COMPARISON OF BED LOAD SAMPLER AND TRACER DATA ON INITIATION OF MOTION

By M. Ashiq[1] and J. C. Bathurst[2]

ABSTRACT: Concerns that the Helley-Smith bed load sampler and painted tracer techniques measure different critical discharges for the initiation of motion for each particle size in coarse bed material rivers are investigated for two sites on the Roaring River in Colorado. For the sampler technique, the size of the largest particle trapped is paired with the discharge at the time of sampling. For the tracer technique, the maximum size of tracer moved is paired with the maximum discharge between emplacement and observation. Performance considerations suggest that the sampler technique may yield a larger critical discharge for a given particle size than will the tracer technique. The limited field data support this when the tracer measurements refer to the absolute maximum size moved. When the tracer measurements refer to the largest size moved for which all smaller sizes were moved, the data overlap the sampler data. Caution should therefore be displayed when using data from either technique to develop or test formulas for initiation of particle motion, as such formulas may show a small level of technique dependence.

INTRODUCTION

Recent years have seen a number of attempts to derive formulas for calculating the critical flow conditions for initiation of motion for each particle size in coarse river bed materials of nonuniform size distribution (e.g., Andrews 1983, 1994; Bathurst 1987). Typically, these formulas are of the form

$$\frac{F_i}{F_r} = \left(\frac{D_i}{D_r}\right)^b \tag{1}$$

where F_i = critical flow quantity (e.g., shear stress or discharge per unit width) for initiation of motion of particles of size D_i. The subscript r refers to a reference condition (often for the median value from the particle size distribution). The exponent b is determined empirically and, for this, it is necessary to collect data. A common technique is to use bed load samplers (such as the Helley-Smith pressure difference sampler) to determine the maximum particle size that can be moved under given flow conditions. Data may also be collected using the tracer technique, in which the conditions required for movement of painted, or otherwise marked, particles placed on the bed are observed. However, tracer data collected at U.K. river sites (Inpasihardjo 1991; Ashiq 1997) yield a different distribution of values of exponent b from that for data collected with a Helley-Smith pressure difference bed load sampler at sites in Colorado and Austria (Bathurst 1987; Inpasihardjo 1991). It is not clear whether this difference is a function of some physical effect differing between the sites or a result of the different measurement technique. The latter possibility must be quantified before the former can be investigated with confidence. However, there do not appear to have been any comparative studies of the Helley-Smith sampler and tracer techniques. This note therefore reports a study in which direct comparison is made of the Helley-Smith sampler and tracer techniques to investigate their compatibility. The duration of the study and the resources available for the fieldwork were limited, and the study should therefore be viewed as an initial investigation rather than a definitive conclusion.

FIELD SITE

Measurements were made at two sites on the Roaring River, Rocky Mountain National Park, Colorado, June 1–8, 1995, and July 6–10, 1995, representing periods of early and late snowmelt, respectively. At the upstream site (Ypsilon Lake Trail Bridge), the channel was a little over 6 m wide and had a slope of around 0.035 m m^{-1}. The size of the intermediate particle axis for which 84% of the material is finer was around 230–250 mm [as determined using Wolman's (1954) technique]. The Helley-Smith measurements were made from the trail bridge; the tracer measurements were made in a 30 m reach immediately upstream of the bridge.

At the downstream site (Alluvial Fan bridge), the Helley-Smith measurements were made from the road bridge on the Roaring River fan immediately above its confluence with the Fall River. The tracer measurements were made on a shoal about 60 m upstream from the road bridge, which studies in previous years have suggested controls the bed load transport at the bridge. At the shoal, the channel width was around 7–10 m, the slope varied from 0.033 to 0.048 m m^{-1} between the sampling periods, and the 84% particle size increased from 150 to 240 mm, also between the two periods. (A major snowmelt event caused significant channel changes in mid-June. Such was its severity that the June and July sampling periods may almost be considered to refer to two different rivers.)

Further details of the Roaring River sites are given in Bathurst et al. (1986a), Bathurst (1987), and Bathurst and Ashiq (1998).

FIELD MEASUREMENTS

Water discharge was obtained from stage measurements using a stage/discharge relationship derived from discharge gaugings with a Price AA cup current meter. Typical snowmelt peak discharges are around 5 m^{3}s^{-1}, although the major event of mid-June 1995 probably reached at least twice this value. The data collected to investigate initiation of motion were pairs of size D_i of the particle intermediate axis and the critical unit water discharge q_{ci} associated with movement of that size.

Tracer Technique

The tracer technique monitors the movement of the tracer particles by flood events. The maximum size of tracer moved is assumed to have a critical discharge for initiation of motion equal to the peak flood discharge.

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[1] Staff Member, Ctr. of Excellence in Water Resour. Engrg., Univ. of Engrg. and Technol., Lahore 54890, Pakistan; formerly, Res. Student, Dept. of Civ. Engrg., Univ. of Newcastle upon Tyne, Newcastle upon Tyne NE1 7RU, U.K.

[2] Reader, Water Resour. Sys. Res. Lab., Dept. of Civ. Engrg., Univ. of Newcastle upon Tyne, Newcastle upon Tyne NE1 7RU, U.K.

Note. Discussion open until November 1, 1999. To extend the closing date one month, a written request must be filed with the ASCE Manager of Journals. The manuscript for this technical note was submitted for review and possible publication on April 2, 1998. This technical note is part of the ***Journal of Hydraulic Engineering***, Vol. 125, No. 6, June, 1999. ©ASCE, ISSN 0733-9429/99/0006-0661–0664/$8.00 + $.50 per page. Technical Note No. 18009.

TABLE 1. Maximum Upper Size (MUS) and Maximum Lower Size (MLS) of Moved Tracers and Corresponding Maximum Water Discharges

Site (1)	Period of data collection (2)	Date of tracer emplacement (d/m/y) (3)	Date of tracer observation (d/m/y) (4)	Mean channel width (m) (5)	Maximum water discharge (m^3 s^{-1}) (6)	Maximum discharge per unit width (m^3 s^{-1} m^{-1}) (7)	Maximum upper size of moved tracers[a] (mm) (8)	Maximum lower size of moved tracers[a] (mm) (9)
Ypsilon Lake trail bridge	May–June 1995	31/5/95	6/6/95	6.25	1.85	0.30	57	32
		6/6/95	7/6/95	6.25	2.10	0.34	60	40
		7/6/95	8/6/95	6.25	1.96	0.31	65	40
	July 1995	6/7/95	7/7/95	6.88	3.53	0.51	100	<65[b]
		7/7/95	8/7/95	6.88	3.80	0.55	100	<60[b]
		8/7/95	9/7/95	6.88	3.80	0.55	120	60
		9/7/95	10/7/95	6.88	4.13	0.60	135	65
Alluvial Fan road bridge	May–June 1995	5/6/95	6/6/95	9.83	1.98	0.20	88	50
		6/6/95	7/6/95	9.83	2.25	0.23	82	40
		7/6/95	8/6/95	9.83	2.10	0.21	62	<35[b]
	July 1995	6/7/95	7/7/95	7.5	3.53	0.47	70	45
		7/7/95	8/7/95	7.5	3.80	0.51	125	70
		8/7/95	9/7/95	7.5	3.80	0.51	115	85
		9/7/95	10/7/95	7.5	4.13	0.55	110	85

[a] Measurement refers to intermediate axis of tracer.

[b] Minimum tracer size (shown) did not move. MLS is therefore less than this size.

For the Roaring River sites, tracers were selected from the bed material to represent a range of particle sizes (27–230 mm at the upstream site and 28–210 mm at the downstream site). The tracers were painted with yellow road paint, their sizes were recorded, and they were placed in a single line across each site. Discharge varied diurnally, with peak snowmelt flows occurring at the sites in the early evening. The positions of the tracers were therefore recorded in the morning, noting which tracers had been moved by the previous evening's flow and which had not. Tracers that had disappeared were replaced by new ones, and the line was reformed, ready for the next evening's high flow.

In pairing the maximum size of moved tracer with the peak discharge of the previous evening, it was usually found that not all the tracers smaller than the maximum size moved had themselves moved. A few smaller ones remained at their original positions, perhaps because they happened to be located in a slower part of the flow or were protected by larger bed material particles. Both the absolute maximum size of tracer moved and the largest tracer size moved for which all smaller sizes were moved were therefore recorded. These are referred to as the maximum upper size (MUS) and the maximum lower size (MLS), respectively. A record of the tracer sizes moved and the associated peak discharges measured between particle emplacement and observation of movement is given in Table 1.

Helley-Smith Sampler Technique

In the sampler technique, the size of the largest particle trapped is paired with the discharge at the time of sampling.

Bed load transport was measured with a 150 mm aperture Helley-Smith sampler held from a rod. The samples were collected in a 4,000 cm^2 mesh bag, with a mesh size of 0.2 mm. Sampling time varied but was shorter (30–90 s) in early June, when fine sediment caused clogging of the mesh bag, compared with typically 180 s in July. Measurements were made at intervals of 30 minutes during periods of 30 minutes to 8 1/2 hours. At the downstream site, measurements covered most of the range of discharges from the daytime minimum to the evening peak. A more restricted coverage was obtained at the upstream site because of its greater remoteness. The maximum particle size in each sample was identified by eye, and its intermediate axis was measured; there was rarely any difficulty in making such an identification, but a ruler was used if there was any doubt.

Because the sampler did not catch all the bed load passing a section and because the samples represented a restricted time period, the maximum particle size in any individual sample was not necessarily equal to the maximum size that could be set in motion by the recorded water discharge. In order to obtain a more representative value, therefore, the maximum particle size was taken, not from each individual bed load sample, but from the combined samples collected during the periods, or parts of the periods, of continual sampling. These periods corresponded to either steady or rising discharge regimes. The pairs of particle sizes and discharges so obtained

TABLE 2. Maximum Particle Sizes Trapped by Helley-Smith Sampler

Site and period of data collection (1)	Date (d/m/y) (2)	Discharge (m^3 s^{-1}) (3)	Discharge per unit width (m^3 s^{-1} m^{-1}) (4)	Maximum size of trapped particle (mm) (5)
Ypsilon Lake trail bridge, July 1995	6/7/95	2.32	0.34	9
	8/7/95	3.31	0.48	16
		3.47	0.50	60
		3.64	0.53	45
		3.70	0.54	29
	9/7/95	3.35	0.49	20
Alluvial Fan road bridge, May–June 1995	5/6/95	1.63	0.17	10
		1.77	0.18	17
		2.00	0.20	46
	6/6/95	2.00	0.20	13
		2.12	0.22	29
	7/6/95	2.12	0.22	21
July 1995	6/7/95	2.73	0.36	24
		3.43	0.46	38
		3.53	0.47	46
	7/7/95	3.43	0.46	39
		3.80	0.51	37
		3.80	0.51	70
	8/7/95	2.99	0.40	17
		3.80	0.51	40
	9/7/95	3.72	0.50	50
		4.05	0.54	62
		4.13	0.55	35
	10/7/95	4.88	0.65	100

are given in Table 2. An analysis of the wider bed load transport regime is given in Bathurst and Ashiq (1998).

The Helley-Smith sampler is described by Helley and Smith (1971) and Emmett (1980). Its efficiency and use for gravel-bed rivers has been investigated by, among others, Johnson et al. (1977), O'Leary and Beschta (1981), and Hubbell et al. (1985). Use of the standard 76 mm Helley-Smith sampler to trap coarse gravel (32–64 mm) is documented for a large number of cases in Williams and Rosgen (1989) and by individual studies such as Andrews (1994). Use of the 150 mm sampler is more rarely reported [Johnson et al. (1977) and Hubbell et al. (1985) test this among a range of aperture sizes] but the procedure for the Roaring River is documented in Bathurst et al. (1986b). Ryan (1998) shows that differences in sampler design and the lack of a consensus on the correct sampling procedure can significantly influence the results. In particular, there is no standard approach for boulder-bed rivers like the Roaring River. It should be noted, though, that this study is concerned not with the bed load catch (the subject of most previous studies of the Helley-Smith sampler), but with the measurement of the maximum particle size in motion. The deficiencies of the sampler in this respect are raised in the discussion.

COMPARISON OF TECHNIQUES

The data are plotted on graphs of unit water discharge against maximum particle size. Figs. 1(a and c) compare the Helley-Smith sampler data with the tracer maximum upper size (MUS) data. Figs. 1(b and d) compare the sampler data with the tracer maximum lower size (MLS). In each case the data are distinguished by site and sampling period. Regression lines are fitted to the sampler data, but the tracer data are too few to be represented in the same way. The diagram and the tables show there to be a degree of variability in the results. For example, successive sampler results at the Alluvial Fan bridge on July 7 show maximum particle sizes of 37 and 70 mm at the discharge of 3.8 $m^3 s^1$. This is partly an indication of the deficiencies of the techniques but may also be a function of the bed load flux, which is well known to be unsteady even in steady flow (e.g., Hubbell et al. 1985; Reid and Frostick 1986). Nevertheless, despite the uncertainty in the techniques, there is strong order of magnitude agreement between their results. This suggests that the techniques are relatively robust and inspires confidence in their use. At the detailed level, though, there is a consistent pattern of both differences and agreement. For the limited range of data available, there is a generally good agreement between the sampler and tracer MLS data. The tracer data fall neatly within the range of scatter of the sampler data. The tracer MUS data, however, show a slight offset from the sampler data, as they refer to larger particle sizes than the MLS data.

The largest particle size recorded moving by either technique was 135 mm, smaller than the sampler aperture. Larger tracers were not moved by any flow during the study period.

DISCUSSION

Tracers might be thought to provide the more appropriate technique for determining the critical conditions, because they deal explicitly with initiation of motion, whereas the bed load sampler traps material already in motion. Tracers are also site specific, while samplers may trap material set in motion at some upstream location. Moreover, samplers are likely to miss the larger moving particles, partly because such sizes move relatively infrequently (and may not be caught during short sampling periods) and partly because the size of the sampler mouth limits the maximum size that can be caught. This suggests that the sampler technique is likely to underestimate the maximum size in motion at a given discharge and therefore to overestimate the critical discharge for a given particle size. By contrast, the tracer technique is open to the charge that artifi-

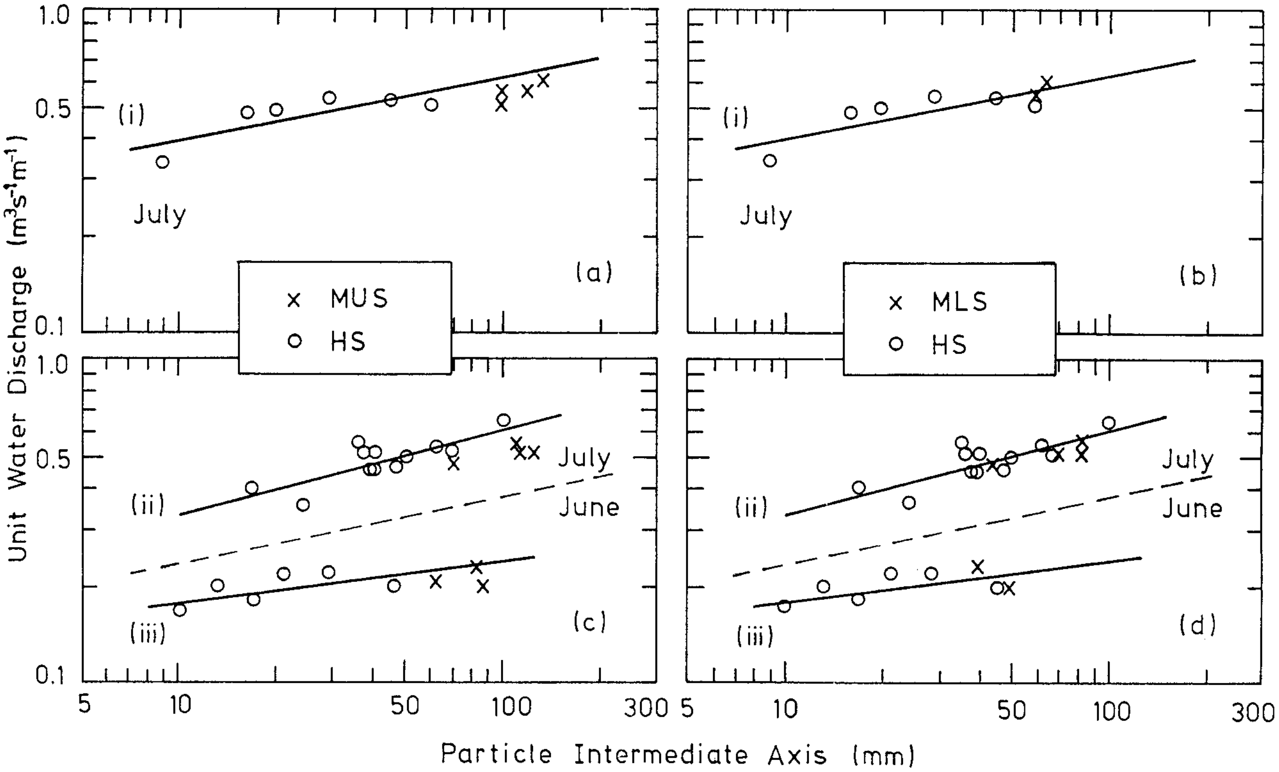

FIG. 1. Relationship between Unit Water Discharge and Maximum Particle Size (Intermediate Axis) Moved for June and July 1995; Comparison of Helley-Smith Sampler Data (HS) with: (a) MUS and (b) MLS Tracer Data for Ypsilon Lake Trail Bridge Site; and (c) MUS and (d) MLS Tracer Data for Alluvial Fan Road Bridge Site [Power Laws Fitted to Helley-Smith Sampler Data Have Coefficient/Exponent Values: (i) 0.253/0.196; (ii) 0.181/0.266; and (iii) 0.137/0.120]

cial placement of the tracers means that they are not naturally settled in the bed and can be moved relatively easily, giving an underestimate of the true critical discharge. (At the Roaring River sites, an attempt was made to avoid this problem by letting the tracers achieve natural positions through their initial movements before monitoring their subsequent travels. Tracers that moved less than 2.5 m from their original position were recorded as not moving.) Recovery of tracers is also a source of error; a tracer which cannot be found is likely to be recorded as having moved, whereas in reality it may simply have been buried at its placement position; again, the result is an underestimate of the true critical discharge. (This problem can be avoided to some extent by using magnetic or radio-tagged tracers.) The deficiencies in both techniques suggest, therefore, that the sampler technique may yield a larger critical discharge for a given particle size than will the tracer technique. Neither technique may be completely accurate in representing the true critical conditions.

If the above deficiencies were ineffective, the Helley-Smith sampler technique would correspond to the tracer MUS technique, since both concern the maximum particle size in motion without consideration as to whether all available such sizes and all smaller sizes are set in motion. The observation [Figs. 1(a and c)] that the sampler technique does indeed yield a slightly larger critical discharge for a given particle size than the tracer MUS technique suggests that the deficiencies do have an effect and that they act in the manner described above.

The good agreement between the sampler and tracer MLS results for the Roaring River sites may be fortuitous. Nevertheless, it raises the possibility that the sampler technique, with its deficiencies, yields results which equate with the critical conditions for particle movement representative of the bed as a whole, as measured by the tracer MLS technique. Further research, though, is needed to examine such a correspondence.

CONCLUSIONS

The data collected in this study are too few to enable a definitive conclusion to be drawn on the compatibility of the sampler and tracer techniques for determining the critical conditions for initiation of particle movement. However, the data are considered worthy of publication to highlight a problem that has received little previous attention. For the Roaring River sites, the data show that the sampler technique yields a slightly larger critical discharge for a given particle size than does the tracer MUS technique. With the present data, it cannot be stated whether this difference accounts for the variation in the exponent b referred to in the introduction. This leaves open the possibility that formulas for the initiation of motion are incomplete and must account for further physical effects, perhaps particle shape. Researchers should nevertheless be aware of the inexact compatibility of the tracer and sampler techniques and be cautious when using data from either to develop and test formulas for initiation of particle motion. Until the differences between the techniques have been more accurately defined, such formulas may show a small level of technique dependence.

ACKNOWLEDGMENTS

The writers thank Dr. Kenneth Czarnowski, Research Administrator, and the staff of the Rocky Mountain National Park for supporting this study and for their most helpful provision of laboratory and other facilities. The writers are also extremely grateful to Dr. Bob Jarrett (United States Geological Survey) and Dr. Lee MacDonald (Colorado State University) for their most generous loan of essential field equipment, and to John England (Colorado State University) for his enthusiastic help with the July 1995 measurements. Fieldwork funding was provided (for the first writer) by a travel award and (for the second writer) partly by staff travel funds, in both cases from the University of Newcastle upon Tyne. Two anonymous referees provided constructive suggestions for improving this technical note.

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