) When the heights of road surface and torrent bed surface do not differ much, the use of submergence road as a measure is also reviewed.
- (b) When the road surface is low in comparison with the height of torrent bed, a debris flow shed is under review.
- (c) In the deposition zone of debris flow, when the riverbed of the alluvial fan is already higher than its neighboring plain, tunnel underneath the river is possible. Further, it is put into consideration when the deposition downstream is predicted to affect the upstream.
- (d) When the improvement of the road itself and so on as an answer is difficult, the following measures are carried out. ① To trap a part of or all the discharge of a debris flow by dams or other structures. ② To check the movement of the sediment on torrent bed which is predicted to run off as a debris flow by low dams. And ③ to remove sediment which is predicted to run off as a debris flow ahead of time.

The above is summarized in Figure 3-2

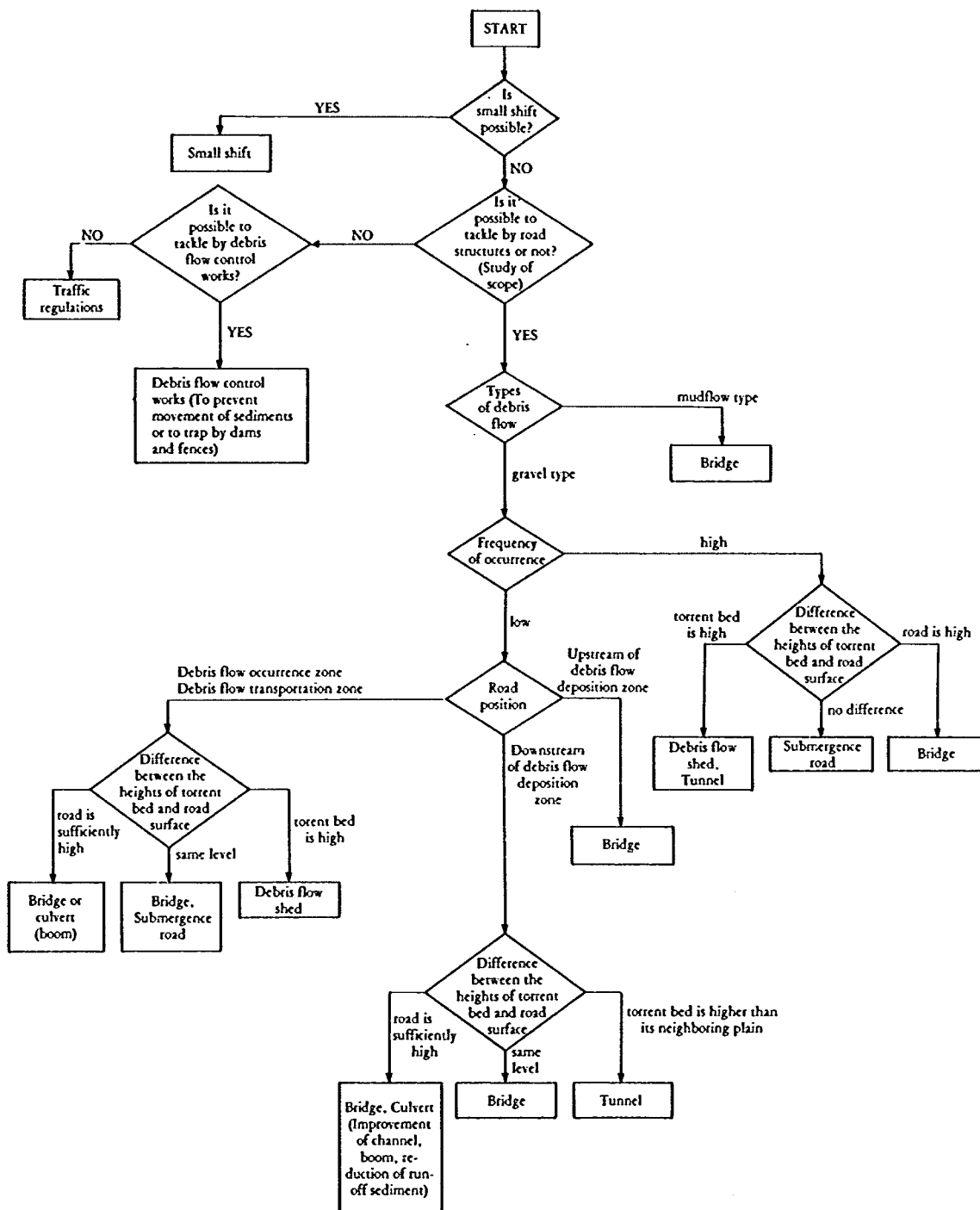


Fig. 3-2: Flow chart of the selection of debris flow countermeasure works.

3.4 Debris flow countermeasure works and some areas of attention

1- Bridges

Plan the cross section which is passable for the peak discharge of debris flow. Determine the height of the bridge girder after adding the marginal height to the wave height of debris flow. It is better not to set up a bridge pier on the torrent bed as much as possible. Besides, take care that the width of channel does not narrow at the section of the bridge. Even when it is unavoidable to construct a bridge pier on the torrent bed, try to avoid the central part so that it won't be damaged by the debris flow.

2- Culvert

In designing the cross section which is passable for the peak discharge of debris flow, items of more than twice the largest grain size of the gravels inside the debris flow both vertically and horizontally are to be used. Care must be taken so that the culvert portion is not narrower than the width of the channel on the upper reaches and that a straight alignment to the upstream channel in order to keep in line with the direction of flow as much as possible is to be maintained. Further, take care to avoid sudden reduction of the section of downstream channel and channel gradient in comparison with the culvert portion.

It is also necessary to pay attention to blockade caused by driftwood. It is desirable to set up booms inside the torrent on the upper reaches when huge quantity of driftwood flow is predicted. (Fig. 3-3)

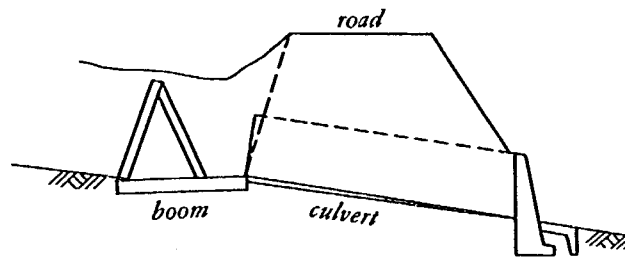


Fig. 3-3 Culvert boom

3- Submergence road

When the height of torrent bed and that of road surface have not much difference in the debris flow occurrence and transportation zones, a structure (submergence road) which is difficult to be ruined even if the debris flow passes through the road surface is to be used. (Fig. 3-4)

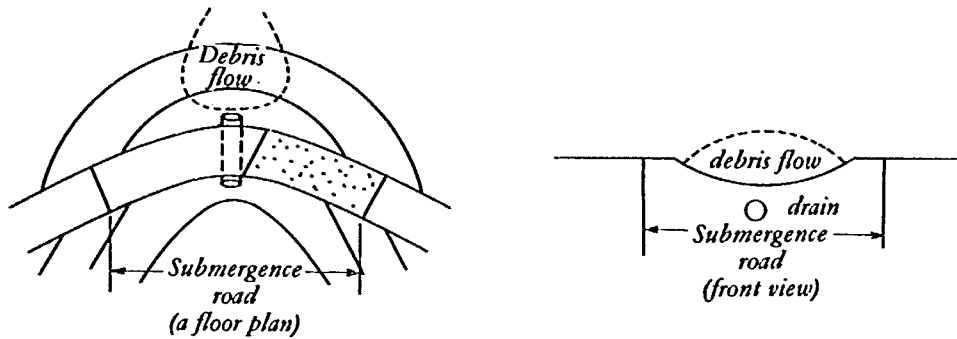


Fig. 3-4: Submergence road

4- Debris flow shed

Debris flow shed is applied correspondingly as a measure against avalanche and rock-fall. It is as a rule to make the gradient of the vertical section about the same as that of the torrent bed upstream. Care is taken so that the sediment does not accumulate on the shed. The width is made identical with that of the torrent bed upstream with marginal breadth on the left and right respectively. (Fig. 3-5) The sidewalls are to be the height of wave height of debris flow on the shed with marginal height added to it, and to lead the debris flow from the torrent to the shed.

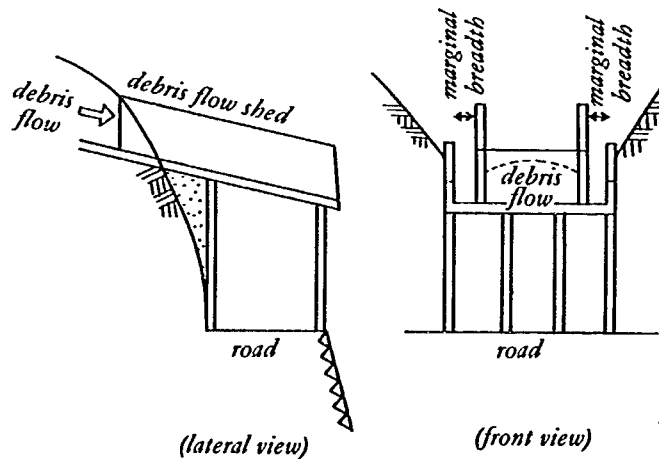


Fig. 3-5: Debris flow shed

5- Removal of dischargeable sediments

When the sediments on torrent bed exist on comparatively thin rockbed, they are to be removed in advance. Take care that the removal works do not trigger slope failure.

6- Trap of runoff sediments by dams and fences

The entire debris flow or boulders and driftwood are to be trapped by one or many dams and by fences. Drainable water and sediments are to be drained off by drainage facilities on road.

Planned gradient of sedimentation is to be $1/2$ that of the present torrent bed. In order to prevent the decrease in sediment storage capacity due to deposition caused by ordinary overflow, it is as a rule to use concrete dams or permeable dams made of steel or fences. Size of the openings is to be less than 1.5 times the biggest grain size. (Fig. 3-6)

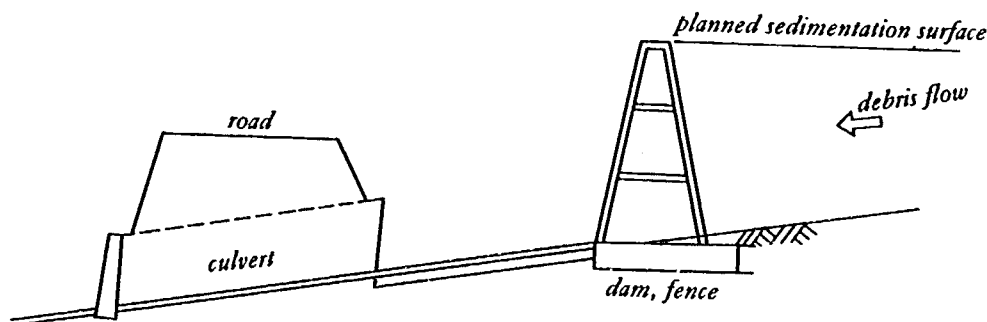


Fig. 3-6: Trap of runoff sediment by dams or fences

7- Prevention of the movement of sediments on torrent bed by dams

Set up many comparatively low dams to prevent the movement of sediments on torrent bed. Dams are to be set up in such a way that the foundation of the dams upstream is on the same level as the planned sedimentation surface of the dams downstream. As materials for dams, there are concrete, steel, ferro-concrete and so on. Which-ever is used, it is to be a structure in which fall, sliding and damage of dams do not arise in regard to dead load, sedimentation pressure, lift-up pressure, hydrostatic pressure, hydromechanics of debris flow etc.

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- 4) Tatsuo Yamazaki, Toichiro Tsubaki, Masao Saita et al.: 'Debris Flow of Sakura-jima', Sakura-jima Area Academic Survey Conference, Survey Research Report, 1980.
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4. MAINTENANCE MANAGEMENT

4.1 Inspection of dangerous torrents of debris flow occurrence

Every year before rainy season and after heavy downpours, find out if there is anything unusual by field survey and aerial observation by helicopter. It is desirable to take actions such as setting up countermeasure works as occasions demand.

4.2 Maintenance of debris flow countermeasure works

Examine whether dams, bridges and culverts are blocked by driftwood and trash, whether there are any depositions of sediment, and whether there are any damages on the structures. Carry out repair of countermeasure works and removal of earth and sand as the need arises.

4.3 Preparation and regular modification of examination maps of predicted places of debris flow occurrence

It is desirable to draw up beforehand examination maps of predicted places of debris flow occurrence which recorded the predicted places of debris flow occurrence and predicted flood zone on topographical maps. It is good to record the existing erosion and flood control facilities as well as places on present roads which need improvement. They are to be modified as the needs of the case demand based on regular survey.

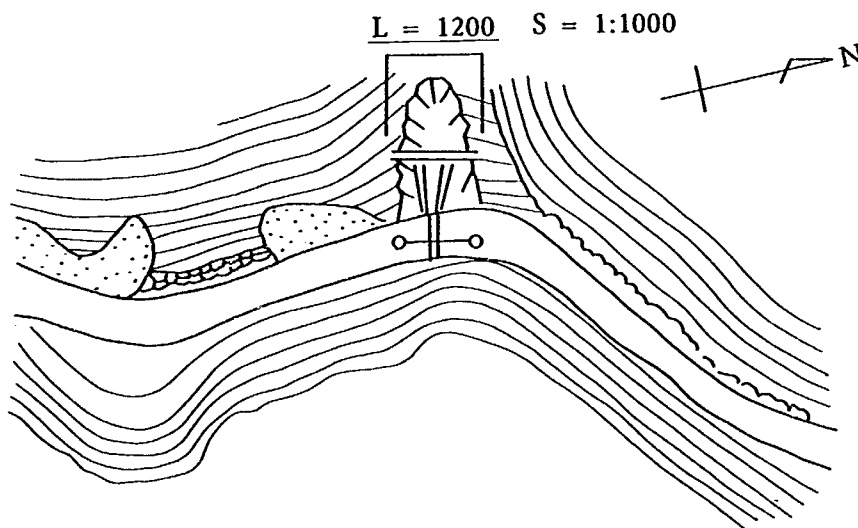
Appendix 1 Example of Disaster Relief.

1- State of debris flow

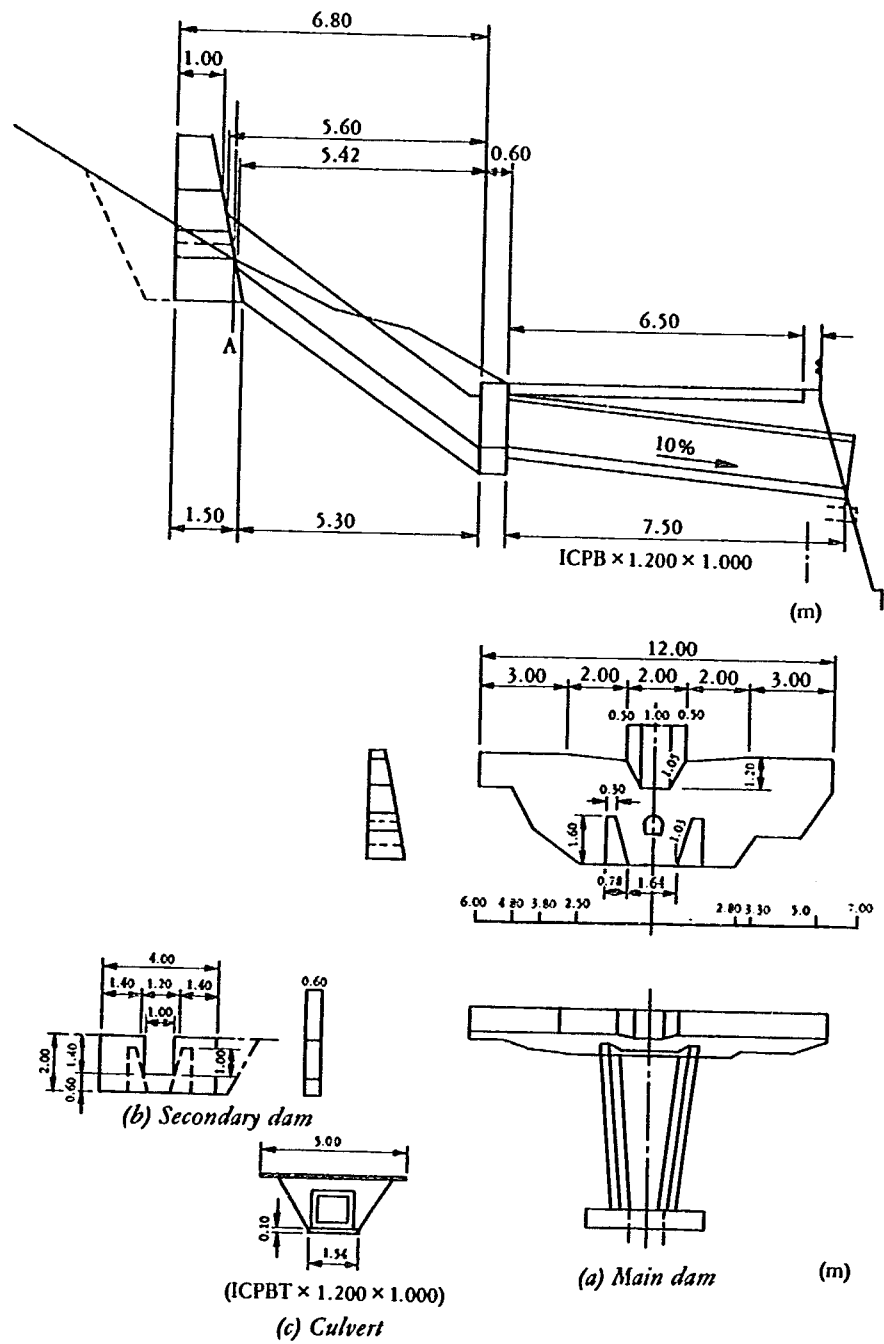
In the San-in downpour disaster of 1983, many debris flows occurred and roads were buried and washed away by sediment.

2- Method of rehabilitation works

In Shimane Prefecture, dams and channels were set up in about 100 spots after the disaster. The dams are structures which cope with sediment discharge due to even small rainfalls after the occurrence of debris flow. In the example shown in the appended Figures 1-1, 1-2, the box culvert was made to slant by 10% in gradient to improve discharge capacity.



Appended Fig. 1-1: Contour map of the restored area



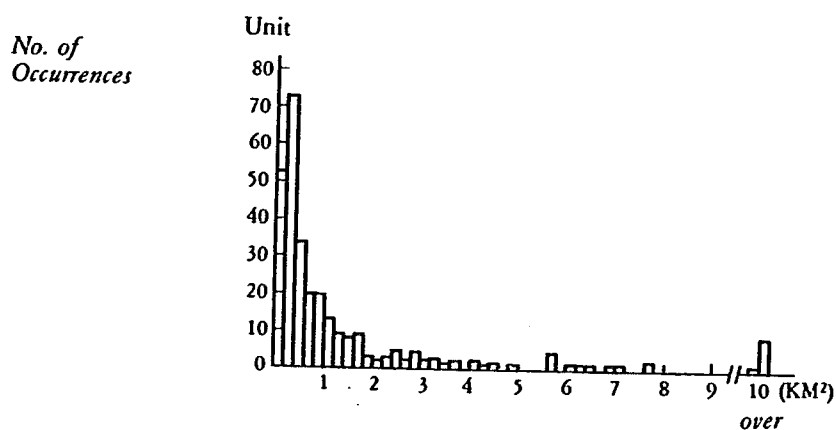
Appended Fig. 1-2: Countermeasure works (Dam).

Appendix 2 Research on the Actual Condition.

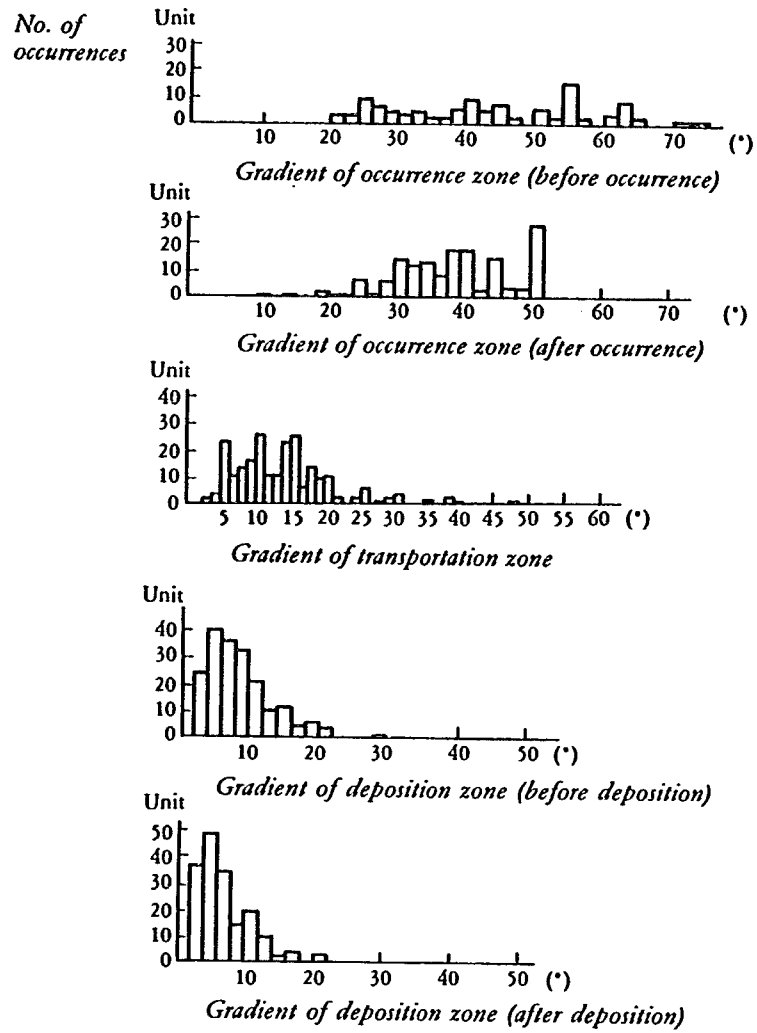
Research results of debris flows which occurred between 1972 — 1977 are shown in the appended Table 2-1 and the appended Figures 2-1, 2-2 and 2-3. Besides, appended Figure 2-4 shows the example of the limit of precipitation in the occurrence of debris flow obtained from the data of rainfall which caused debris flow to occur or not.

Appended Table 2-1: Frequency of debris flow occurrence at each division of rock type.

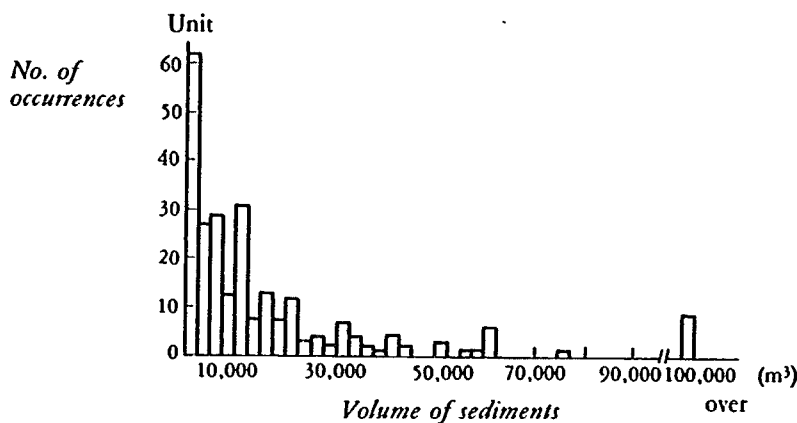
ROCK	No. of debris flow occurrence A		Distribution area of rock B	A/B
Regional metamorphic rock	36	9.3%	3.6%	2.54
Granitic magma	180	46.3%	13.3%	3.48
Basic and ultrabasic intrusive rock	—	—	1.6	—
Volcanic rock of the Tertiary & Quaternary Periods	50	12.9	20.4	0.63
Palaeozoic sedimentary rock	38	9.8	12.2	0.80
Mesozoic sedimentary rock	9	2.3	9.3	0.25
Tertiary sedimentary rock	55	14.1	18.9	0.75
Quaternary sedimentary rock	21	5.4	20.7	0.26
Total	389	100	100	



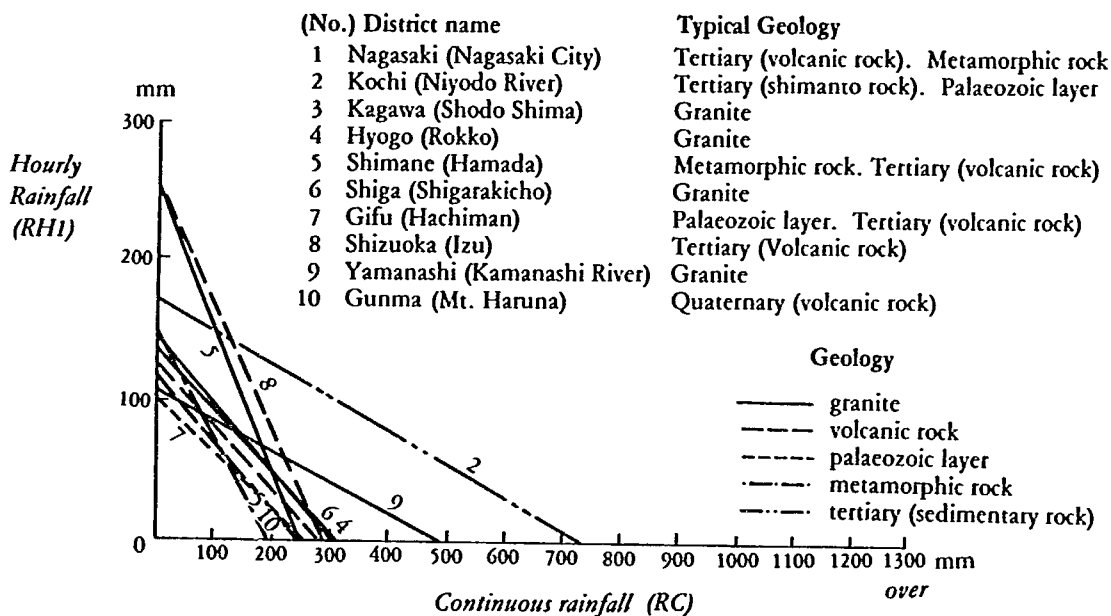
Appended Fig. 2-1: Catchment area of torrents where debris flow has occurred.



Appended Fig. 2-2: Gradient of each zone



Appended Fig. 2-3: Volume of deposited sediments.



Appended Fig. 2-4: Example of the limit of precipitation in the occurrence of debris flow.

References

- 7) Sabo (Erosion Control) Department, Public Works Research Institute, Ministry of Construction, 'Study of the Judgment of the Degree of Danger in the Drainage Area', 32nd Technical Research Meeting of the Ministry of Construction p. 525 — 547, 1979.
- 8) Sabo Division, Sabo Dept., PWRI, Ministry of Construction: 'Study on the Setting up of Standard Rainfall for the Warning and Evacuation of Debris Flow', Technical Memorandum of PWRI, No. 2215, 1985.

MEASURES AGAINST DEBRIS
FLOW ON ROADS

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Sabo Division, Public Works Research Institute

Akio YAZAWA

Takahisa MIZUYAMA

Synopsis:

This pamphlet relates the general technical guideline concerning the survey, design and construction, and maintenance management of various measures against debris flow on roads.

Keywords:

Debris flow, survey, design, construction, maintenance management, measures against debris flow.

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Sabo (Erosion Control) Division
Erosion Control Department
Public Works Research Institute
Ministry of Construction
Government of Japan
Tsukuba City
Ibaraki 305, JAPAN

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