Erosion and Sediment Transport Measurement (Proceedings of the Florence Symposium, June 1981). IAHS Publ. no. 133.

Analysis of a simple suspended load integrating sampler

I. BECCHI, P. BILLI & P. TACCONI
Istituto di Ingegneria Civile, Università di Firenze, Via di S. Marta 3, 50139 Firenze, Italy

ABSTRACT The behaviour of a new type of suspended load integrating sampler (Becchi *et al.*, 1979) is studied and analysed. The physical characteristics of this sampler and the calibration methods are described. On the basis of a large quantity of experimental data on the sediments collected and the flow velocity, the behaviour of the sampler is analysed. An assessment is made of the effects of various modifications on the performance of the sampler, in particular the type of paper used for the filtering bag. Finally, measurement errors and their causes are determined.

Etude sur un échantillonneur simple intégrateur du transport en suspension

RESUME On étudie dans ce qui suit un nouveau type d'échantillonneur du transport solide en suspension qui a *été déjà presenté dans un article précédent* (Becchi *et al.*, 1979). On décrit d'abord les dispositions de l'échantillonneur et la méthode d'étalonnage employée. Ensuite, d'après de nombreuses données d'étalonnage, nous avons analysé les variations de son fonctionnement en fonction des caractéristiques des sédiments recueillis et de la vitesse de l'eau. Les lois de comportement de l'appareil sont décrites en fonction des changements dans les solutions techniques adoptées pour l'échantillonneur, *en particulier* du type de sachet de papier-filtre. On a enfin essayé de déterminer l'erreur intrinsèque de l'appareil et les moyens de la réduire.

INTRODUCTION

The filtering bag integrating sampler for suspended sediment and an assessment of its performance have been described in a previous paper (Becchi *et al.*, 1979). This type of sampler has been developed mainly for use in the field in order to analyse sediment transport in small basins, where it is very important to have automatic suspended sediment samplers.

Data collected by the filtering bag integrating sampler differ substantially from those collected by standard bottle or pumping samplers (DH 48, D 59, P 63, etc.) as follows.

(a) The filtering bag integrating sampler measure a weight of sediment not a concentration, and so it is not extended to the water discharge but to the flow cross section.

(b) It cannot collect data over long periods: depending on the sediment concentration and the discharge, the filtering bag integrating sampler can function for a period of a few hours to a week, so it is capable of measuring the full range of natural sediment transport phenomena.

(c) Because of its low cost the filtering bag integrating sampler can be installed at more points along a river section, thus giving a more detailed spatial description of the sediment transport.

(d) The data are easily collected, and obtained from dry weighing.

(e) The sampler can also give the grain size distribution (with a maximum weight of 50 g) of the suspended sediment transport.

(f) The sampler can remain in water (two weeks), or stay dry, or both alternatively.

(g) The samples obtained are easily stored and transported.

For these reasons the filtering bag integrating sampler is suitable for extensive use in sediment transport analyses of rivers under different climatic and morphological regimes.

No significant problems have arisen from its use in the field, other than the nozzle occasionally becoming blocked by mud balls, or the sampler sloping or rotating. Because of the shape of the nozzle of the sampler, it is generally not blocked by leaves, paper and other organic material that usually obstruct the intakes of other samplers and it is too small to attract insects or other animals.

At this moment, the greatest problem is the accurate calibration of the sampler.

In an earlier paper (Becchi *et al.*, 1979) it was stated that the weight of sediment G_T at time T was proportional to the water velocity:

$$G_T = \frac{1}{T}\int_0^T v_x \ c \ dt \qquad (1)$$

where v_x and c are the point velocity and concentration. In this way we avoid determining the sediment transport from the product of mean velocity and mean concentration with the consequent need of cross relation coefficient evaluation (De Vries, 1976).

From a theoretical point of view, the preliminary analysis gave a nearly proportional kinematic behaviour expression in the form

$$v_e = v_i \ \frac{\left[a_1 + (a_2/v_i)\right]^{\frac{1}{2}} - (a_2/v_i)}{a_3} \qquad (2)$$

where v_e and v_i are outgoing and incoming velocity respectively, and a_1, a_2, a_3 are coefficients of the sampler for different types of hydraulic resistances.

The first results confirmed it is possible to use (1) as a quasilinear relation but they also indicated it was impossible to specify the sampling output at different grain size distributions.

The present study describes laboratory tests using different types of filtering bag and sampling nozzle, and sediments with varying grain size, concentration, and velocity.

DESCRIPTION AND CALIBRATION OF SAMPLER

The filtering bag integrating sampler (Fig. 1) comprises: a perforated metal cage, a paper filtering bag and a moulded polythene nozzle. The nozzle and the filtering bag are heat sealed by a simple operation and are then inserted into the cage. The nozzle is fixed at an angle of 15° to the horizontal in order to avoid bubble occlusion. Initially the nozzle (T type) had a symmetrical truncated conical shape, but this resulted in sediment collecting inside the nozzle because of the angled intake. Subsequent modifications included a vertical intake and then an asymmetrical nozzle. The present nozzles have flanges for easy fastening to the case and setting in the right direction. The nozzle and bag are represented in Figs 2, 3, and 4.

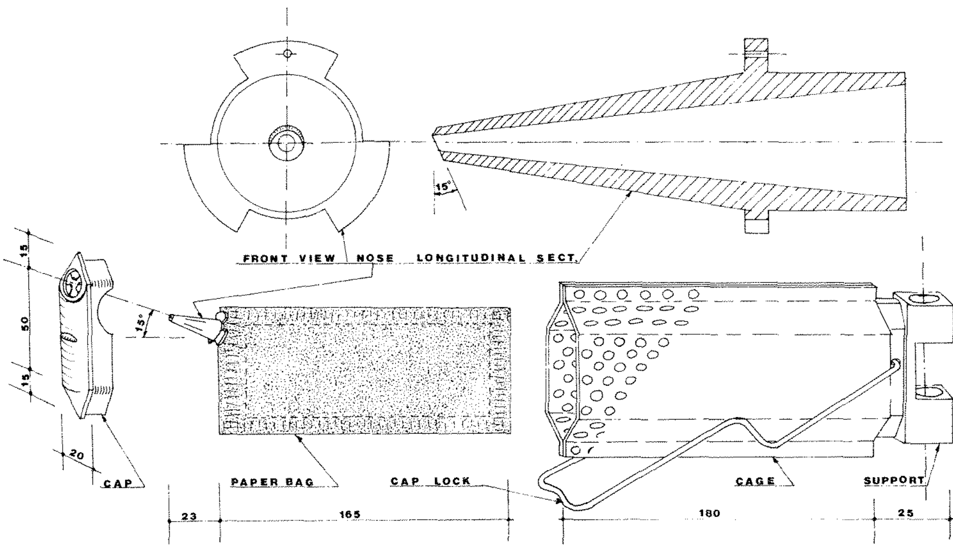

Fig. 1 Exploded diagram of the sampler showing the different parts and an enlarged view of the nozzle from the front and in section.

For sampler calibration a recirculating flume was used with cross section = 20 x 30 cm, length = 120 cm, discharge $\lesssim$ 10 l s^{-1}, slope $\lesssim$ 5%. The flume has a tank for complete sediment recirculation and a diffusor to provide the turbulence necessary for sediment suspension. The calibration runs lasted from an hour of two days of continual working depending on how long the sampler's bag lasted. Filtering bags made from two weights of heat sealed tea bag paper were used: type "T" 17 g m^{-2} and type "B" 25 g m^{-2}. The structure of the unwoven filter paper is shown in Fig. 5, where it can be seen that types T and B have non uniform perforations with average diameters of 80 and 40 μ respectively. These filtering bags are rectangular with inner dimensions of 150 x 60 mm and can contain up to 60 g of dry sediments. The ratio between the nozzle intake (ϕ 1 mm = 0.785mm^2) and the filter surface area (~10^4 mm^2) allows us to neglect the coefficient a_2 in equation (2). As the present calibration tests were intended to specify the sediment ranges for which the

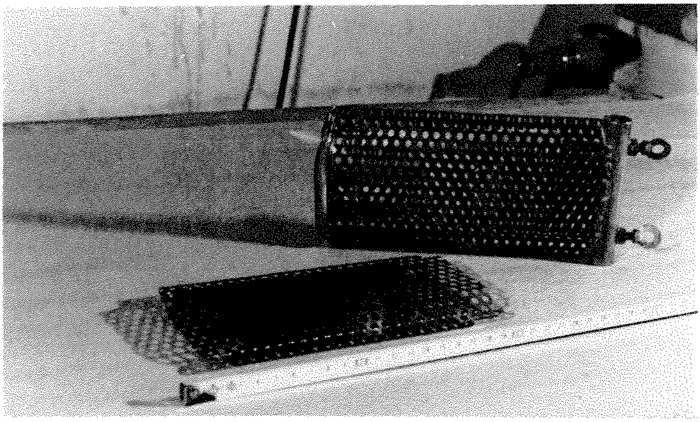

Fig. 2 The "B" type sampler assembled.

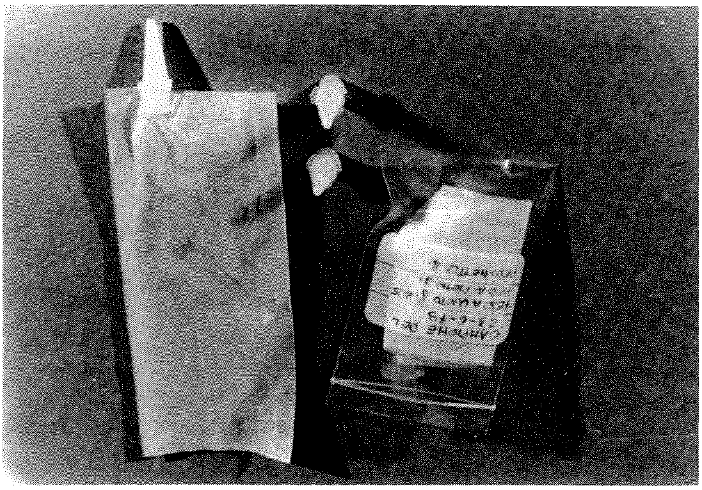

Fig. 3 The filtering bag, the nozzle and the plastic envelope with label to record experimental details.

Fig. 4 The filtering bag showing the sediment collected inside.

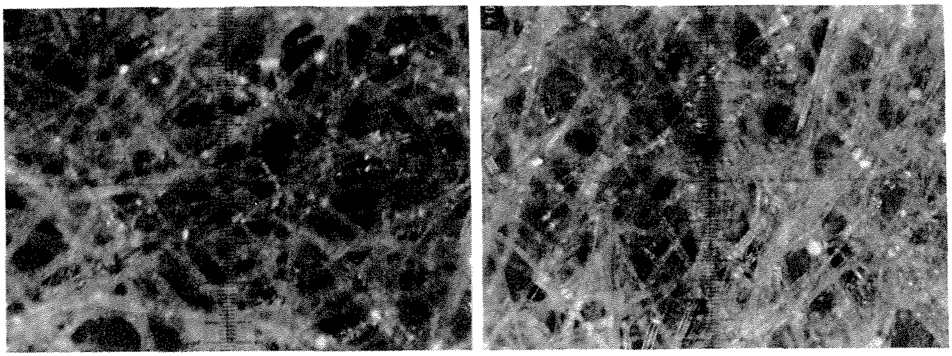

Fig. 5 Microphotographs of the filter papers: type B (*right*) and type T (*left*); each division on vertical scale = 10 μ.

sampler is applicable, the size of the grains and in particular the grain size distribution in the circulating water-sediment mixture in the flume is important.

Figure 6 represents the grain size distribution of the materials used (B1A and B2A) and the grain size distribution of the material collected by the sampler (B1B and B2B). In the same diagram the grain size distribution of the materials (T1 and T2) used in the first analysis are represented too.

The temperature of the water in the flume ranged from 20 to 25°C.

ANALYSIS OF THE LABORATORY RESULTS

The first calibration results (bag T), showed a large scattering of measurements and poor sampling efficiency for fine sediments < 80 µ. We repeated the tests using type B bags made from the thicker paper and finer sediments. The tests results are plotted on loglog paper in Fig. 7, where we have velocity per measured concentration on the x axis and the rate sediments were collected by the sampler on the y axis. From this diagram it is possible to see that, compared with the previous series, either the data scattering has increased or efficiency of average weight

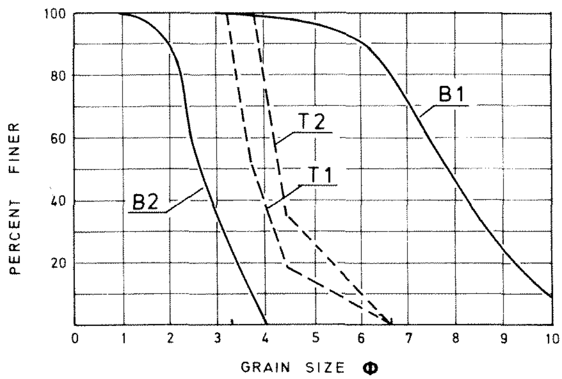

Fig. 6 Grain size distribution of the sediment used for calibration of T and B types of filter paper.

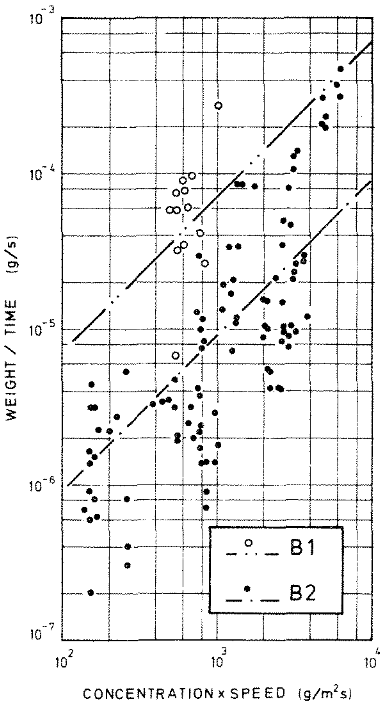

Fig. 7 The results of the B type calibrations plotted as weight over time as a function of sediment concentration per flow velocity; the lines represent the average proportionality coefficient.

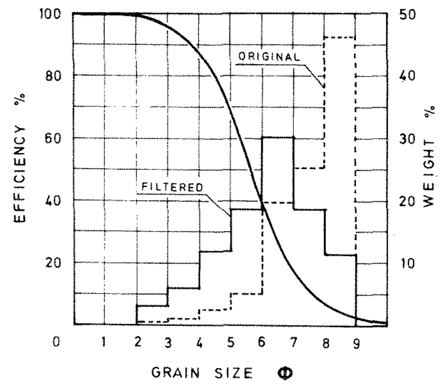

Fig. 8 Comparison of frequencies of weights of original and filtered sediments and the relationship between filtering efficiency and grain size ϕ.

collected has reduced. To investigate the causes of the reduced efficiency we compared the grain size distributions of the sediments collected by the sampler with those in the flume.

Figure 8 shows for the type B tests: the frequency of weight distribution in the flume; the frequency of weight distribution of the sediments collected in the filtering bag; the filtering efficiency of the type B paper. It can be seen that there is good agreement among these three features; in fact, calling f the parent sediment frequency by weight, f' that of the collected sediments and η the filtering efficiency:

$$f' = \eta\ f/\int_0^\infty \eta(\phi).f(\phi)d\phi \tag{3}$$

where the integral ($\leqslant 1$) represents the global capture efficiency of the filtering paper. Taking the dependence of filtering efficiency on grain diameter as

$$\eta = \frac{1}{1+0.00141/d^{1.6}} = \frac{1}{1+10^{(\phi/2-2.85)}} \tag{4}$$

it is possible to obtain the parent sediment frequency by weight from the following relation, inverse to (3):

$$f = (f'/\eta)/\int_0^\infty f'(\phi)/\eta(\phi)d\phi \tag{5}$$

where the integral ($\geqslant 1$) must be equal to the inverse of that in equation (3) and represents the reduction factor of the collected sample.

From the above analysis we found that the filtering paper had a reliable performance, therefore we assumed that the nozzle was the main cause of the data scattering. In fact from preliminary tests using prototype samplers we found that small changes in nozzle shape produced large changes in the behaviour of the sampler.

Then, in order to evaluate the variability of the hydraulic behaviour, we analysed the sampler proportionality coefficient corrected by the reduction factor from equation (5). Results of the statistical analysis are reported in Fig. 9, where data for both type B and type T filter paper are plotted on lognormal paper; it is clear that compared with type T, type B shows not only a large increase in variance but also a strong reduction in the hydrodynamic efficiency of the nozzle.

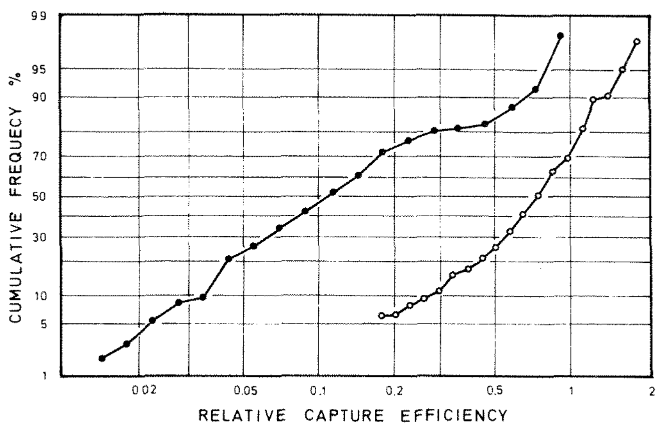

Fig. 9 Frequency analysis for T (open circles) and B (solid circles) tests considering the relative capture efficiency as the ratio between measured and theoretical hydrodynamic efficiency.

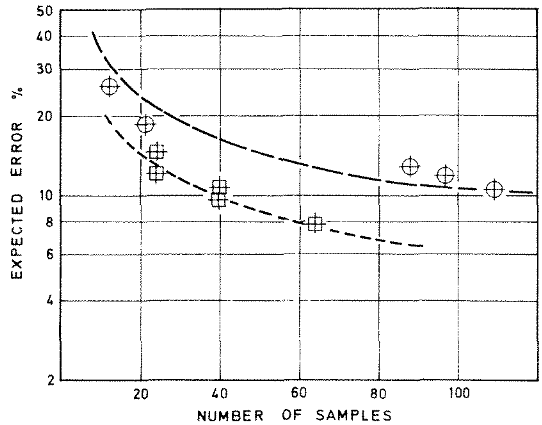

Fig. 10 The expected mean error as a function of the number of samples for type T (squares) and type B (circles) filtering bags.

CONCLUSIONS

The analysis of the experiments on the influence of grain size, paper density, flow velocity and sediment concentration, allows us to have a better understanding of the behaviour of the filtering bag integrating sampler. Knowing the filtering efficiency of the paper makes it possible to obtain the grain size distribution of the parent sediment from the sampled one.

From the above analysis the hydrodynamic efficiency of the nozzle/filter bag system appears very important because moderate increases in hydraulic resistances (≃40%) result in large reductions in efficiency (≃6.5 times); that is, the most critical effect on the sampler behaviour. As an example, Fig. 10 shows the errors expected in the average measurement, obtained from the statistical specimens examined for type B and type T filtering bags. We think it is necessary for type T to undergo further developments especially by previous calibration of the hydraulic resistances.

ACKNOWLEDGEMENTS This work was supported by CNR 'Progetto Finalizzato Conservazione del Suolo' sottoprogetto Dinamica Fluviale - UO no. 21, Ist. Ingegneria Civile, Florence University, Italy.

REFERENCES

Becchi, I., Tacconi, P. & Terrosi, F. (1979) A new type of suspended load sampler. In: *Incontro delle Unità di ricerca toscane con gli enti utilizzatori sui temi concernenti la potenzialità e utilizzazione dei suoli, l'erosione dei versanti, le frane, la dinamica fluviale e la dinamica dei litorali.* CNR Firenze, C.1-10.

De Vries, M. (1976) Morphological computations. Lecture notes, Univ. of Technology, Delft.