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Analysis of sediment yield and transport data for erosion control works

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ABSTRACT Erosion control works in mountain areas (Sabo works) have been undertaken for more than 100 years. However, their purpose and methods of evaluation are still uncertain. In this paper the purpose of erosion control works in mountain torrents and slopes is explained through the analysis of some sediment data, i.e. the sediment discharge of debris flows, the sediment yields of individual storms, and the rates of sedimentation in reservoirs in Japan, with some probabilistic considerations. The correlation between those quantities and drainage basin area are discussed. As results, the relationship of sediment yield to the area of the drainage basin is made clear and the magnitude of catastrophic sediment discharge is estimated. The evaluation of erosion control works in mountain areas is also discussed.

INTRODUCTION

For 100 years many Sabo (erosion control) dams have been constructed on mountain torrents in Japan as erosion control works. At the beginning of the century, the purpose of the erosion control works was to reduce the sediment discharge from mountain areas to maintain navigation, and to prevent floods associated with rapid aggradation. At the present time, navigation is not needed in most rivers and many multipurpose reservoirs constructed in the mountains on large rivers provide good flood control but cause degradation downstream. As a result local scouring at bends of rivers and around bridge piers and erosion at the seashore have become a serious problem. Sedimentation of reservoirs is another serious problem. Reflecting these situations, the purpose of erosion control works has changed to preventing local disasters such as debris flows and sedimentation in reservoirs. However, the danger of catastrophic sediment discharges causing floods in large lowland rivers still remains. A rational theory to evaluate erosion control works is required. Available sediment data are limited and are insufficient to check new theories or to determine the coefficients in models. Some explanation and analysis of available sediment data are introduced below as a background to model development.

ANALYSIS OF FIELD DATA IN JAPAN

The sediment yields of individual debris flows (Sabo Department, 1978) and the total amount of sediment produced in a basin during particular storm events are plotted in Fig.1. All data were obtained in Japan. The plot exhibits considerable scatter, because rainfall intensity and basin characteristics such as geology vary considerably. However certain general tendencies can be seen. In Fig.1 a 45° line would indicate that the total sediment yield of an event is constant regardless of basin area and a horizontal line would show that the specific sediment yield ($m^3 km^{-2}$) is constant. Although the points are scattered widely, the data for debris flows show the former tendency (constant sediment yield) and those for bigger basins show the latter tendency (constant specific sediment yield). These trends are reasonable if sediment delivery characteristics are considered. Bigger basins can be viewed as combining many unit basins, whilst debris flows occur in the unit basins whose areas are usually less than 1.0 km^2. In the case of debris flows, almost all the sediment produced is delivered to the outlet of the basin. Therefore the sediment produced is approximately equal to the sediment discharge at the outlet of the basin. However, a part of the sediment load is deposited there to form an alluvial fan or cone and a part of the remainder is deposited in downstream channels, so that the sediment yield of a bigger basin is considerably less than the total sediment produced in the upstream areas.

The ratio of sediment discharge to the total sediment production varies with time; the shorter the time considered, the smaller the ratio. If a sufficiently long period of time is considered and there is no additional sediment production, almost all sediment may be delivered to the basin outlet except large particles which are below the critical condition of initiation of motion. This may be termed natural adjustment to catastrophic sediment yield. This adjustment function of natural basins is, however, not enough for people in mountain areas to live safely. The frequency of hazard depends on the frequency distribution of sediment discharge.

The mean annual sediment yields estimated from sedimentation in some reservoirs in the central part of Japan are also shown in Fig.1 by the broken line (JSCE, 1971). By comparing the storm sediment yields with the mean annual sediment yields, the mean duration required to discharge the sediment produced by one catastrophic event can be estimated. For example, taking the horizontal solid line and the broken line, it can be estimated that it takes about 3 years for a 10 km^2 basin, 17 years for a 100 km^2 basin, 100 years for a 1000 km^2 basin and 500 years for a 10 000 km^2 basin, if all sediment finally discharges.

The annual sedimentation and the maximum peak discharge for individual years exhibit a good correlation as shown in Fig.2 based on the work of Mizuyama & Watanabe (1981). The regression relationship is similar for similar geological conditions with an exponent of 1.5. With different geology, the exponent remains the same but the constant is different. Koshibu Reservoir exhibits very rapid sedimentation. The larger the drainage basin, the larger is the percentage of fine sediment which is controlled by the stream

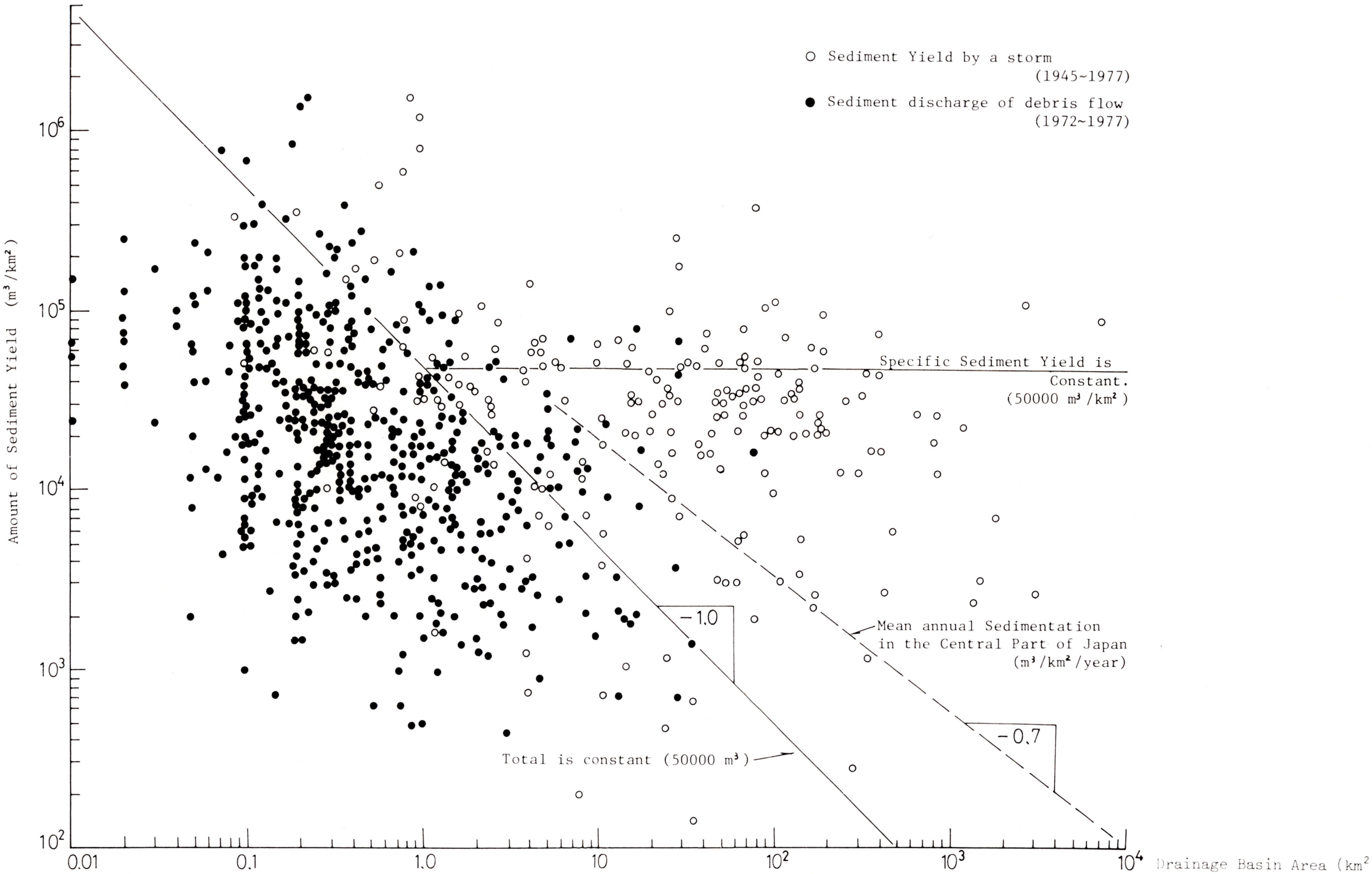

FIG.1 Relationship between sediment yield and drainage basin area.

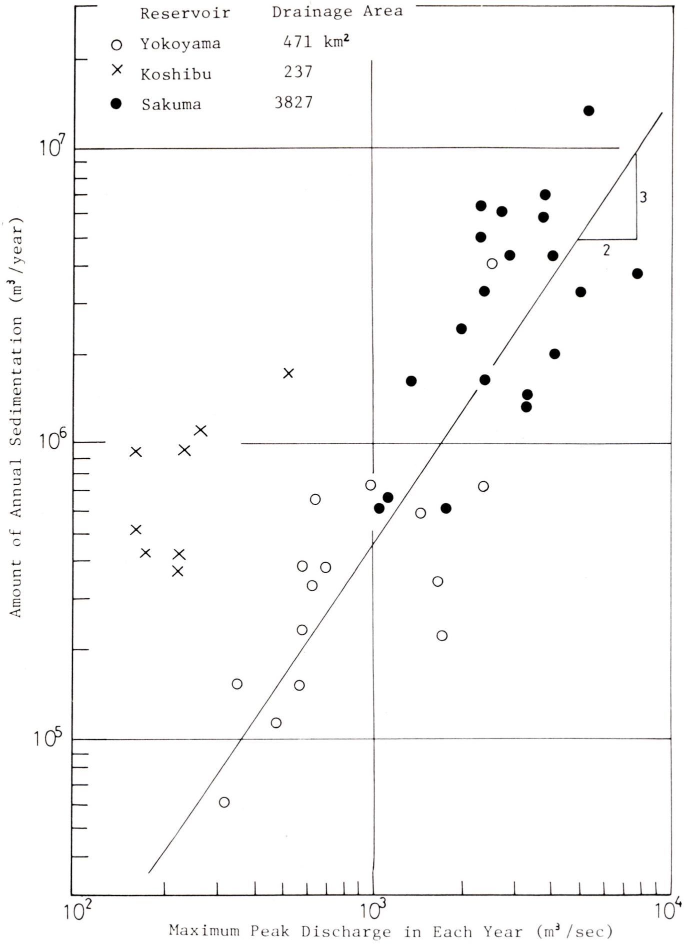

FIG.2 Relationship between the annual maximum peak discharge and annual sedimentation.

discharge.

Although the distribution of sediment discharge or the frequency and magnitude of sediment discharge can be estimated approximately from the relationship with stream discharge, the results are not accurate. Long term sedimentation data are very limited, but the data plotted in Fig.3 show the distribution of annual sedimentation for several reservoirs in Japan which possess relatively long records. From Fig.3 and some information about the basins, the following conclusion can be presented.

(a) The distribution of annual sedimentation shows a logarithmic normal distribution.

(b) Large basins and relatively stable small basins have a similar probability distribution. This is because sediment yields consist primarily of fine sediment.

(c) In unstable or disturbed basins, sediment discharge is relatively constant compared to ordinary large basins.

(d) The 100 year sediment discharge can be estimated as

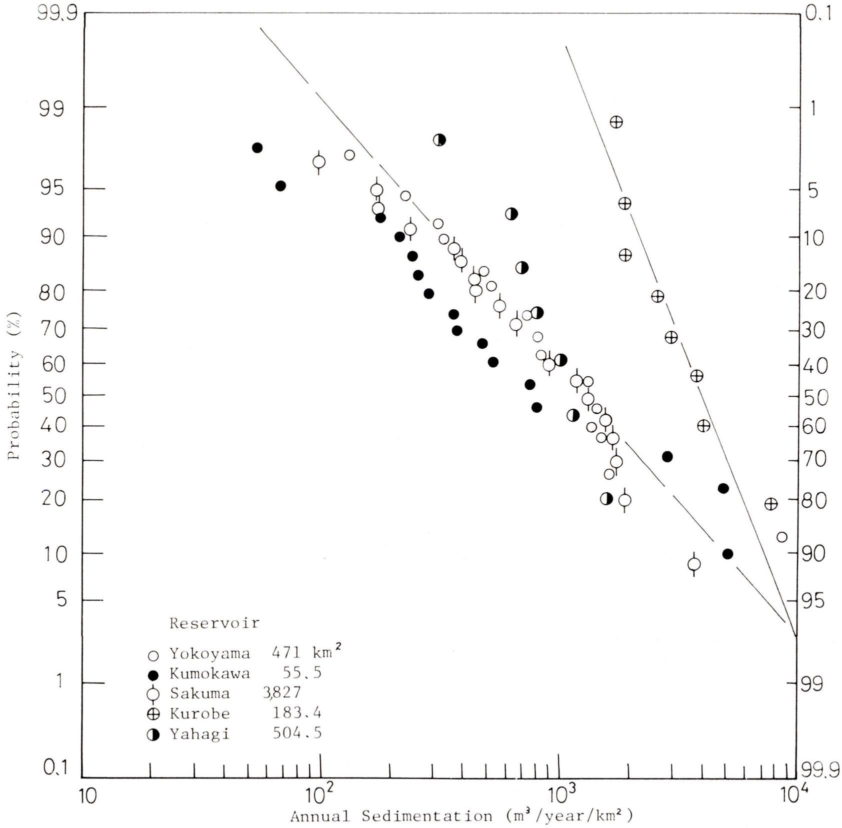

FIG.3 Probability distribution of annual sedimentation.

approximately 10 000 $m^3 km^{-2}$ in relatively large basins.

Based on these data, the purposes of erosion control works can be established as follows; in a small basin to check a very rare catastrophic sediment discharge such as a debris flow with erosion control dams, and in a large basin to reduce the sediment discharge and to make it uniform with erosion control dams or retarding basins.

EVALUATION OF SABO (EROSION CONTROL) WORKS

Erosion control works conducted in Japan can be divided into three; firstly, construction of check dams (Dam works), secondly, terracing and planting trees on bare slopes (Hillside works), and thirdly, improving channels on alluvial fans (Channel works). The first is of major importance in Japan (Ikeya, 1976). If the potential erodibility of the river bed is not taken into account if may be argued that check dams trap much sediment, but that erosion downstream may equal the volume deposited in the dam (Fig.4). If this is the case, check dams may not be efficient for controlling sediment discharge, except for making the sediment discharge more uniform. This situation can be demonstrated in experimental flumes using sand as bed material and by the so-called bed load equations which have been derived from these data. The actual situation is,

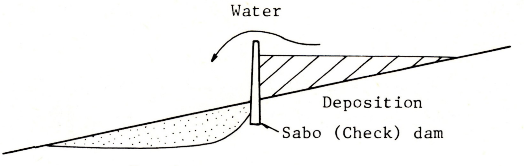

FIG.4 Comparison of the amount of upstream deposition and downstream erosion necessary to assess the effectiveness of Sabo (Check) dams.

however, very different from that suggested by the experimental flumes. The material to be eroded on the river bed or bank will exhibit a certain resistance to erosion. Alluvial deposits, even if composed almost entirely of sand, that were deposited long ago, are not easily eroded, whereas sand deposited recently can be eroded very rapidly. It is very important to evaluate the erodibility of channel materials in order to evaluate Sabo (erosion control) works. Wischmeier *et al.* (1971) presented a soil erodibility nomograph related to the Universal Soil Loss Equation. However, this is applicable only to surface erosion of flat areas. Therefore the channel erodibility factor must be further investigated. To obtain a general relationship between hydraulic factors and erosion rate, more field observations and measurements are necessary. From the point of view of erodibility, check dams trapping sediment should be constructed either near the break of slope, or where the channel width changes, from narrow to wide, or in the upper part of the reach where it is difficult to erode. Considering long term sediment discharge, it is appropriate to introduce control measures at sites where erodible materials exist or where accelerated erosion is going on. On the other hand, almost all types of check dam may work effectively to some extent in the case of short term catastrophic sediment discharges assuming that they are well maintained.

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