Measuring techniques of bed load in the Yangtze River

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ABSTRACT Accuracy of bed load measurement relies on the sampler and careful selection of sampling program. Firstly, this paper describes several instruments used for bed load measurement. Secondly, field inter comparisons of bed load samplers that were designed by the United States, the Soviet Union, and China are summarized. Thirdly, the designing principle of bed load sampler is expounded. Based on the principle, new cobble and sand samplers are being developed in China. Finally, The quantitative determination of duration of sampling and number of repetitions required are presented. Optimum method of the distribution of measuring verticals across the section according to the equal partial bed load transport rate has been demonstrated. Such method can make the measuring errors to the minimum.

INTRODUCTION

Bed load is a significant part of the total sediment transported by many streams. It creates numerous problems for engineers responsible for river management, especially in the design and operation of flood-control works, navigation channels, harbors and reservoirs, and water-power developments. Knowledge of bed load transport rate is necessary in designing reservoir storage because virtually 100 percent of all bed load material entering a reservoir remains in storage.

The bed load movement is quite uneven in both transverse and longitudinal direction and fluctuates considerably. Therefore, it is very difficult to determine the bed load discharge accurately. Although several computational methods for determining bed load have been developed, none is universally applicable to all sediment sizes, bed configurations, and flow regimes. One major difficulty with these computational methods is that the true size distribution of the moving bed load is difficult to determine. Direct measurement of the bed load would provide these size distributions, as well as data on the variation in transport rate in both time and space.

Since the establishment of New China, the technical study on bed load measurement has been systematically made by the Changjiang Water Resources Commission (CWRC). Different kinds of instruments for bed load measurement have been developed and some important problems on measuring methods of bed load have been solved. All of these play an important role in effectively developing the sediment measurement and ensuring the quality of the data.

This paper is concerned with the measurement of bed load transport rate in the Yangtze River. A brief description of the samplers development, the measurement techniques, and the methods of sampling is given in the following.

DESCRIPTIONS OF BED LOAD SAMPLERS

The Don sampler is a pressure-difference type sampler, designed by the Soviet Union. In 50' s, the Don sampler had been used for sand bed load measurement in the Yangtze River. But it was found that the entrance can not fit the river bed during sampling, and the scouring was seriously in the surrounding area of the entrance. Thus, representative samples can not be collected. In 60' s, the sand bed load measurement was interrupted and the development of new instruments begun.

The Y78-1 pressure-difference bed load sampler (Thou et al.,1981) was developed by the CWRC. The main feature of this sampler is the position of its center of gravity, which is maintained in the front part of the sampler by heavy lead strips and by a buoy in the rear part. A protective plate in front of the sampler prevents unnecessary settling and excessive scour around the entrance. It is suitable for use in streams with a velocity of less than 2.5 ms^{-1} and with bed materials smaller than 2 mm. Since 70' s, the instrument has been used for sand bed load measurement at some stations on the middle reaches of the Yangtze River stem and its tributaries.

The Y80 basket-type bed load sampler was developed by the CWRC. This sampler is used to sample gravel and cobble bed load in velocities of less than 6.0 ms^{-1}. It has a flexible chain-mail bottom with a mesh of about 5 mm, and is designed to provide a close fit between sampler and bed material.

The HS-1 pressure-difference bed load sampler, developed by the U. S. Geological Survey (USGS) for use with bed load from coarse sand to medium gravel in size, has a rigid frame and flexible nylon mesh sample catchment bag. The HS-la has the same relative proportions but is twice the size of the HS-1. The flume-calibrated sampling efficiencies of both samplers are greater than 100% but vary with transport rate and particle-size distribution. The field-calibrated sampling efficiency of the HS-1 ranged from 90 to 100% (Emmett, 1980).

TheTR-2 pressure-difference bed load sampler was developed by the USGS in 1986 to sample sand-rich gravel-sized bed load. The sampler has a rigid frame, nylon mesh sample catchment bag, and large tail fins.

Characteristics of bed load samplers tested in the Yangtze River are summarized in Table 1. The hydraulic efficiency (HE) is defined as the ratio of the intake velocity to the natural stream velocity measured before the introduction of the sampler. The sampling efficiency (SE) is defined as the ratio of the weight of bed load collected during a sampling time to the weight of bed load that would have passed through the sampler width in the same time had the sampler not been there.

TABLE 1 Characteristics of bed load samplers tested in the Yangtze River.

Sampler Name	Entrance dimensions Width (mm)	Height (mm)	Flume-determined HE (%)	SE (%)	Sampler Mass (kg)	Sampling capacity (kg)	Bed load sediment sizes (mm)
Don	100.0	100.0	124	46.5	100	15	<2
Y78-1	100.0	100.0	105	61.4	100	16	<2
HS-1	76.2	76.2	154	varies	30	10	1-16
HS-la	152.4	152.1	154	varies	100	20	1-32
TR-2	304.8	152.4	140	varies	300	50	1-64
Y-80	300.0	300.0	92	53.0	200	20	5-128

FIELD COMPARISONS OF BED LOAD SAMPLERS

In order to study the interrelation of the results measured by different kinds of bed load samplers, the inter comparisons for various samplers (including domestic and foreign made) were made in the Yangtze River.

Inter comparison of Y78-1 and HS-1 samplers

The test (Thou Gangyan, 1989) was made on the Xiangyang stretch of Hanjiang River, a tributary of middle reaches of the Yangtze River. Water depths ranged from 0.7 to 5.7 m and mean velocities ranged from 0.3 to 1.4 ms^{-1}. Bed load consisted of sediment finer than 2 mm in particle diameter. Because the mesh diameter of HS-1 catchment bag is 0.25 mm, analyses included only sediment greater than 0.25 mm. The relative trapping efficiencies of two samplers are then obtained in Table 2. It is shown that there are some differences for different velocity ranges, and the mean relative trapping efficiency is close to 1.0.

TABLE 2 Relative trapping efficiencies of HS-1 and Y78-1 samplers.

Ranges of velocity (ms^{-1})	0.30-0.50	0.50-1.00	1.00-1.50	Mean
HS-1/Y78-1	0.88	1.14	0.97	1.00

Intercomparison of Y78-1 and Don samplers

The test was made at the Xinchang Station on the middle reaches of the Yangtze River. The grain diameter of bed material was finer than 2 mm and mean velocities ranged from 0.3 to 2.5 ms^{-1}. Field comparisons indicate that transport rates determined by the Don sampler average 1.5 times the rates determined by the Y78-1 sampler. Tests in clear water flow show the flow lines in front of the intake converge to travel through the Don sampler. This means that Don sampler traps more bed load than should enter the sampler and that the sample is nonreprentative.

Inter comparison of Y80, HS-la, and TR-2 samplers

The tests were made at Zhutuo, Fengjie and Cuntan stations on the upper reaches of the Yangtze River. Sampled bed load consisted primarily of gravel ranging from 1 to 150 mm. Maximum water depth and velocity were 15 m and 3.85 ms^{-1} respectively. The test results are shown in Table 3.

The tests show that the sampling efficiency of basket sampler is lower than that of pressure difference sampler. Both HS-la and TR-2 samplers are pressure difference type sampler, due to the different hydraulic efficiency, the difference between trapping efficiencies approaches 100%. For the same sampler, the trapping efficiencies for different grain diameters are not constant. If the hydraulic efficiency is less than 1.0, the trapping efficiency will increase as the grain diameter increases; and if the hydraulic efficiency is greater than 1.0, the trapping efficiency will decrease as the grain diameter increases.

TABLE 3 Intercomparison test results of Y80, HS-la, and TR-2 samplers.

Sampler pairs	Relative efficiency (%) for each fraction (mm) 1.00 - 2.00	2.00 - 5.00	5.00 - 10.0	10.0 - 20.0	20.0 - 50.0	50.0 - 75.0	75.0 - 100	100 - 150	Mean
Y80/HS-1a	16.2	17.4	18.5	19.6	22.2	24.6	27.3	32.6	23.0
Y80/TR-2	33.4	35.2	36.8	38.5	42.5	45.4	48.6	55.1	46.0

THE DESIGNING PRINCIPLE OF A BED LOAD SAMPLER

When the sampler is set on the river bed, due to the action of sampler resisting water, a dispersion region of water flow diffusing both sides and upside is formed in front of entrance with a velocity smaller than the natural velocity.

As designing a bed load sampler, the obstructive resistance of instrument body and the flow line dispersion should be reduced as small as possible. But the obstructive resistance of the instrument can not be avoided thoroughly. Thus, a pressure difference type sampler is designed, of which the body is designed as a closed type and the ratio of cross sectional area for entrance to exit of the sampler is improved to adjust the intake velocity to be equal to or a little bit bigger than natural velocity. Fig. 1 shows Y78-1 the relation between the ratio of entrance area to exit area (W_{in}/W_{out}) and the hydraulic efficiency (HE). If the exit area is greater than two times entrance area, the intake velocity may be 22% greater than natural velocity. If the hydraulic efficiency is large, the flow line will contract in front of entrance and the local scouring will occur, resulting a faulty collected sample. Therefore, for bed load sampler design, the obstructive resistance of the sampler body should be made as small as possible as to reduce the dispersion of flow line and the intake velocity should be increased (HE a little bit greater than 1.0) properly to contract the flow line at the entrance. The result from the above two effects will make the flow line at the entrance to be nearly straight. Based on the above knowledge, new cobble and sand samplers are being developed in China.

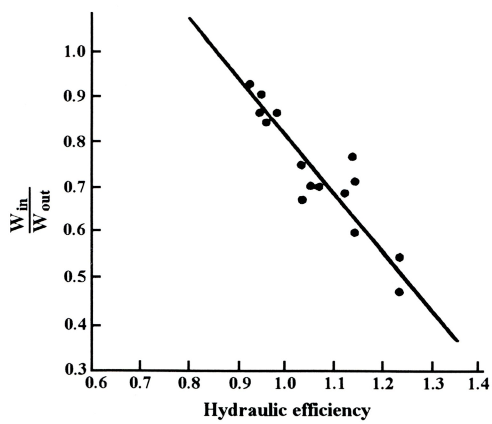

FIG. 1 Relation between ratio of entrance area to exit area and hydraulic efficiency.

DISTRIBUTION OF VERTICALS AND DURATION OF SAMPLING

For bed load movement, there is intensive pulsation on time distribution and it is nonuniform on width distribution. In order to eliminate the error of pulsation and to control the variation of transverse distribution, the multi-verticals were distributed in cross section and three repeating samplings for each vertical were made formerly in the Yangtze River. In America, two viewpoint exist, one suggests 20 verticals assigned by order foreward and backward for each, the other suggests four verticals assigned, repeating 10-20 times for each vertical. Which one will conform the practice, the theoretical demonstration shows that the method of the distribution of measuring verticals across the section according to the equal partial bed load discharge can minimize the measuring error (Tang Yunnan, 1990).

In addition, based on the field data, the transverse distribution of vertical bed load discharge are plotted and then the curve is smoothed. Two computations are made for bed load discharge in cross section; one is based on uniform distribution method and the other is based on equal bed load discharge method. The computation results show that if the number of verticals for both methods are the same, and the number of verticals is less than 10 verticals, the measuring error of equal bed load discharge method is much smaller than the uniform distribution method (see Fig. 2).

In order to minimize the influence of fluctuation, the duration of sampling should be larger than 100 s. As the duration of sampling be increased to larger than 250 s, the variation coefficients of two adjacent time intervals will vary very small. In general, the quantity of material sampled should not exceed sampling capacity of the sampler. If the transport rate is fairly high, the duration may be reduced to not less than 30 s.

In practical work, based on the equal bed load discharge method, the verticals are distributed and the number of repeating sampling is determined approximately, as following: Close distribution is made in violent strip and sparse distribution in weak strip. The number of repeating sampling for each vertical is determined by the weight of the partial bed load discharge to the cross sectional bed load discharge. The number of repeating samplings for the vertical in violent strip will be more, and in weak strip generally only one sampling is made for each vertical. Using this method, the Zhutuo Station had reduced the 9-16 verticals to 6 verticals. The systematic error for the later is only -0.7%, the standard deviation is 3.9% and the maximum random error is only -17.8%.

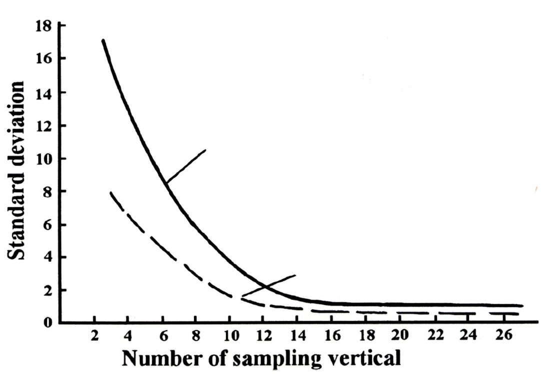

FIG. 2 Relation between the number of sampling vertical and standard deviation.

CONCLUSONS

Measurement of bed load by various samplers is a straightforward method in nature. According to the flow and sediment conditions under which the bed load will be measured, bed load samplers can be selected from Y78-1, HS-1, HS-la, TR-2, and Y80. The Y78-1 sampler is suitable for sampling bed load on sandy streambeds where the bed load consists of sediment predominantly finer than 2 mm in particle diameter. HS-1, HS-la, and TR-2 samplers are suitable for sampling mixtures of sand and gravel moving across relatively smooth beds lacking obvious bed forms or other roughness elements. The Y80 appears to function well in gravel and cobble streams where the flexible bottom provides a good fit between sampler and stream bed.

In designing a bed load sampler, the obstructive resistance of sampler should be reduced as small as possible and hydraulic efficiency should be a little bit greater than 1.0, which will make the flow line at entrance to be nearly straight.

In order to eliminate the error of pulsation, the duration of sampling should be increased to larger than 100 s. If the transport rate is fairly high, the duration may be reduced to not less than 30 s. In order to control variation of transverse distribution, the multi-verticals should be distributed in cross section. The method of the distribution of measuring verticals across the section according to the equal partial bed load discharge can make the measuring error to the minimum.

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