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PREDICTION OF DEBRIS FLOW PEAK DISCHARGE

PRÉDICTION CONCERNANT LE DÉBIT DE CRÊTE DE COULÉE DE BOUE

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SUMMARY

Debris flow characteristics have been well documented as a result of numerous investigations. In the design of debris flow control structures, the peak discharge of debris flow is one of the most important factors to be considered. However, no method of accurate predicting the peak discharge has yet been developed. In this paper, two methods of predicting the peak discharge are introduced. The first one is an empirical method based on the close relationship between the peak discharge and the total debris flow volume, called the 'magnitude'. This relationship was discovered by the authors through analysis of debris flow rate data observed in Japan. The relationship can be applied to various field data obtained in China, Canada, the U.S.A., and Colombia, and to experimental results using small flumes. The second is the hydrological method in which debris flow hydrographs were predicted based on rainfall. The information required this evaluation such as, sediment concentration and the coefficient of peak discharge was obtained from data observed in China.

SOMMAIRE

Le problème de la coulée de boue a été bien compris à travers plusieurs sortes d'expérience. Le débit de crête de coulée de boue est un des facteurs les plus imortants quand on dessine des ouvrages pour contrôler celles-ci. Quant à nous, nous n'avions pas de méthodes pour prédire de manière précise le débit de crête. Nous proposons cependant deux méthodes en vue de prédire ce débit de crête de coulée de boue. La première constitue une méthode empirique qui se base sur les relations intimes entre le débit de crête et la magnitude totale de coulée de boue. Ces relations ont été découvertes par les auteurs à travers l'analyse de données concernant les coulées de boue observées au Japon. Les relations pouvent être appliquées à des donnés sur le terrain en Chine et également à des résultats expérimentaux utilisant de petites canalisations. La seconde constitue une méthode plutôt hydrologique. Les hydrogrammes de coulée de boue sont prédits en tenant compte des chutes de pluie. Les informations nécessaires telles la concentration de sédiment et le coefficient de débit de crête nous ont été fournies grâce a des données observées en Chine.

1. Introduction

With the exception of facilities prepared specifically for debris flow study, it is usually difficult to observe the peak discharge rate of debris flow. The peak discharge rates were generally estimated using residual flood marks. The coefficient of peak discharge obtained was almost always greater than one. Figure 1 shows the peak discharge rates of observed debris flow and the corresponding flood discharge rate estimated using the rational equation based on rainfall data (MIZUYAMA, 1990). The coefficient of peak discharge for the majority of events was greater than one. A considerable quantity of sediment is contained in the debris flow. In the cases, where the debris flow carried the same volume of sediment as water, the coefficient of peak discharge of the debris flow reached a value as high as 2.0. However, in any case the coefficient cannot exceed 2.0. Figure 1 also indicates that in many instances, extraordinary large coefficient values occurred. The large values are understandable when considering that landslides often turn into debris flows, and landslide dams can break up into debris flows. The magnitude of debris flow is shown in Figure 2 along with the total volume of water derived from the total observed rainfall (UEHARA and MIZUYAMA, 1984). It is reasonable to assume that the total water discharge is at most equivalent to the total amount of rainfall if the degree of sediment concentration is considered.

It is necessary that we predict the peak discharge of the debris flow to prepare hazard maps and to design debris flow control structures, if the prediction is difficult and not accurate.

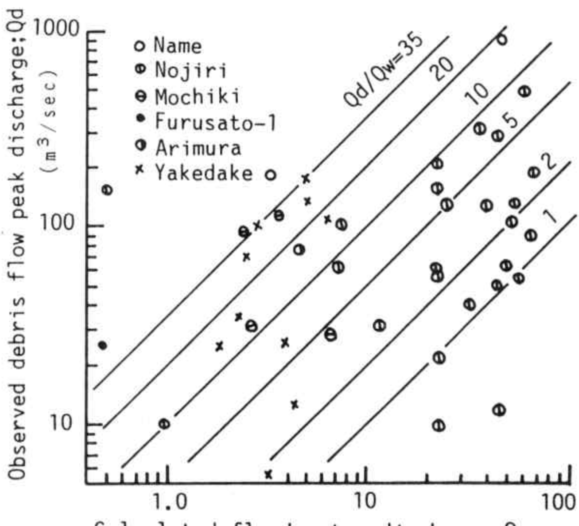

Fig. 1 Observed debris flow peak discharge and estimated flood water discharge.

Fig. 1 Débit de crête de coulée de boue observée et débit estimé de crue.

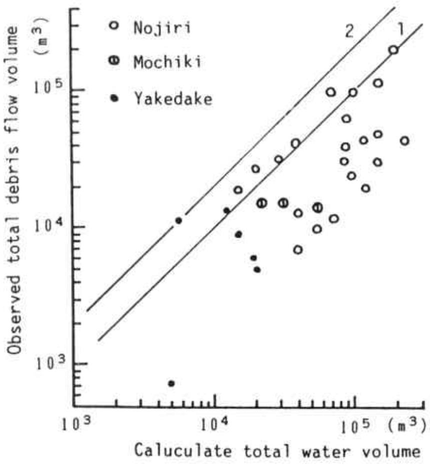

Fig. 2 Calculated total water volume and observed total debris flow volume; magnitude.

Fig. 2 Volume total calculé de débit liquide et volume total observé de débit solide de coulée de boue, magniutde.

2. Empirical method

A close correlation was found between the total amount and the peak discharge of debris flow through analysis of debris flow data accumulated at observation facilities in Japan. The correlation is in agreement with the data obtained in Canada (HUNG et al., 1984), China, the U.S.A. and Colombia, and in experimental results with flumes (MIZUYAMA and HU, 1989). The data analysis is shown in its entirely in Figure 3. It illustrates that granular debris flow and muddy debris flow show different tendencies in peak discharge. Granular debris flow as a whole had a peak discharge rate greater than that for muddy flow. This difference was proven to be caused by the fact that the flow resistance for granular flow is greater than that for muddy flow. The following empirical equations represent the peak discharge rates of these two types of debris flows:

$Q_p = 0.0188Q_t^{0.790}$ for muddy debris flow

$Q_p = 0.135Q_t^{0.780}$ for granular debris flow

where, units of peak discharge (Q_p) is m3/sec and magnitude (total debris flow discharge, Q_t) is m3.

The total volume of sediment likely discharged as debris flow can be estimated easily, and to some extent accurately, through field surveying. We can then at least predict the most probable volume of the debris flow. By assuming the sediment concentration, the peak discharge rate of debris flow can be calculated.

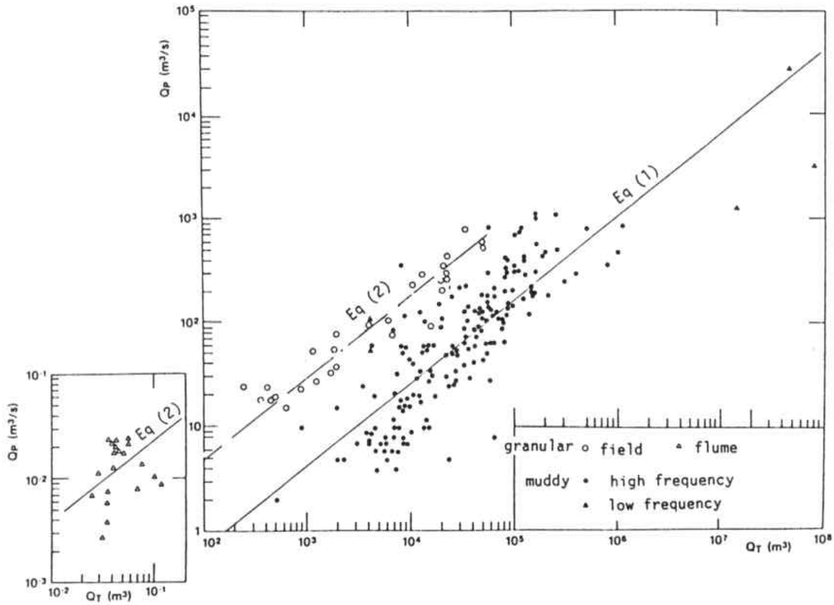

Fig. 3 Debris flow peak discharge (Q_P) and magnitude (Q_T).

Fig. 3 Débit de crête de coulée de boue (Q_P) et magnitude (Q_T).

3. Hydrological method

It was proposed that the ordinary hydrological method based on rainfall-runoff responses was not directly applicable to the prediction of the peak discharge of debris flow. Hydrological methods, however, are still basic methods to predict debris flow hydrographs. In a basin where debris flow does not originate from small landslides at the neighboring watershed divides, but from inflow of small landslides or the erosion of torrent beds at middle reaches, the ordinal rainfall-runoff model may be applied to prediction of the peak discharge rare of debris flow. Hirano, et al. attemped to apply a rainfall-runoff model to the prediction of debris flow hydrographs observed in Sakurajima (HIRANO et al., 1985). They could to some extent successfully explain debris flow hydrographs, except in the case of large volume debris flows. The mechanism of the occurrence of debris flow in Sakurajima has not yet been made clear. However, due to the constant local volcanic activity, it is still believed that a huge volume of accumulated volcanic ash, sand and gravel on the slopes and in torrents is the source of debris flow. When the debris flow is not large in scale, the rain that falls onto slopes flow down to the slopes and torrents, where the flow picks up the accumulated sediment turning it into debris flow. In this case, the hydrological method could be used to predict debris flow hydrographs and the peak discharge of debris flow. When a large amount of debris flow is produced, slope failures and landslide dams may occure, contributed to the debris flows. In such cases, the ordinary hydrological method can not adequately explain the debris flow hydrographs.

In Hunshui Gully, China, debris flow was intensively monitored during the late 1970's. The basin's drainage area was 4.5 km^2 and more than 50 incidents of debris flows occurred yearly during that time. Rainfall, discharge rate of debris flow, and sediment concentration were all monitored. The upper area of the basin was covered by forest, however, many landslides were active in the middle part of the basin where debris flows formed and developed. Figure 4 shows an example of some of the results of the observation. As can be seen, the sediment concentration which was very high and almost constant, represented around 60 percent of the total volume. Figure 5 indicates the relationship between the water discharge and the sediment discharge. The debris flow was muddy in nature and contained amount of much silt, clay and fine sand. Figure 6 shows the total amount of rainfall and total loss as calculated from the observed debris flow hydrographs and sediment concentrations. No difference was noted when compared with the ordinary water flow. The coefficient of peak discharge rate is shown in Figure 7. The majority of the data is a coefficient less than one. This means that the hydrological method can be used to explain debris flow discharge. We can also find that if the amount of peak water discharge of debris flow is large, the coefficient increases.

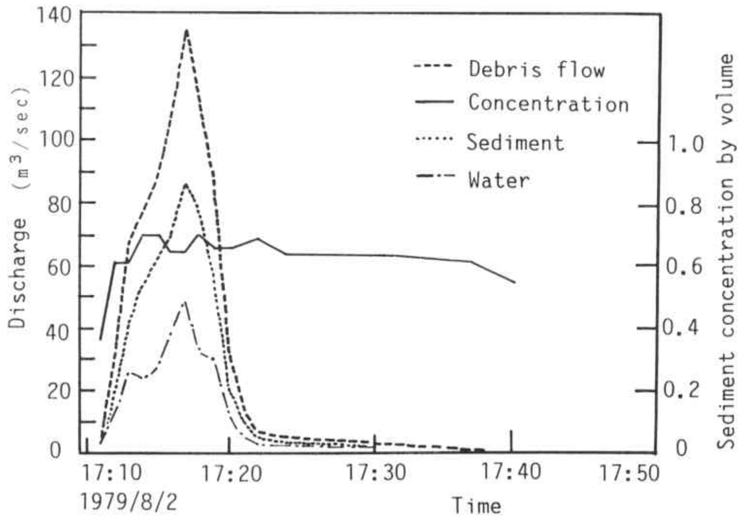

Fig. 4 an example of observed debris flow at Hunshui Gully, China.

Fig. 4 Un exemple de coulée de boue observée au ruisseau de Hunshui, Chine.

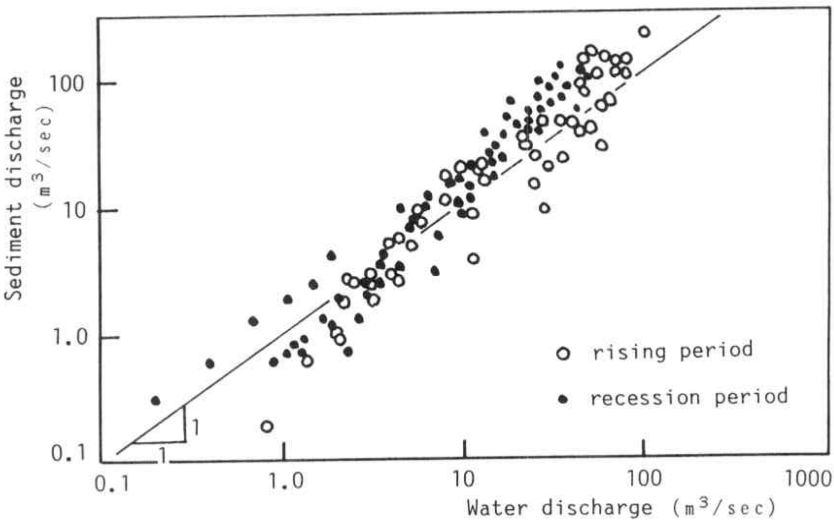

Fig. 5 Water discharge and sediment discharge of debris flows observed at Hunshui Gully.

Fig. 5 Débit liquide et débit solide de coulées de boue observées au ruisseau de Hunshui.

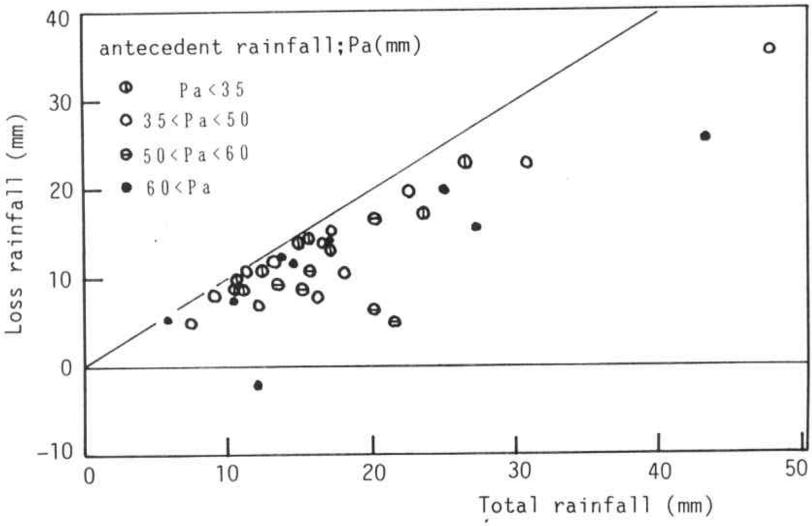

Fig. 6 Total amount of rainfall and amount of loss.

Fig. 6 Quantité totale de plouie et quantité de perte.

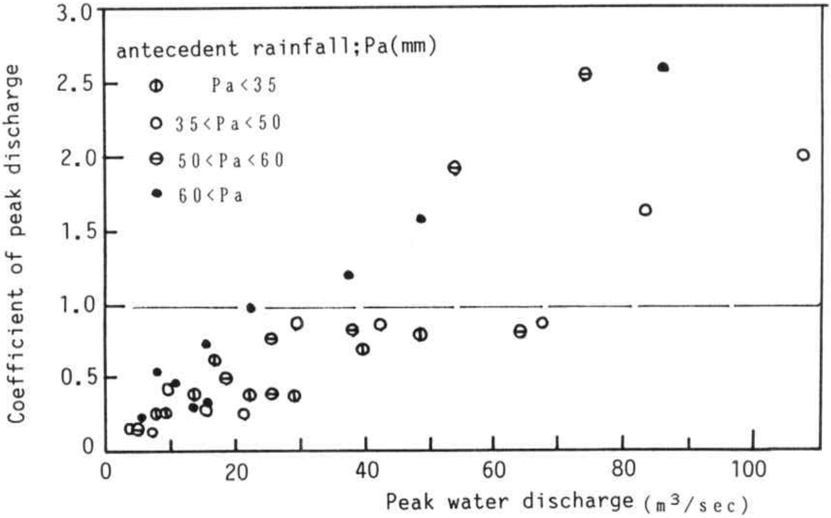

Fig. 7 Peak water discharge and the coefficient of peak discharge.

Fig. 7 Débit liquide de crête et coefficient de débit de crête.

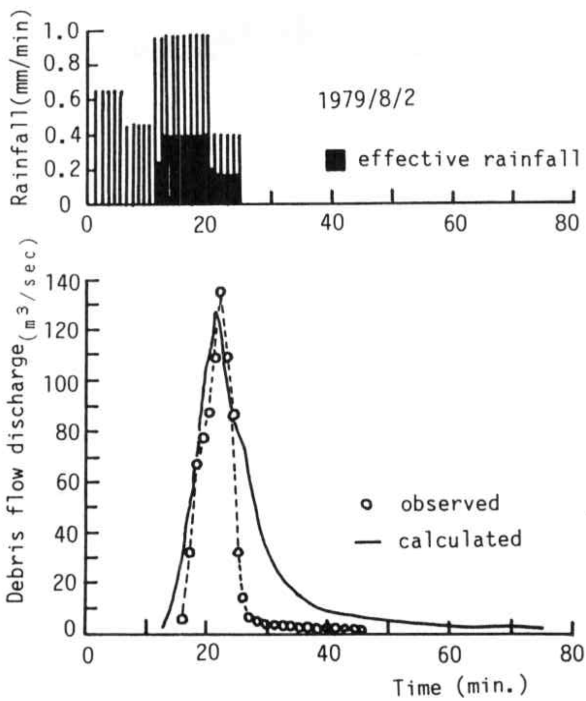

Fig. 8-1 Calculated debris flow hydrograph and observed hydrograph.

Fig. 8-1 Hydrogramme de coulée de boue calculé et hydrogramme observé.

The storage function method for rainfall-runoff was adopted for analysis. Figure 8-1 is an example of a good fit between the theoretical and actual results. Figure 8-2 and Figure 8-3 show a large amount of debris flow. The observed discharge in Figure 8-2 decreased during the rising period. The one in Figure 8-3 increased with some delay. Both Figures 8-2 and 8-3 suggest the occurrence of landslide dams.

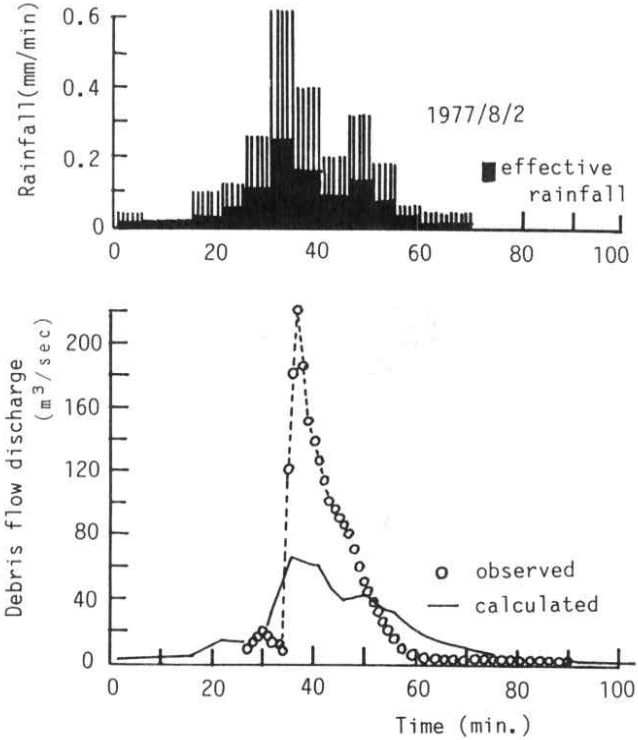

Fig. 8-2 Calculated debris flow hydrograph and observed hydrograph.

Fig. 8-2 Hydrogramme de coulée de boue calculé et hydrogramme observé.

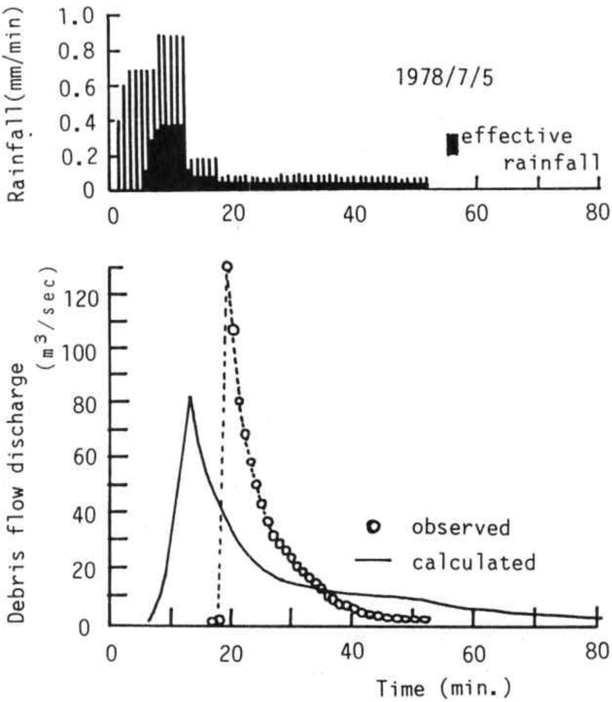

Fig. 8-3 Calculated debris flow hydrograph and observed hydrograph.

Fig. 8-3 Hydrogramme de coulée de boue calculé et hydrogramme observé.

4. Conclusions

Two methods of predicting the peak discharge rate of debris flow were proposed and investigated. The empirical method proved to be easy to use although it was limited its scope of application. The hydrological method incorporates a rainfall-runoff response model. This latter method can be used to predict debris flow without significant landslides or landslide dams. However, large debris flows are invariably affected by landslides or landslide dams. Unfortunately, since no quantitative method of predicting both large and small debris flows has yet been developed, the continued use of existing empirical methods must be maintained.

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