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APPLICATION TO PAST DISASTERS OF A METHOD OF SETTING THE RANGE OF DEBRIS FLOW DAMAGE TO HOUSES

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ABSTRACT

A method of easily predicting the area of land where a debris flow will damage buildings was studied with reference to records of past debris flow disasters, then the method was applied to actual past debris flows (16 cases). The house damage range is the range of the land where the hydrodynamic force of a debris flow exceeds the strength of its buildings. The hydrodynamic force of a debris flow and the strength of houses are calculated at a point on the predicted flow route of the debris flow. In the results, the range of damage to buildings predicted by this method enclosed about 70% of the buildings actually damaged by the debris flows.

Key words: Debris flow, Method for identifying dangerous area

INTRODUCTION

Debris flow disaster occurred evey year, killing people and damaging houses. Photo 1 shows the debris flow disaster occurred on July 11, 2002 in Kamaishi, Iwate Prefecture (Mizuno, 2002). A slope collapsed about 200 m upstream from the damaged buildings, the soil fluidized, then flowed into the residential area, damaging the buildings. Photo 2 shows the debris flow disaster occurred on July 19, 2003 in Dazaifu, Fukuoka Prefecture (Terada et al., 2003). A debris flow plunged into a village, killing one resident and damaging 40 houses.

Photo 1. Damaged house in Kamaishi

Taking measures to prevent or mitigate such debris flow disasters is an urgent challenge. Such measures include physical measures that include constructing check dams or non-physical

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Photo 2. Damaged house in Dazaifu

measures such as warning and evacuation systems. This research has, as shown by the Law Concerning the Promotion of Sediment Disaster Prevention Methods in Sediment Disaster Hazard Zones (below called the "Sediment-related Disaster Prevention Law", Ministry of Land, Infrastructure and Transport, 2001) that was enacted on April 1, 2001, focused on methods of setting the range of hazardous land where the occurrence of a debris flow disaster is predicted, or in other words the range of land where houses will be damaged by a debris flow (below called the "house damage range").

One method of setting the house damage range is a "debris flow inundation calculation."(Takahama, 2001) But throughout Japan, about 180,000 torrents are designated as debris flow hazard torrents etc. (as of 2003). A simple method of setting the house damage range should be established to set the range in these districts in a short period of time. This purpose of this study is to apply debris flow hazard torrent charts and similar existing documents in addition to the flow width setting method obtained from past debris flow disasters based on a method stipulated in an MLIT Notification (Ministry of Land, Infrastructure and Transport, 2001) concerning the Sediment-related Disaster Prevention Law to past debris flow disasters in order to verify the damaged house inclusion percentage, and at the same time, to clarify the impact on the results of the setting of the quantities of debris etc. at a reference point and the quantity carried by a debris flow. This report focuses on the debris flow width setting method and the results of applying it to past debris flow disasters.

METHOD OF SETTING THE HOUSE DAMAGE RANGE

The house damage range is the range of the land where the hydrodynamic force of a debris flow exceeds the strength of its buildings. The hydrodynamic force of a debris flow and the strength of houses are calculated at a point on the predicted flow route of the debris flow (below called the "calculation point").

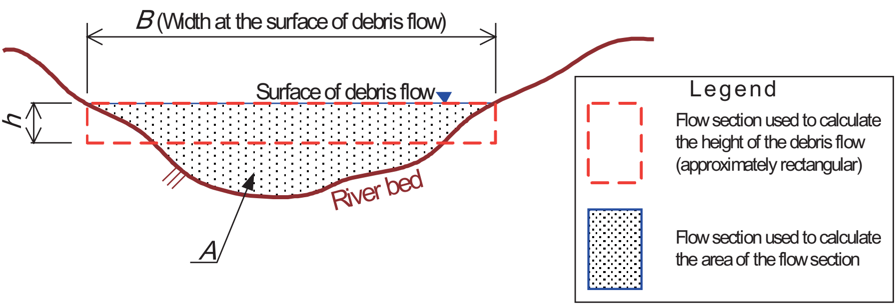


Fig.1 Flow Section of the Debris Flow

Estimation of the hydrodynamic force of debris flow

The hydrodynamic force of a debris flow is calculated by substituting the flow speed of the debris flow obtained from equation (2) and equation (3) in equation (1). Figure 1 shows the lateral section at a certain calculation point. The flow speed of the debris flow is obtained by performing a uniform flow calculation such that equation (2) and equation (3) are satisfied. However, the area of the flow section is assumed to be the area of the range enclosed by the ground and the surface of the debris flow, but the shape of the flow section resembles a rectangle such as the one enclosed by the dotted lines in Figure 1. This means that the wave height of the debris flow is a value obtained by dividing its section area by the width of the surface of the debris flow.

$$F_d = \rho_d U^2 \qquad \text{-----(1)}$$

$$U = \frac{1}{n} \cdot h^{2/3} \cdot (\sin\theta)^{1/2} \qquad \text{-----(2)}$$

$$Q_{SP} = BUh \qquad \text{-----(3)}$$

$$B_{\max} = 4\sqrt{Q_{SP}} \qquad \text{-----(4)}$$

Where:

- U: flow speed of the debris flow (m/s)
- n: roughness coefficient
- h: flow depth of the debris flow (m)
- θ: gradient of slope of the torrent bed (degrees)
- Q_{sp}: peak flow volume of the debris flow (m^3/s)
- B: flow width of the debris flow (m)

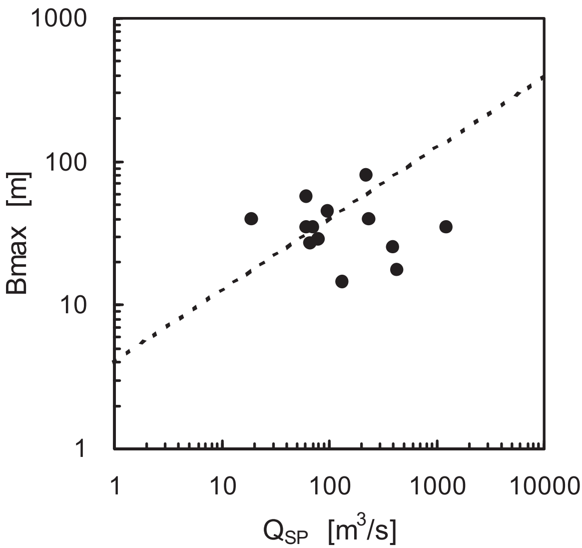


Fig.2 Relationship between peak discharge and maximum flow width

The value of θ is calculated between two points: the calculation point and a point on the flow route separated only by a stipulated horizontal distance upstream from the calculation point. The value of B is the width of the surface of the debris flow, and this surface is assumed to be horizontal.

A study of past debris flow disasters shows that the flow width of a debris flow does not expand to its full width in the lateral direction on an alluvial fan. But if B is calculated by the above method, there are presumed to be cases where, on an alluvial fan, the value of B is identical to the full width of the alluvial fan or cases where it cannot be set. So B is set as the upper limit value (B_{MAX}). In Figure 2, the peak discharge and the flow width of a debris flow hypothesized from records of past debris flow disasters are plotted. Assuming that it is possible to apply a regime type equation, the flow width of a debris flow is represented by equation (4) on the average. Assuming that this equation (4) is B_{MAX}, the uniform flow calculation is performed so that the width of the surface of the debris flow does not exceed B_{MAX}.

Estimation of the peak discharge of debris flow at the reference point

The peak discharge of debris flow at the reference point is computed by Equation (5).

$$Q_{SP0} = \frac{0.01 V_0 C_*}{C_{d0}} \qquad \text{-----(5)}$$

Where:

- Q_{SP0}: peak discharge of debris flow at the reference point (m^3/s)
- V_0: smaller of the volume of deposition on the stream bed (*Ve'*) and the amount of sediment that can be transported by surface flow due to rainfall(*Vec'*)
- C_*: sediment concentration of deposition on the torrent bed
- C_{d0}: sediment concentration of debris flow at the reference point and is computer from Equation (6).

$$C_{d0} = \frac{\rho \tan\theta_0}{(\sigma-\rho)(\tan\phi - \tan\theta_0)} \qquad \text{-----(6)}$$

Where

- ρ: density of water (kN/m^3)
- σ: density of sand (kN/m^3)
- θ_0: slope of the ground at the reference point (degrees)
- ϕ: friction angle of sand (degrees).

Ve' is the maximum value in the flow upstream from the reference point. The flow in this case is the flow along a line drawn upstream from the reference point. *Vec* is computed from equations (7) and (8) (Ministry of Construction, 2000).

$$f_r = 0.05 \cdot (\log A - 2.0)^2 + 0.05 \qquad \text{-----(7)}$$

$$V_{ec} = \frac{10^3 \cdot R_T \cdot A}{1-\lambda} \left(\frac{C_{d0}}{1-C_{d0}} \right) f_r \qquad \text{-----(8)}$$

Where:

- f_r: outflow correction factor
- A: area river basin (km^2)
- R_T: amount of rainfall in 24 hours (mm/24hrs)
- λ: void ratio of deposition on stream bed

Estimation of the peak discharge of debris flow at the calculation points

The peak discharge of debris flow at the calculation points is computed by Equation (9).

$$Q_{SP} = \frac{0.01VC_*}{C_d} \qquad \text{-----(9)}$$

Where:

- Q_{SP}: peak discharge of debris flow at the calculation point (m^3/s)
- C_d: sediment concentration of the debris flow at the calculation point
- V: sediment volume of debris flow at the calculation point (m^3)

C_d is computed by Equation (10).

$$C_d = \frac{\rho \tan\theta}{(\sigma - \rho)(\tan\phi - \tan\theta)} \qquad \text{-----(10)}$$

In general, the reference point is conceived of as being at the apex of the alluvial fan, so the downhill path of the debris flow is considered to be the area where debris is deposited. In other words, it is necessary to consider the deposition of earth and sand when computing V. Assuming that the debris flow has earth and sand concentration C_d and that earth and sand are deposited with the volume concentration C_*, Q_{SP} becomes as in Equation (11).

$$\begin{aligned} &C_{d0} \cdot Q_{SP0} = C_d \cdot Q_{SP} + C_* \cdot (Q_{SP0} - Q_{SP}) \\ &\therefore Q_{SP} = \frac{C_{d0} - C_*}{C_d - C_*} \cdot Q_{SP0} \end{aligned} \qquad \text{-----(11)}$$

Substituting Equations (5) and (9) into (11), and simplifying the expression for V, we obtain an equation that looks like Equation (2.13).

$$V = \frac{C_* - C_{d0}}{C_* - C_d} \cdot \frac{C_d}{C_{d0}} \cdot V_0 \qquad \text{-----(12)}$$

In addition, the downhill flow path of the debris flow which is the object of calculation is a deposition area, so it is unnatural for Q_{SP} to become larger as one proceeds downstream. To prevent Q_{SP} from becoming larger proceeding downstream, if, at (and only at) the time when Equation (12) is calculated, the slope of the land θ_a at a certain point a is greater than the slope of the land θ_b at a calculation point b upstream from point a ($\theta_a > \theta_b$), then we take $\theta_a = \theta_b$.

Estimation of the strength of houses

The strength of buildings (P[kN/m^2]) is calculated by equation (13) (Ministry of Land, Infrastructure and Transport, 2001).

$$P = \frac{35.3}{h(5.6-h)} \qquad \text{-----(13)}$$

In this study, at a point where F_d exceeds P, the house damage range is within the range of the flow width of a debris flow. For the method of calculating the peak flow volume etc. of the debris flow and other items not included in this report, please refer to the documents (Ministry of Land, Infrastructure and Transport, 2001).

APPLICATION TO PAST DEBRIS FLOW DISASTERS

Two new indices are designated for use in evaluating the results of the application. These are the "damaged house inclusion percentage" and the "undamaged house percentage." The damaged house inclusion percentage is the percentage of those houses actually damaged that are damaged houses included in the house damage range that has been set. Damaged houses are houses (dwellings) that are completely or partially destroyed from among buildings damaged by the debris flow. And the undamaged house percentage is a value obtained by dividing the undamaged houses included in the house damage range by the number of houses in the house damage range (total of damaged houses and undamaged houses). Undamaged houses are houses (homes) that were not actually damaged. It is considered to be a highly accurate method that predicts that the higher the damaged house inclusion percentage, the lower the undamaged house percentage.

The method described in the former chapter was applied to 16 past debris flow disasters selected because documents which contain information that is needed for this application and concerns damage related to damage to houses by these disasters are still available. The horizontal line between the two points used to calculate the value of θ was set to provide three measurement distances (10m, 100m, 200m) and the results for the three distances were compared in order to study the impact of this horizontal distance on the damaged house inclusion percentage and undamaged house percentage. The parameters necessary for the calculations were set based on existing documents. The reference points were the exits from the valleys as shown by topographical maps.

Table 1 shows the values for calculations which were applied to 16 past debris flow disasters and the volume of sediment transported by a designed debris flow. In each case the peak discharge of debris flow at the reference point was estimated by using table 1.

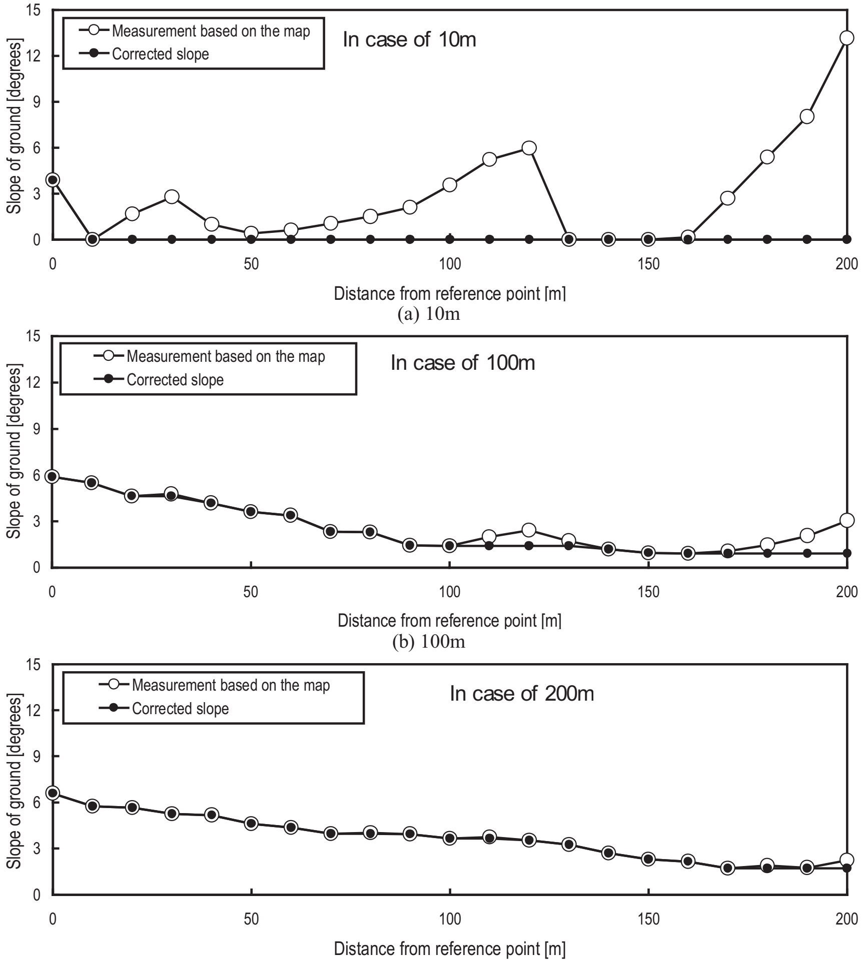
Figure 3 shows an example of measuring and correcting the values of θ in case of the stream O, and figure 4 shows an example of the application results in case of the stream O. Three houses were actually damaged, and because the numbers of these inside the house damage range were one house (10m case), and three houses (100m case and 200m case), the damaged house inclusion percentage was 33% (10 m case) and 100% (100m case and 200 m case). Because there were two undamaged houses (10m case) and one undamaged house (100m case and 200m case), the undamaged house percentage was 66.7% (10 m case) and 25% (100m case and 200m case). In this example, the damaged house inclusion percentage was highest in two of the three cases—the 100m and 200m cases—and the undamaged house percentage was lowest in two of the three cases, also the 100m and 200m cases.

Table.1 Vlume of sediment transported by debris flow to a reference point

Torrent	Sediment deposition on torrent bed $[m^3]$	Watershed area $A[km^2]$	Runoff correction rate fr	24-hour rainfall R_T [mm/24hrs.]	Gradient [°]	Volume of transportable sediment Vec[m3]	Volume of sediment transported by debris flow to a reference point $V_0[m^3]$
A	26,460	0.90	0.2745	250.0	8	33,107	**26,460**
B	13,910	0.64	0.3108	340.8	6	21,643	**10,992**
C	1,536	0.09	0.5000	310.0	12	20,620	**1,536**
D	7,700	0.29	0.3720	250.0	6	19,263	**7,700**
E	4,750	0.20	0.4408	292.8	10	20,819	**2,950**
F	9,000	0.11	0.4665	399.0	6	9,506	**9,000**
G	7,000	0.07	0.5000	351.0	6	4,827	**4,827**
H	2,300	0.07	0.5000	305.7	17	20,934	**2,300**
I	1,215	0.04	0.5000	305.7	20	11,962	**1,215**
J	6,150	0.20	0.4142	305.3	8	16,052	**6,150**
K	3,500	0.06	0.5000	280.0	17	10,957	**3,500**
L	61,560	1.09	0.2450	247.5	6	25,251	**25,251**
M	6,634	0.39	0.3254	328.0	6	34,303	**6,634**
N	3,700	0.10	0.4408	209.0	10	14,900	**3,700**
O	6,000	0.09	0.5000	292.8	7	6,616	**6,000**
P	9,600	0.04	0.5000	292.8	10	5,903	**5,903**

Table.2 Damaged House Inclusion Percentage and Undamaged House Percentage

		Horizontal distance used to calculate gradient of the land (m)								
		10m			100m			200m		
		① / ②	Breakdown		③ / ④	Breakdown		⑤ / ⑥	Breakdown	
			Pertinent number ①	All ②		Pertinent number ③	All ④		Pertinent number ⑤	All ⑥
Damaged House Inclusion Percentage	Total completely or partly destroyed	0.600	18	30	0.800	24	30	0.767	23	30
	Completely destroyed	0.500	5	10	0.900	9	10	0.800	8	10
	Partly destroyed	0.650	13	20	0.750	15	20	0.750	15	20
Undamaged house percentage		0.871	122	140	0.786	88	112	0.802	93	116



(a) 10m

(b) 100m

(c) 200m

Fig.3 Examples of corrected slope (stream O)

Table 2 shows the results of totaling the damaged houses and the undamaged houses and calculating the damaged house inclusion percentage and the undamaged house percentage for all 16 cases. "All" in the table is the actual total number of damaged houses or it is the total of damaged houses and undamaged houses in the house damage range. "Pertinent number" means the total number of damaged houses in the damaged house range or the number of undamaged houses in the damaged house range. The damaged house inclusion percentages (completely and partly damaged) arranged from highest to lowest are 70.0% (200m case), 66.7% (100m case), and 56.7% (10m case). The undamaged house percentages are, from lowest to highest, 78.0% (100m case), 79.6% (200m case), and 87.4% (10m case). As stated above, if the horizontal distance between the two points used to calculate the value of θ is between 100m and 200m, although the undamaged house percentage would be about 80%, the damaged house inclusion percentage would be high at about 70%. And if the horizontal distance between the two points used to calculate the value of θ is approximately 200m, the house damage range is an undivided continuous land area.

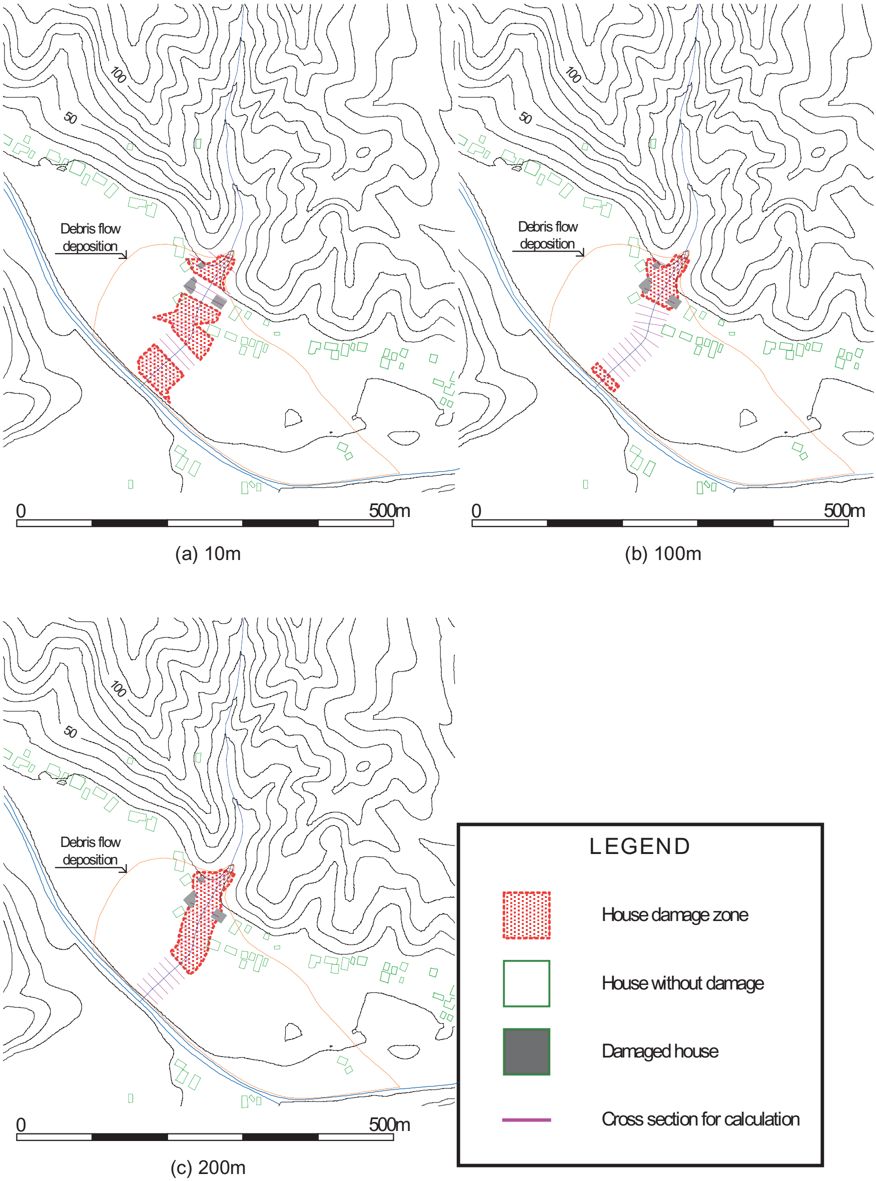


Fig.4 Examples of predicted house damage range (stream O)

CONCLUSION

The study has shown that if the horizontal distance between the two points used to calculate the gradient of the land is about 200m, the house damage range set by the method described in this report includes about 70% of the past damaged houses. For the sake of brevity, the study results are not shown, but it has been revealed that in a case where the value of the quantity of debris that is carried down by the debris flow at the reference point is higher than the maximum value of the discharged sediment from a single torrent and the actual quantity of sediment discharged by a debris flow, the damaged house inclusion percentage is high, but the undamaged house percentage is also high. A study of changes in the damaged house inclusion percentage and the undamaged house percentage in a case where the reference point is assumed to be the start point of the inundation by the actual debris flow has shown that if the reference point is located downstream from the mouth of the valley on a topographical map, the damaged house inclusion percentage tends to be high and the undamaged house percentage tends to be low. Inversely, if the point is located upstream, the damaged house inclusion percentage and the undamaged house percentage both tend to be low.

As shown by this report, because the undamaged house percentage is high, ranging from 70% to 80%, a method of studying a way of lowering the undamaged home percentage should be studied. The authors wish to express their gratitude to everyone who generously provided existing documents including reports on past debris flow disasters.

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