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The development of a sand bed load sampler for the Yangtze River

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ABSTRACT This paper describes several bed load samplers used in the Yangtze River during the 1950's. The results of intensive experiments on the characteristics of these samplers and their problems are discussed. Criteria for the design of a satisfactory sand bed load sampler have been established as follows: the lower edge of the sampler entrance must fit closely to the stream bed without causing erosion or deposition; the ratio of the intake velocity to the natural stream velocity must be nearly equal to 1.0; and the trapping efficiency should be comparatively high, etc. Based on all these requirements, the Yangtze 73 and Yangtze 78 samplers have been developed and improved. The process of development and improvement of these samplers, their characteristics, and the results of the laboratory flume experiments on their sampling efficiencies are described.

Mise au point d'un appareil à prélever le sable charrié sur le fond du lit du fleuve Yangtzé
RESUME Dans ce rapport nous donnons une description sommaire des problèmes que présente un tel appareil et nous présentons les résultats expérimentaux d'études intensives des caractéristiques de plusieurs types d'appareils utilisés pour prélever le sable charrié sur le fond du lit du fleuve Yangtzé, au cours des années cinquantes. Aussi certaines caractéristiques idéales pour cet appareil peuvent être formulées comme suit: la base de l'entrée de l'appareil doit s'ajuster de très près au lit du fleuve sans provoquer ni érosion ni dépôt; la vitesse d'entrée pour la prise d'échantillon doit être voisine de la vitesse de l'eau dans le fleuve; l'efficacité d'échantillonnage doit être élevée. Enfin le rapport présente sur la base des exigences mentionnées ci dessus les diverses étapes de la réalisation et de la mise au point des échantillonneurs Yangtzé 73 et Yangtzé 78 et les caractéristiques de ces appareils ainsi que l'étude au laboratoire de leur efficacité par comparaison avec un piège à sédiments du type citerne.

NOTATION

V_s sampler intake velocity (m s^{-1})
V_f natural stream velocity measured before the introduction of the sampler
q_s measured bed load discharge per unit width of the stream

(kg s^{-1} m^{-1})

q_f bed load discharge per unit width actually transported in the natural stream (kg s^{-1} m^{-1})

K_v intake velocity coefficient $K_v = V_s/V_f$, i.e. the ratio of the intake velocity to the natural stream velocity measured before the introduction of the sampler

K_e trapping efficiency $K_e = q_s/q_f$, i.e. the ratio of the measured bed load discharge per unit width to the bed load discharge per unit width transported naturally before the introduction of the sampler

PROBLEMS OF SEVERAL EXISTING SAND BED LOAD SAMPLERS

The Polyakov sampler

This sampler is composed of three parts: a sample collecting trap, a leading plate and a tail vane. The major drawbacks of this sampler are: firstly, the front edge of the leading plate may not provide close contact with the stream bed; secondly, sediment accumulated in the open collecting trap may be flushed out by flowing water; and, thirdly, the capacity of this sampler is easily exceeded and the trap volume is not large enough for long duration sampling. Figure 1 shows the character of the erosion and deposition induced by the presence of the sampler. Scour holes may develop in front of the leading plate, and on both sides and at the back of the sampler during sampling. Because it takes time for the sediment to travel across the leading plate, errors could be associated with the sampling times recorded. Some of the accumulated sample may be washed out during the closing of the collecting trap and the raising of the sampler. Sampling efficiency is therefore very low and values of 19.9% have been obtained. When the stream velocity is greater than 0.7 m s^{-1} the trap efficiency will be further reduced.

The Netherlands (or Dutch) sampler

This sampler is inconvenient to operate because of the large framework on which two heavy streamlined weights are mounted. Because the mesh sampling bag causes much resistance to flow, especially under high water conditions, the intake velocity is greatly reduced. Figure 2(b) shows that the velocity reduction begins 1 m from the nozzle intake, and that the velocity at the intake is only 50% of the ambient stream velocity. Figure 2(a) shows the development of a scour hole in front of the intake. It is formed rapidly as soon as the sampler is lowered. The subsequent development of the scour hole causes the representativeness of the sample to be questionable. The trapping efficiency of this sampler measured in flume experiments is 17.5%, and a finer sediment size distribution is obtained from this sampler than from other bed load measuring devices. The value of K_v obtained from field investigations is 58.7%.

The Don sampler

This is a pressure-difference type sampler with a metal sampling case flared from the entrance towards the rear. The size of its

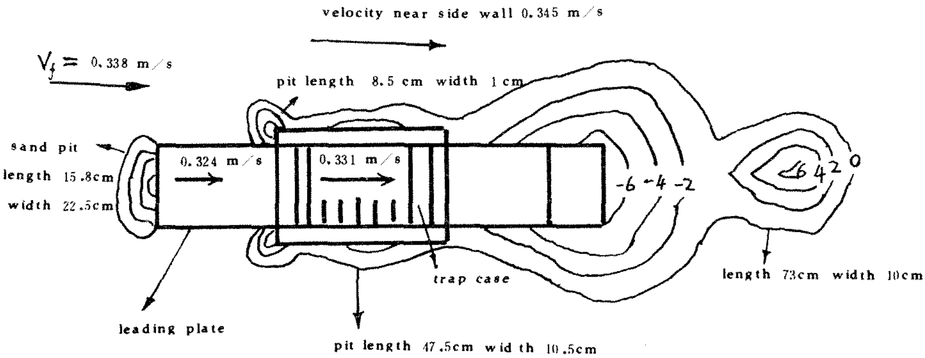
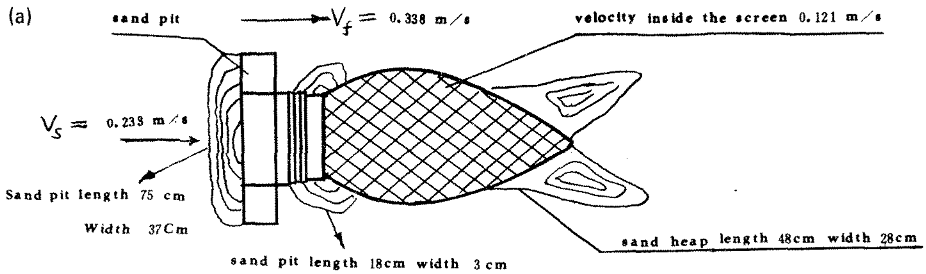


Fig. 1 Schematic diagram of the Polyakov sampler.

(a)



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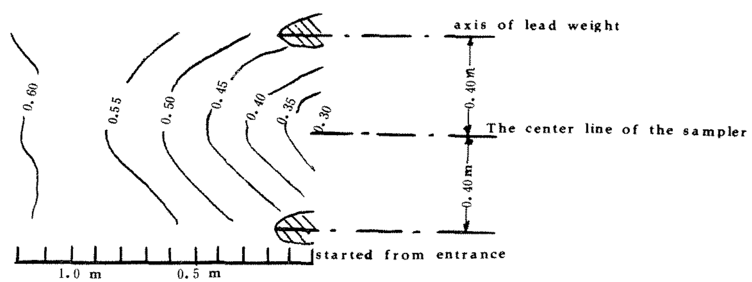

Fig. 2 The experiments on the Netherlands sampler: (a) scour and deposition around the sampler, (b) velocity contours in front of the sampler.

nozzle intake is 100 x 100 mm, K_v = 92.7% and K_e = 46.5%. Tests in clear water flow show that the flowlines in front of the intake converge to travel through the sampler. This means that this sampler traps more bed load than should enter the sampler and that the sample is unrepresentative. Field observations indicate that the lower edge of the intake cannot maintain close contact with the stream bed (especially on a loose fine sand bed), because the centroid of this sampler is located towards the rear of the sampler due to its flared construction (Fig. 3). A 90% failure of contact was observed in 300 runs. If the sampler is positioned manually, with the intake in close contact with the stream bed, erosion will immediately occur along the lower edge of the entrance and the size of the scour hole will rapidly enlarge so that in a short time the front of the sampler will be suspended and only the rear will be in contact with the stream bed. An average time for the intake nozzle to lose contact with the stream

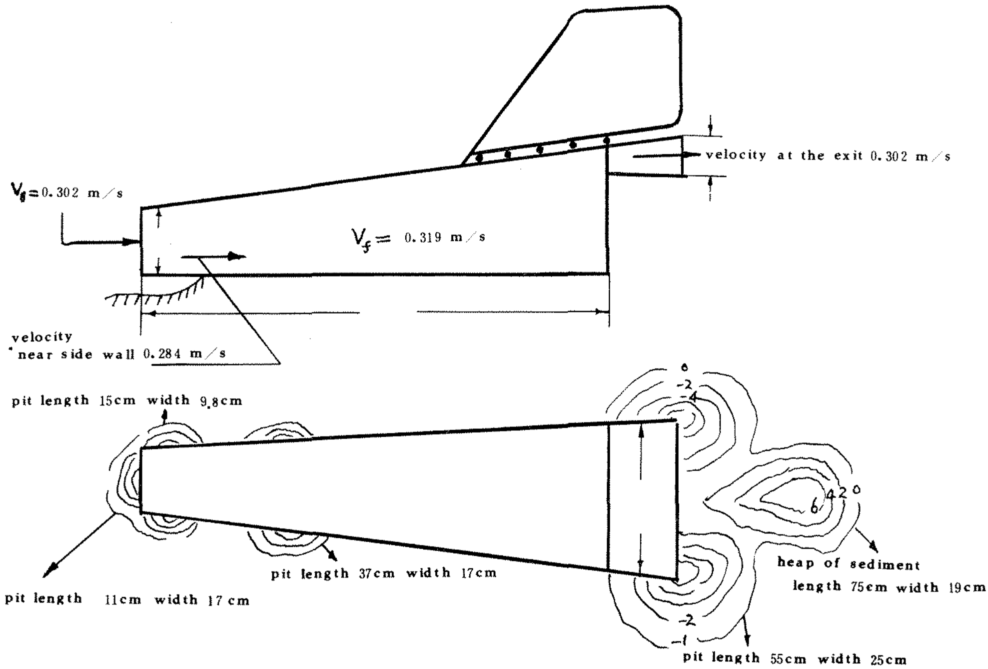

Fig. 3 Sediment scour (in mm) around the Don sampler.

bed is about 9 s in flume tests with a water depth of 0.7 m, and a velocity of 0.167 m s^{-1}. It is concluded that the results obtained using this sampler may involve many problems.

EXPERIMENTS TO EVALUATE THE CHARACTERISTICS OF AN IMPROVED SAND BED LOAD SAMPLER

Close contact between the sampler intake and the stream bed is essential

Field investigations in streams with clear water flow have shown that differences in the centroid position of a sampler produce differences in the effectiveness of the contact between the intake and the stream bed. The probability of the intake making contact with the bed was evaluated for different samplers. Because the centroid of the Don sampler is located at the rear, it demonstrated a 90% probability of not making contact with the stream bed. The centroid of the Yangtze 112 sampler is only 13 cm from its intake, and this sampler demonstrated 100% success in making contact with the stream bed. This sampler is specially constructed with a lead weight mounted at the top of the sampler intake, and a buoyancy cylinder attached to the rear. This shifts the centroid of the sampler forward. Experiments show that these devices greatly improve the contact with the stream bed.

Avoiding scour at the sampler entrance is very important for representative sampling

As the sampler is lowered, the loose sand bed will be scoured due to the resistance of the obstructing sampler to the flow. This phenomenon usually occurs close to the sampler, for example in front of the entrance, and along both sides of the sampler wall. Experiments have been undertaken with a protecting plate mounted below the entrance (see next section, Yangtze 73 sampler). The sharpened edge of this plate is curved downwards to facilitate its insertion into the sand bed surface. In this way, the erosion at the front of the sampler can be avoided, so that representative samples can be obtained using this sampler.

The relationship between the intake velocity coefficient (K_v) and the natural stream velocity (V_f)

A good stable relationship between K_v and V_f is required and when $K_v \approx 1$ the sampler possesses good hydraulic characteristics. Figure 4 shows the results obtained from the Yangtze 78 sampler. In these, K_v is stable at a value of 1.05. The K_v value for the Yangtze 73 sampler obtained from field tests is less than that obtained from the flume test and there is a tendency for K_v to decrease with an increase in V_f. If the intake area (W_1) is kept constant, different values of W_1/W_2 can be obtained by decreasing or increasing the area of the exit by changing the height of the sampler backwall, and different values of K_v will result (Fig. 6). This plot shows that the values of W_1/W_2 and K_v are inversely related. The required value of K_v can therefore be obtained by adjusting the value of W_2 to attain $V_f \approx V_s$.

Observations on the velocity and the flow pattern inside and outside the sampler

Results of tests on the velocity distribution inside the samplers are listed in Table 1 and shown in Fig. 5. A guide plate is mounted in this sampler and if the value of K_v beneath the guide plate is small, bed load will not enter the sampler chamber. It is clear from Fig. 5 that there is little variation in the velocities measured in front of the entrance.

The results of the flow pattern observations show the existence of longitudinal eddy currents in the sample chamber (Fig. 7). When the sampler is fitted with a guide plate, a counter clockwise eddy is formed. If the sampler is constructed without a guide plate, a clockwise eddy will be formed.

Observations on the position of the collected sediment

Figure 8 shows the nature of sediment accumulation for a sampler fitted with a guide plate with a flat edge,for a sampler fitted with a guide wall with a curved front, and for a sampler without a guide wall. In the sampler without a guide wall, the sediment may accumulate as high as the back wall and part of the sediment sample may be lost through the exit. This means that space should be provided in the sampler chamber for the water flowing through. The upper limit for the volume of load collected is called the effective volume. This experiment shows that the effective volume of a sampler fitted with a guide wall is too small and inadequate for sampling large rivers. The Yangtze 78 sampler has been constructed without the interior guide wall.

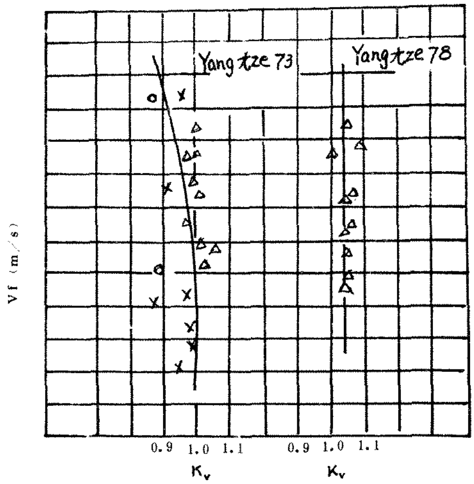

Fig. 4 The relationship between V_f and K_v for the Yangtze 73 and Yangtze 78 samplers. Δ, Cheng Dou 1.5 m wide flume experiment (1:1 model); ○, Guan Yian field channel experiment (1:1 model); X, Wuhan 1.2 m wide flume experiment (1:0.2 model).

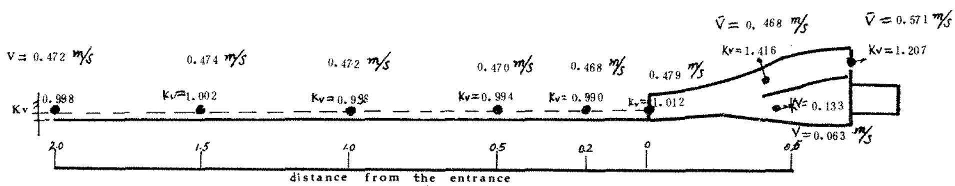

Fig. 5 Schematic profile of velocities measured inside and outside the S.T.1 type sampler.

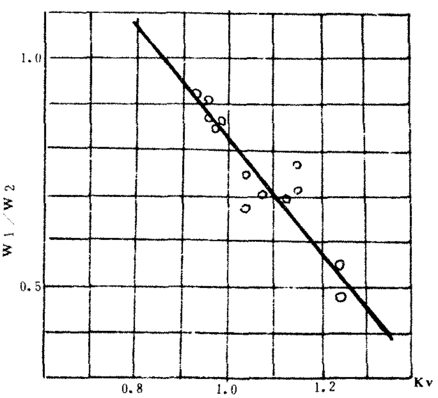

Fig. 6 Plot of W_1/W_2 *vs.* K_v.

Table 1 Flow velocity characteristics of the S.T. samplers

	Entrance		Exit		Measured above guide wall		Measured under guide wall	
Sampler	Velocity	K_v	Velocity	K_v	Velocity	K_v	Velocity	K_v
S.T.1	0.496	1.028	0.583	1.207	0.684	1.416	0.064	0.133
S.T.2	0.501	1.037	0.567	1.175	0.657	1.382	0.138	0.285

Note $V_f = 0.483\ m\ s^{-1}$, $h = 0.548–0.610\ m$.

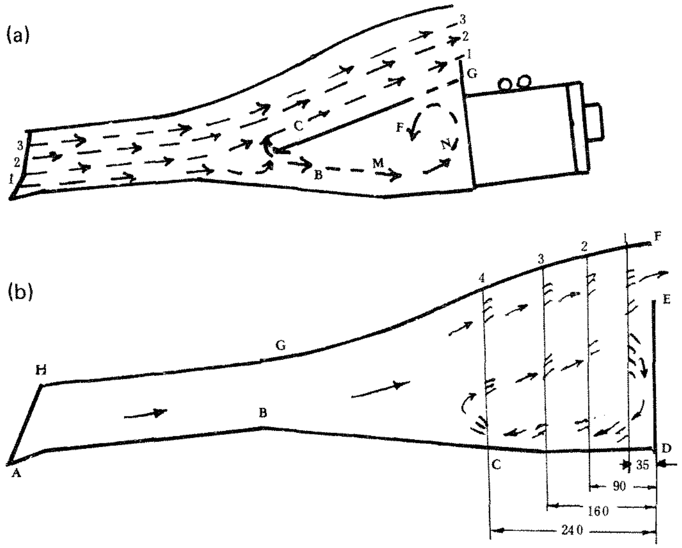

Fig. 7 Schematic drawing of the flow patterns observed (a) inside the S.T.1 sampler with a guide wall, (b) inside the S.T.3 sampler without a guide wall.

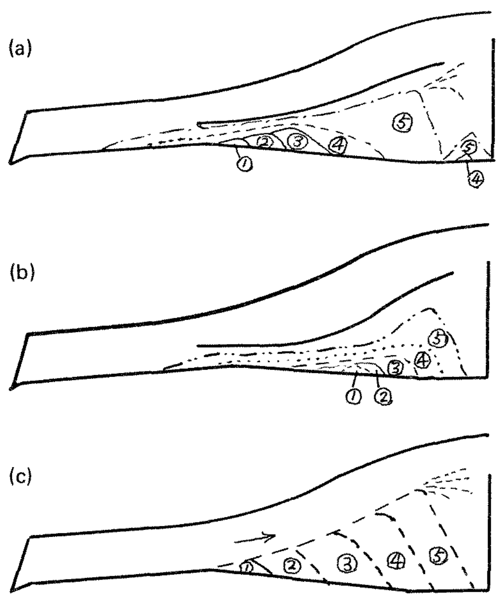

Fig. 8 Schematic profile of the sediment collection process in the S.T.3 sampler: (a) round edged guide wall; (b) sharp edged guide wall; (c) no guide wall.

THE TECHNICAL REQUIREMENTS FOR A SAND BED LOAD SAMPLER

Based on the results of the above experiments, the following criteria were established for the design of an effective sand bed load sampler:

(a) The sampler entrance should maintain close contact with the stream bed when the sampler is lowered.

(b) No erosion or deposition should occur close to the nozzle.
(c) The flowlines in front of the sampler entrance should be straight (K_v = 1).
(d) the trapping efficiency should be high and the value of K_v kept stable during use. The load should collect inside the sampler in a suitable position and the particle size distribution of the sample trapped should be identical to that of the bed load naturally transported in the stream.
(e) The capacity of the sample chamber should be large enough to permit sampling under conditions of high velocity and intensive bed load movement.
(f) The streamlined weight should be designed and constructed so as not to influence the characteristics of the sampler, and a loose sand bed surface should not be deformed by the sampler due to this streamlined weight.
(g) The construction of the sampler should provide simplicity and rigidity. The catch on the entrance cover should be operated easily and reliably.

THE DEVELOPMENT OF THE YANGTZE 73 AND YANGTZE 78 SAMPLERS

The Yangtze 73 sampler
The Yangtze 73 sampler is shown in Fig. 9. The size of its entrance is 100 x 100 mm. The front part of this sampler is straight and 225 mm long, and the rear part is flared along both side walls. The width of the back wall of the sampler is 200 mm, and the size of the exit is 200 x 60 mm. In addition, a protective plate with a sharp curved edge (lip knife) is mounted beneath the entrance. This can be inserted into the bed surface

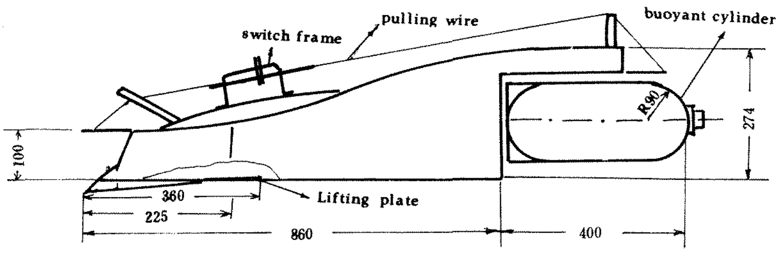

Fig. 9 The Yangtze 73 sampler.

during sampling. The values of K_v and K_e for this sampler obtained from field investigations are 86.1 and 43.5% respectively. This sampler has been used at stations such as the Fengjie station and the Yichang station on the main stretch of the Yangtze River. Two streamlined weights of 100-150 kg are mounted on the steel framework. The forward point of the streamlined weight is located 0.3 m behind the nozzle, so that these weights and the framework do not influence bed load movement in front of the sampler intake. The sampler is connected to the framework by light cables, and it can be moved freely up and down without depression into the loose sand bed surface by these streamlined weights.

The Yangtze 78 sampler

This sampler incorporates improvements based on the experiment described previously and the characteristics of the S.T.3 sampler. The protective plate of the sampler is rectangular in shape (Fig. 10) and the front part of the bottom plate of the sampler is inclined upward towards the rear at an angle of 5°28". The rear part of the bottom plate is inclined downward towards the rear, and the bed load accumulates on this part. The water carrying the load flows along the upward sloping bottom plate into the sampler chamber, but does not project directly against the back wall of the sampler. The bed load is carried by the flow into the flared chamber, and settles out due to the reduction of the velocity.

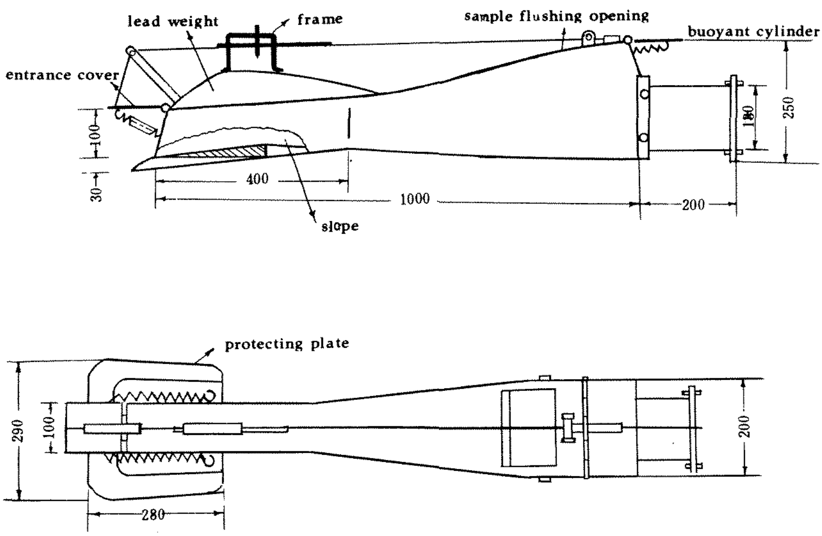

Fig. 10 The Yangtze 78 sampler.

The downward inclined slope of the rear bottom plate facilitates the accumulation of the bed load and minimizes the influence of the eddy current. The entrance cover and the exit cover of the Yangtze 78 sampler are both fitted outside the sampler. This arrangement enables these covers to be closed tightly by a spring. The exit cover is fixed by a cotter pin, and the value of K_V can be kept stable. An opening set on the top of the sampler is adequate to flush out the sample from the sampler chamber. The size of the entrance is 100 x 100 mm. Both side walls of the sampler are flared to the rear, and the effective sampling capacity is 16 kg. This sampler is useful for bed load measurements in rivers with an average velocity less than 2.5 m s^{-1} and bed load sediments with a grain size less than 2 mm. The results of calibration in the laboratory flume are: K_V = 1.05, K_e = 61.4%. Comparisons based on field observations shows that the bed load discharge measured with the Yangtze 78 sampler is more stable than that measured with the Yangtze 73 sampler. The Yangtze 78 sampler is now used at stations on the main stretch of the Yangtze river, such as the Yichang and the Xinchang stations.

THE TRAP EFFICIENCY CALIBRATION OF THE YANGTZE 78 SAMPLER IN THE LABORATORY

The calibration

The calibration of the trap efficiency of the Yangtze 78 sampler was performed in the glass flume at Chengdu University of Science and Technology in 1979. The dimensions of this flume are width 1.5 m, and total length 62.6 m. In this calibration the maximum discharge was 600 l s^{-1} and the maximum bottom velocity 1.1 m s^{-1}, and the flume was filled with natural sand 20 cm thick. A collecting tank was built for bed load discharge measurement in order to provide a reference against which to compare the sampler. The tank's outer case was fixed in the sand bed and two thin metal walls, 5 cm higher than the sand surface, were mounted on both sides of the inner case in order to avoid collection of sediment from both sides of the tank. The collecting tank was located 11 m ahead of the tail gate of the flume. The top edge of the tank was at the same level as the sand bed surface. Two different types of sediment were provided for the tests. One was fine sediment with an average grain diameter less than 0.63 mm, and the other was coarse sediment with an average size of 3-5 mm. In the first test, fine sediment was used with a thickness of 20 cm. In the second test, a lower 10 cm thick layer of coarse sediment was overlain by a similar depth of fine sediment. During the test 5-10 kg of fine sediment was supplied every minute. The sampling site was 3 m ahead of the collecting tank, and the cross section for velocity measurement was 0.5 m ahead of the tank. No erosion and deposition occurred at either the sampling site or the flume cross section near the collecting tank during the duration of the experiment. Variations of the bed surface at both cross sections were identical indicating that the hydraulic conditions for bed load transportation were the same at both locations.

During the calibration process, depth and velocity were measured first, then two successive samples were collected (each for a duration of 3 min), then the collecting tank was used for load measurement over a duration of 6 min, and finally two further samples were collected. The mean of these four samples was used to calculate the bed load discharge measured by the sampler, and this was compared with the standard discharge obtained from the tank. Finally, the ratio of the discharge per unit width measured using the sampler to that obtained from the collecting tank was calculated to provide the required value of K_e.

Determination of the trapping (or sampling) coefficient

Figure 11 shows the relationship between V_f and q_s, and V_s and q_f plotted on rectangular coordinates. Both plots show clearly defined trends. Curve A shows the result of the test with fine sediment (d_{50} = 0.5-0.63 mm). Curve B shows the result of the test with coarsened sediment with d_{50} = 0.53-1.60 mm (the coarse sediment 3-5 mm in size in the lower layer was mixed with the fine sediment by turbulence). It is clear that the transport values obtained from curve B are less than those obtained from

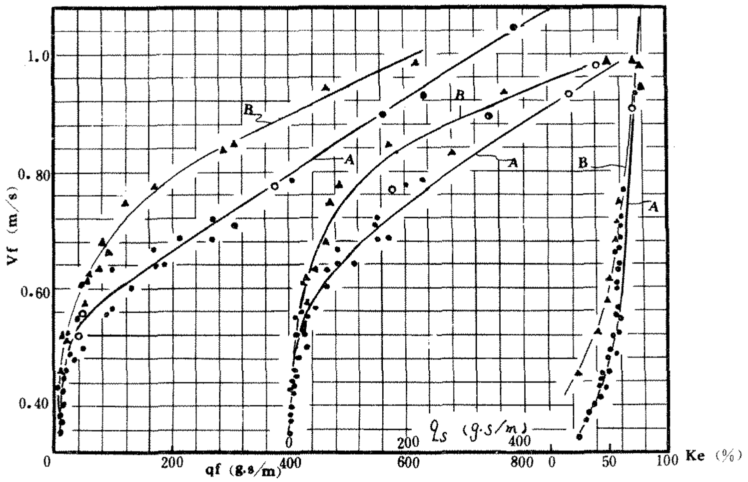

Fig. 11 Plots of V_f/q_f, V_s/q_s, and V_f/K_e for the Yangtze 78 sampler.

curve A. This means that the bed load discharge per unit width is affected by sediment grain size and this is clearly seen on the curve relating V_f and K_e. The value of K_e varies considerably at values of V_f less than 0.5 m s^{-1}, but remains relatively constant when V_f exceeds 0.5 m s^{-1}. If velocity is held constant, the value of K_e increases as the particle size decreases, and the value of K_e decreases as the particle size increases. When V_f exceeds 0.9 m s^{-1}, the value of K_e is nearly the same for the different particle sizes used in the test.

In Table 2, when V_f exceeds 0.5 m s^{-1} the measured value of K_e is between 60.2 and 64.4% for both kinds of sediment. This value approaches that obtained from the curve (i.e. K_e = 60-62.8%). It is suggested that an average value of 61.4% should be used. Because of the influence of the flume boundary and the restricted water depth, the flume calibration conditions differ from those in natural streams. The trap efficiency of the Yangtze 78 sampler therefore still requires testing in the field, but because stable conditions of water flow and sediment transport cannot be maintained in the field, the results from such investigations are not entirely reliable. The result of the calibration obtained

Table 2 The trapping efficiency of the Yangtze 78 sampler

Particle size of bed material d_{50} (mm)	Velocity range V_f (m s^{-1})	Number of tests	K_e (%) mean value: $V_f < 0.5$ (m s^{-1}) Measured	From curve	$V_f > 0.5$ (m s^{-1}) Measured	From curve
0.5 ~ 0.63	V_f 0.347 ~ 1.045 K_e 22.1 ~ 87.0%	36	47.8	43.6	60.2	62.8
0.53 ~ 1.60	V_f 0.518 ~ 0.911 K_e 30.8 ~ 122.3%	15			64.4	60.6

using the wide flume at the Chengdu University of Science and Technology is therefore extremely valuable (the width of the flume is 7.5 times that of the sampler in test).