UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

LABORATORY HYDRAULIC CALIBRATION OF THE HELLEY- SMITH BEDLOAD SEDIMENT SAMPLER

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LABORATORY HYDRAULIC CALIBRATION OF THE HELLEY-SMITH BEDLOAD SEDIMENT SAMPLER

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ABSTRACT

The Helley-Smith bedload sampler operates on a pressure-difference principle and consists of an expanding nozzle, nylon-mesh sample bag, and external components for structural integrity and stability under flow conditions. The Helley-Smith bedload sampler has a hydraulic efficiency, the ratio of the mean velocity in the sampler nozzle to the mean ambient velocity, of approximately 1.54. Factors affecting the hydraulic efficiency include the geometry of the orifice and the open area of the sampler bag.

The exit-to-entrance area ratio of the nozzle is the major factor influencing hydraulic characteristics of the sampler. For the nozzles tested, the hydraulic efficiency rapidly increased to a maximum value as the exit-to-entrance area ratio increased. The hydraulic efficiency increased from 1.06 to 1.54 as the exit-entrance area ratio increased from 1.00 to 2.62. With an exit-entrance ratio greater than 2.62 but less than 3.22, this efficiency remained constant at 1.55.

Filling the sample bag to 40 percent capacity with a sediment larger in diameter than the mesh size of the bag had no effect on the hydraulic efficiency. Particles close to the 0.2 mm mesh size of the sample bag plugged the openings and caused the efficiency to decrease in an undetermined manner.

INTRODUCTION

The measurement of bedload transport in alluvial channels is a significant problem in river hydraulics. Hubbell (1964) and U.S. Interagency Committee on Water Resources (1963) described techniques and samplers used to measure bedload. In general, bedload samplers can be classified into two types: The direct-measuring type accumulates sediment in a chamber within the sampler, and the indirect-measuring type measures some phenomenon that occurs as a result of bedload transport. The direct-measuring type is the simplest and most widely used. Ideally, a direct-measuring sampler collects the bedload moving in its path without distorting the velocity profile or sediment being moved by the adjacent flow. Collected samples would then be representative in that every particle-size fraction is present in the sample in the same proportion as in the bedload discharge. The ideal sampler can be placed on the stream bed and retrieved without altering the quantity or composition of the sample. Direct-measuring samplers that operate on a pressure-difference principle show promise of meeting the criteria of an ideal sampler. Pressure-difference samplers consist of an expanding nozzle which intercepts the sediment-laden flow and a chamber in which the sample is collected. The expanding section of the nozzle creates the pressure difference across the nozzle necessary to cause flow through the nozzle.

Helley and Smith (1971) introduced a pressure-difference bedload sampler that is a structurally modified version of the Arnhem sampler (Hubbell, 1964). The Helley-Smith bedload sampler has an expanding nozzle, sample bag, and frame (fig. 1). The sampler was designed to be used in flows with mean velocities to 3 m/s and sediment sizes from 2 to 10 mm. The sampler had a square 7.62 cm entrance nozzle and a 0.46-m-long sample bag constructed of 0.2 mm mesh polyester. The standard sample bag had a surface area of approximately 1,900 cm^2.

Since this original design, several versions of the sampler have been made to adapt the sampler to various field uses. One extensively used version has been scaled up from the 7.62 cm sampler. The orifice is twice scale (15.24 cm) and the frame is one and one-half scale. This unit is used to sample larger sediment sizes at high velocities. The 7.62-cm and 15.24-cm versions of the Helley-Smith sampler are illustrated in figures 2 and 3.

The hydraulic and sampling efficiency are two measures of sampler performance in the field application of a bedload sampler. Hubbell (1964) defined hydraulic efficiency (H.E.) as the ratio of the mean velocity of water discharge through the sampler (V_o) to the mean velocity of the water discharge which would have occurred through the area occupied by the opening in the sampler nozzle had the sample not been there (V_a). Sampling efficiency (S.E.) is the ratio of W_o, the weight of the bedload collected by the sampler to W_t, the weight of the bedload that would have passed through the area occupied by the opening in the sampler nozzle, had the sampler not been there. For an ideal sampler, the hydraulic and sampling efficiencies are equal to one.

The purpose of this investigation was to measure the hydraulic efficiency of the 7.62-cm and the 15.24-cm Helley-Smith sampler in a laboratory flume

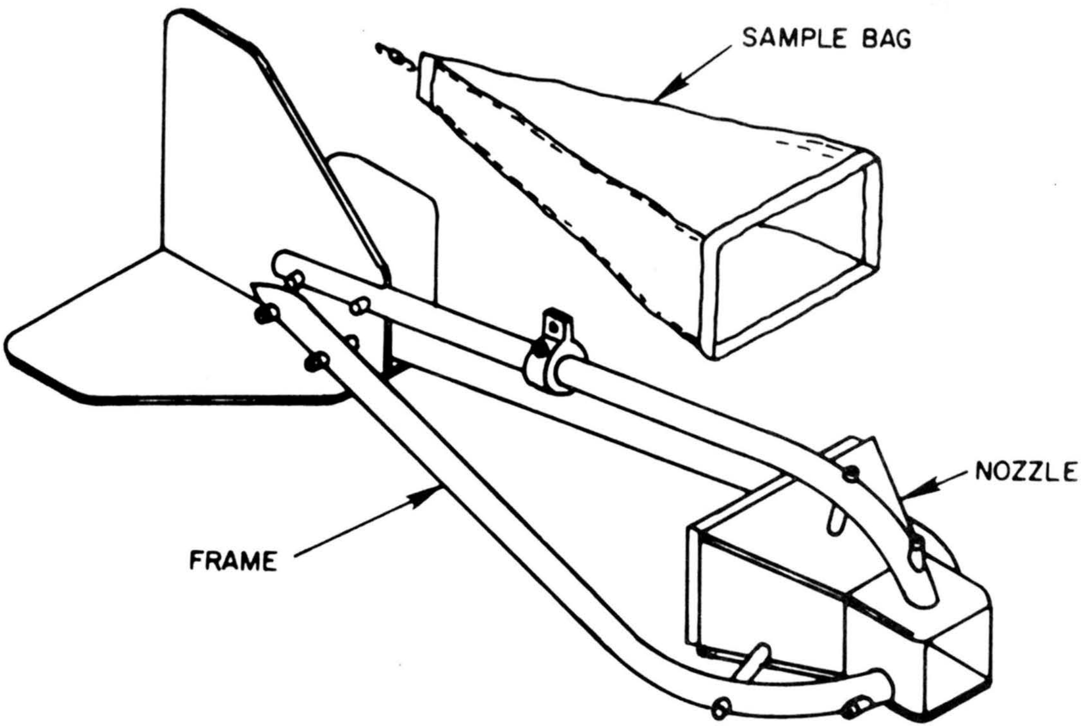


Figure 1. Helley-Smith bedload sampler

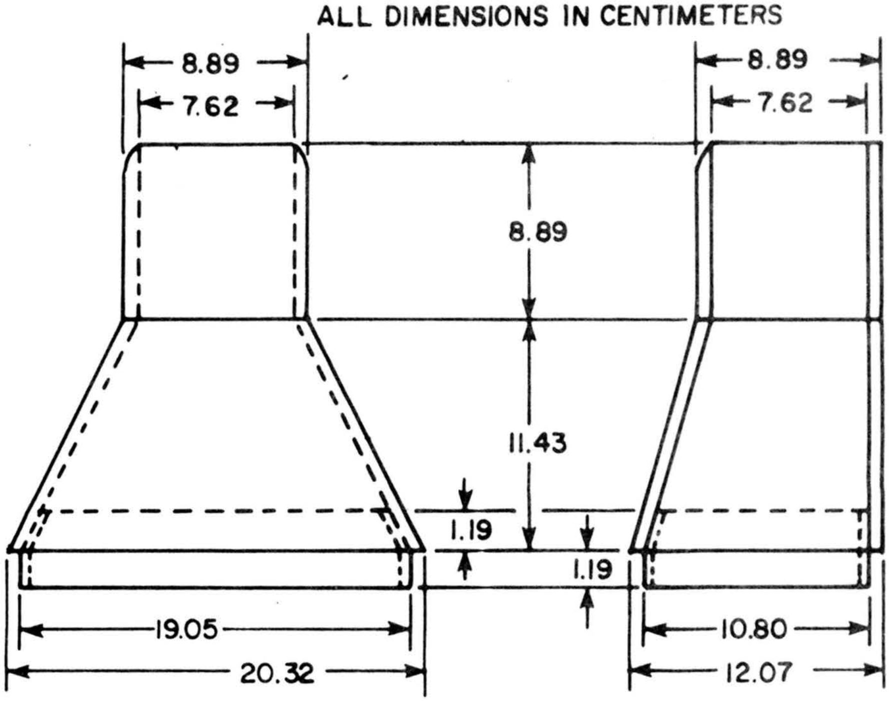


Figure 2a. Plan and side elevation of 7.62-cm Helley-Smith bedload sampler nozzle

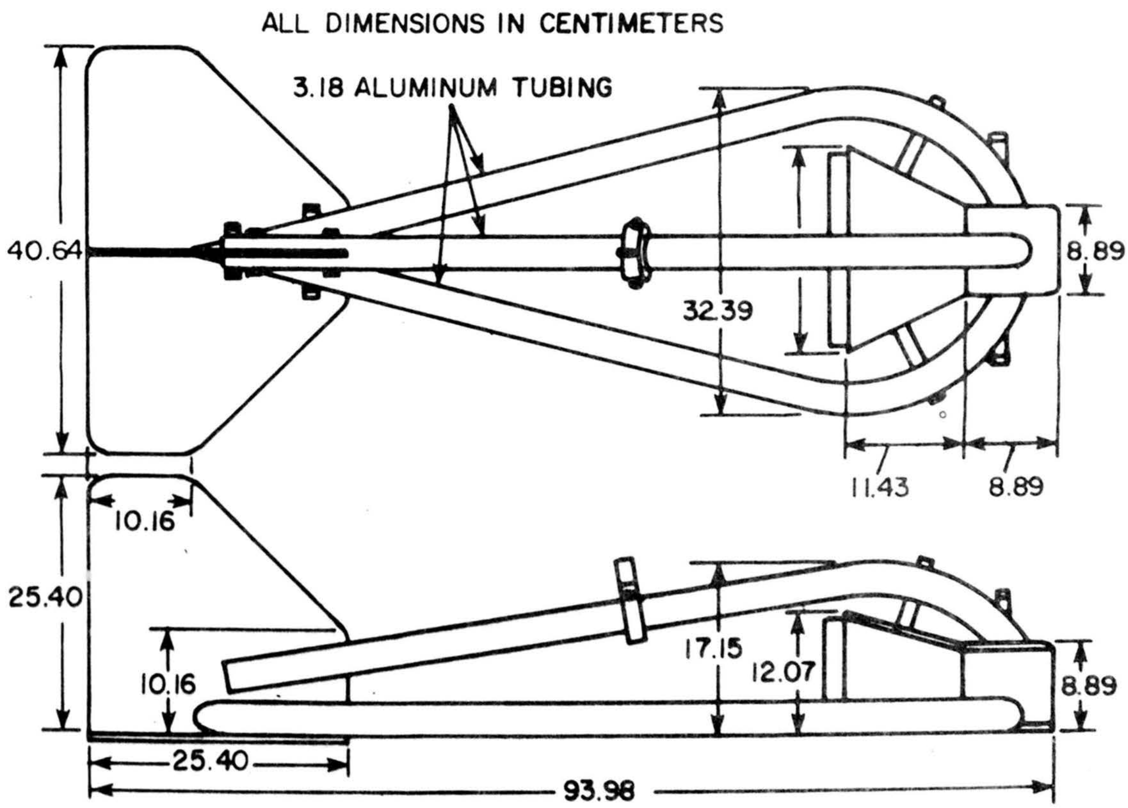


Figure 2b. Plan and side elevation of 7.62-cm Helley-Smith bedload sampler

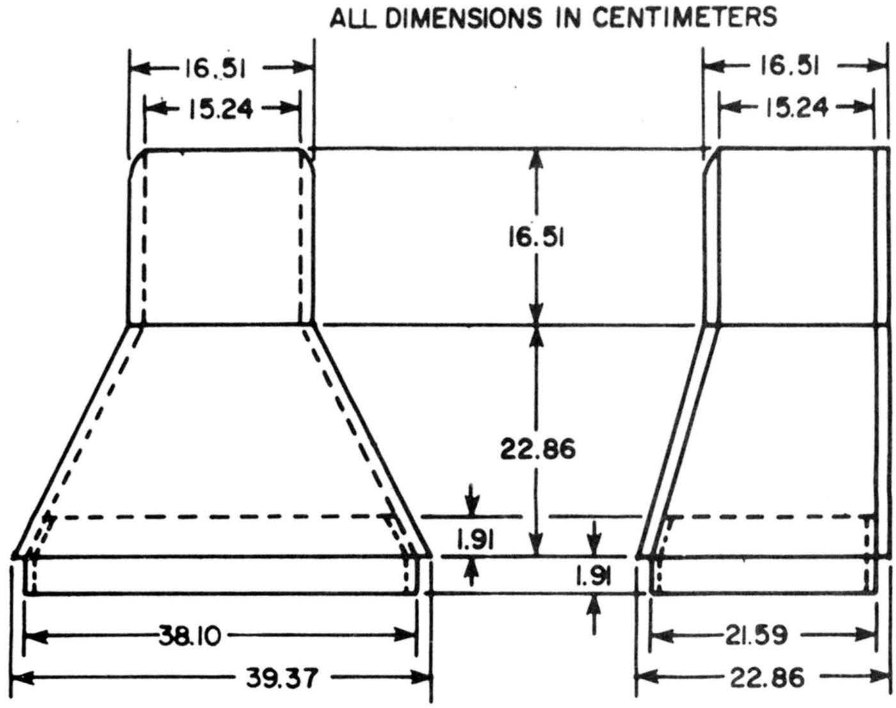


Figure 3a. Plan and side elevation of 15.24-cm Helley-Smith bedload sampler nozzle

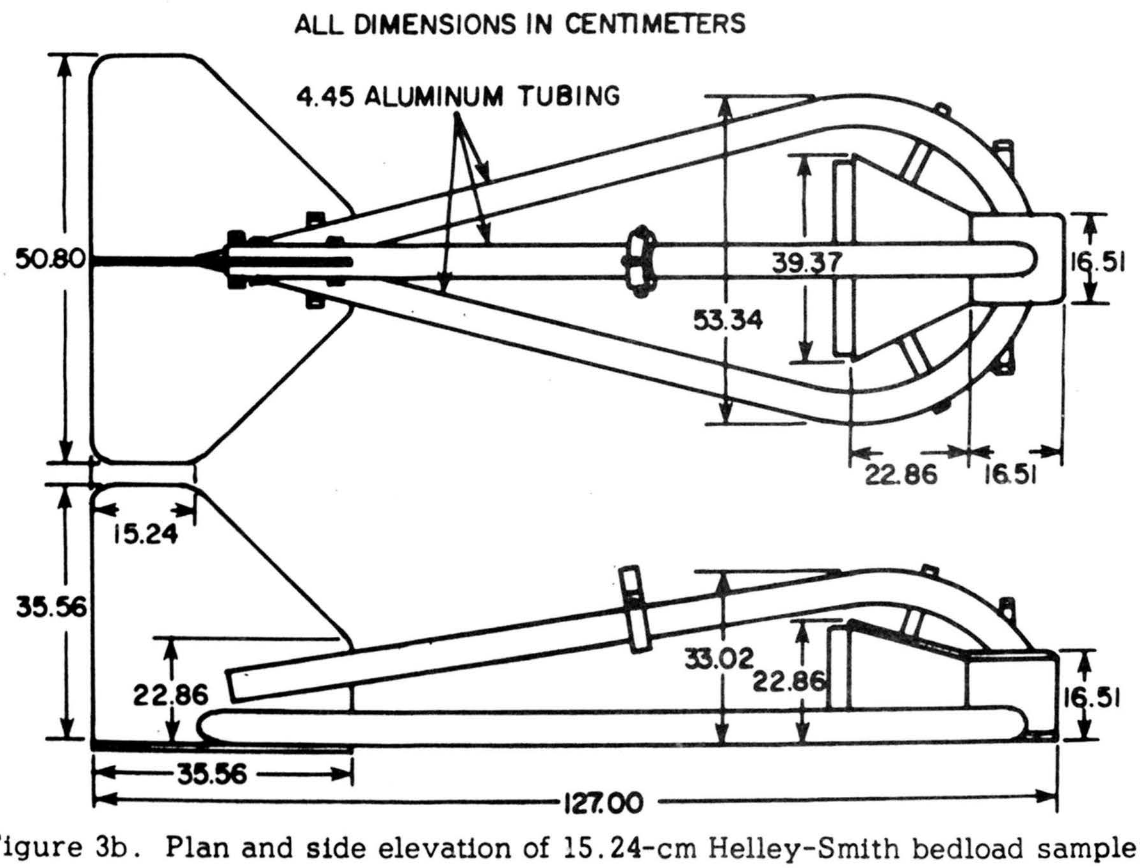


Figure 3b. Plan and side elevation of 15.24-cm Helley-Smith bedload sampler

and to determine the effects of exit-entrance area ratio of the nozzle, sample bag size, and the volume of the sample bag filled with sediment on hydraulic efficiency. A single dye-streak experiment was conducted to define the region upstream of the sampler influenced by the presence of the sampler. The scope of these experiments is best presented by breaking the different types of tests into test series:

Test series 1 - Measure the hydraulic efficiency for the 7.62-cm and 15.24-cm Helley-Smith samplers.

Test series 2 - Measure the relations between the exit-entrance area ratio of the sampler nozzle and the hydraulic efficiency.

Test series 3 - Define the effect of sediment in the sample bag and reduction of sample bag area on hydraulic efficiency.

Test series 4 - Use a dye-streak test to ascertain the region in front of the sampler influenced by the presence of the sampler.

The hydraulic efficiency investigation will give an insight into the hydrodynamic operating principles of the sampler. The results will aid in designing the experiments to determine sampling efficiency and in redesigning the sampler if it becomes necessary to adjust sampling efficiency.

PREVIOUS WORK

Helley and Smith (1971) measured hydraulic efficiency for the 7.62-cm sampler. In their tests the sampler was placed on a tow cart and pulled through the water. The velocity was measured with a pitot tube at the center of the nozzle. The hydraulic efficiency was computed as the ratio of the velocity measured in the nozzle and the towing speed. The water flowed around all sides of the sampler. However, the discharge through the sampler could be significantly different when the sampler is placed on the flume floor (stream bed) where flow occurs only on three sides. Therefore the results of Helley and Smith's (1971) tests are not directly comparable to these experiments.

APPROACH

The hydraulic efficiency can be obtained in a laboratory flume by measuring the velocity profile in the undisturbed flow and, after placing the sampler at the same flow section, measuring the velocity profile in the nozzle. The velocity is integrated over the area of the nozzle to obtain V_a and V_o, and H.E. is V_o/V_a. In steady, uniform flow, instead of removing the sampler each time, the velocity profiles in the undisturbed flow are measured upstream at a flow section unaffected by the sampler.

EQUIPMENT

Two flumes were used in the experiments. For the hydraulic efficiency tests, all but one of the sample-bag-area tests, and dye tests, a 0.91-m deep, 1.83-m wide, and 76.2-m long tilting flume was used. The sidewalls of the flume were smooth aluminum plates except for a 27-m long plexiglass observation window. The floor was covered with a 13-mm long plastic grass mat. The mat was left from a previous experiment, and because it introduced bottom roughness, it was thought to be more desirable than a smooth floor. The flume is capable of conveying a 1.7 m^3/s discharge and its slope can be varied from 0 to 1 percent. Discharge is measured with calibrated orifice plates in the supply lines. Depth was controlled by a sluice gate at the end of the flume. This flume will be referred to as flume 1 in this report; it is located at the Gulf Coast Hydroscience Center, Bay St. Louis, Miss.

For the exit-entrance area ratio tests and one sample-bag-area test, a smaller flume, 0.84-m deep, 0.5-m wide, and 9.9-m long, was used. This flume had a lucite floor and glass sidewalls. The floor was horizontal with a 7.6-cm high step downward located 4.1 m from the tailgate. The discharge in the flume was held constant at 0.1 m^3/s. The discharge gave a flow depth of 0.26 m. This flume will be referred to as flume 2 in the report; it is located at the St. Anthony Falls Hydraulic Laboratory, Minneapolis, Minn.

All velocity profiles were determined with pitot-static probes connected to a differential-pressure transducer. The transducer output was recorded on a strip-chart recorder.

EXPERIMENTAL PROCEDURE

A common coordinate system was used for all experiments. Figure 4 illustrates the position of the zero point of the coordinate system in relation to the nozzle of the sampler. The nozzle of the sampler was placed at the test section of the flume and positions referred to in the report are relative to the coordinate zero point on the nozzle. The test section for flume 1 was 37 m from the inlet and that for flume 2, 4.3 m from the inlet. In both flumes the nozzle was centered laterally on the floor of the flume at the test section. Both test sections were in zones of developed flow as determined by velocity profiles. The hydraulic characteristics of the flume flow used in the test series are listed in table 1. Flow conditions A through F are from flume 1 and flow condition G is from flume 2. The range of hydraulic characteristics for the flow conditions was determined by the physical limitations of the flumes.

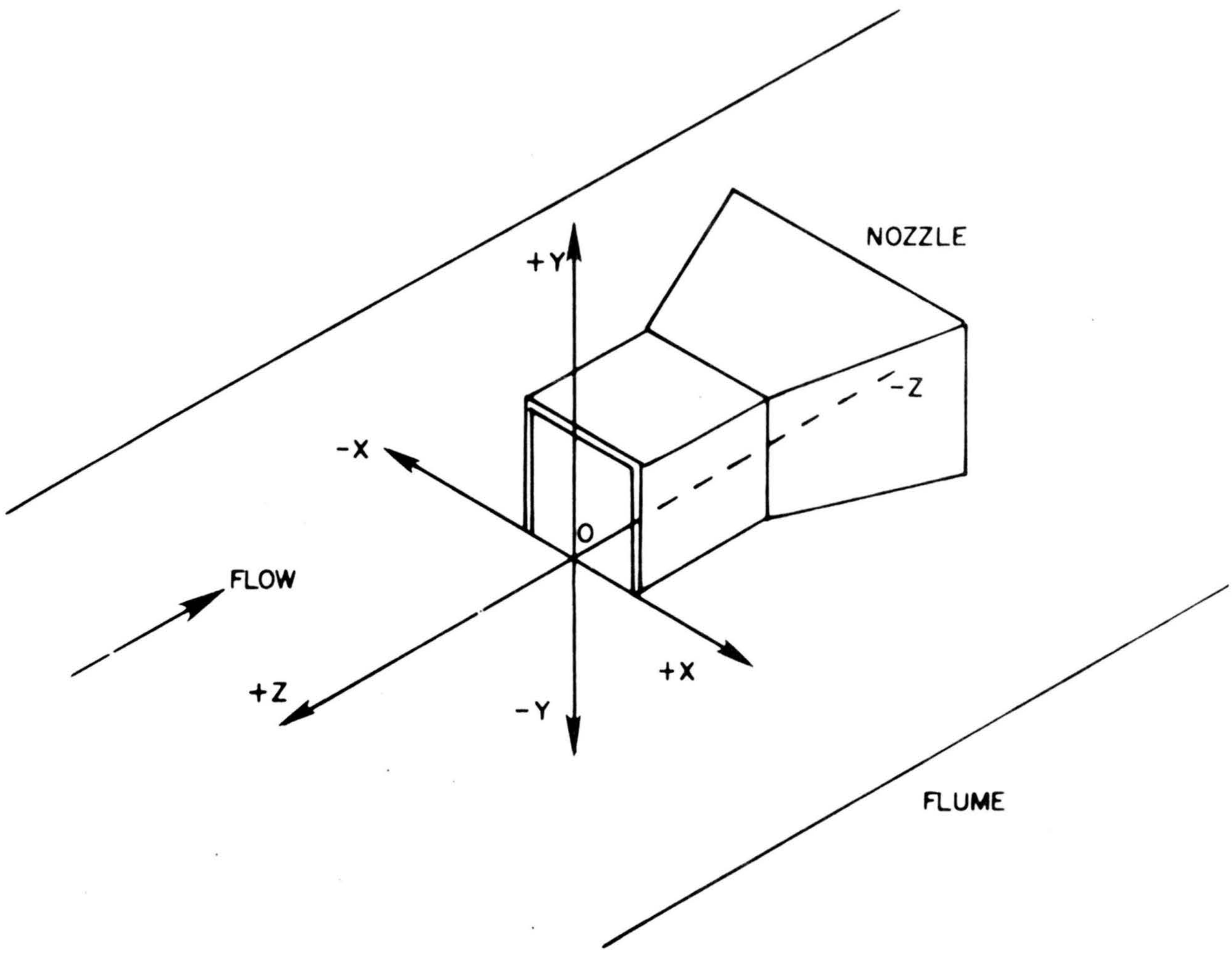


Figure 4. Coordinate system for Helley-Smith bedload sampler tests

Table 1. Summary of hydraulic characteristics of flumes 1 and 2

	Flow condition						
Parameter	A	B	C	D	E	F	G
Nozzle size, cm	15.24	15.24	15.24	15.24	7.62	7.62	Variable
Discharge, m^3/s	0.98	0.69	1.36	1.38	1.37	1.37	0.1
Depth, m	0.57	0.45	0.68	0.59	0.56	0.67	0.26
Width, m	1.83	1.83	1.83	1.83	1.83	1.83	0.50
Area, m^2	1.04	0.82	1.25	1.07	1.03	1.23	0.13
Velocity, m/s	0.94	0.83	1.09	1.29	1.33	1.12	0.77
Froude number	0.40	0.39	0.42	0.54	0.57	0.44	0.48
Reynolds number	3.5×10^5	2.7×10^5	4.6×10^5	4.9×10^5	5.0×10^5	4.7×10^5	1.1×10^5
Slope, m/m	0.0015	0.0015	0.0015	0.0028	0.0028	0.0015	0

Test Series 1

Test series 1 was conducted in flume 1 to determine the hydraulic efficiency of the 7.62-cm and 15.24-cm Helley-Smith bedload samplers. Flume 1 with flow conditions A through D was used to test the 15.24-cm sampler. The same flume with flow conditions E and F was used in testing the 7.62-cm sampler. For a particular flow condition, the flume slope and discharge were set and the tailgate adjusted until uniform flow was achieved. The sampler was positioned at the test section and velocity data were collected.

Point velocities were measured to construct velocity profiles in the regions of interest. The output of the strip-chart recorder was visually averaged to determine a mean velocity head. The mean velocity head was used to compute the point velocity. Velocity profiles were taken in the undisturbed flow, inside the nozzle of the sampler, and in areas of flow influenced by the sampler. The undisturbed velocity was measured at a section 1.52 m upstream of the sampler. Three vertical profiles were obtained in the undisturbed flow at the flume centerline, 7.6 cm right of the center, and 15.2 cm right of the center. The profiles were measured from the floor of the flume to the water surface.

The velocities inside the sampler nozzle were obtained 0.6 cm inside the nozzle entrance. Three vertical velocity profiles were taken at the nozzle centerline, the one-quarter point, and as near the sidewall as possible. A lateral velocity profile was obtained at mid-height of the nozzle. The nozzle and undisturbed velocity profiles were used to compute the mean nozzle and undisturbed velocities. Velocity profiles were also obtained at several positions in the vicinity of the sampler to determine the extent of the flow disruption caused by the sampler.

Test Series 2

The second test series was the determination of the relation between exit-entrance area ratio and hydraulic efficiency. This series was conducted in flume 2 with flow condition G.

The exit-entrance area ratio was varied by holding the entrance and length dimensions constant and changing the exit area of the nozzle. Six nozzles with geometries as listed in table 2 were tested in this phase of the experiment. The exit-entrance area ratio varied from 1.00 to 2.62 with nozzles 1 and 6 being constructed of 6.4-mm plywood and nozzles 2 through 5 being constructed of 3.2-mm lucite. In this test series, only the nozzle was installed in the flume; the sample bag and frame were not present.

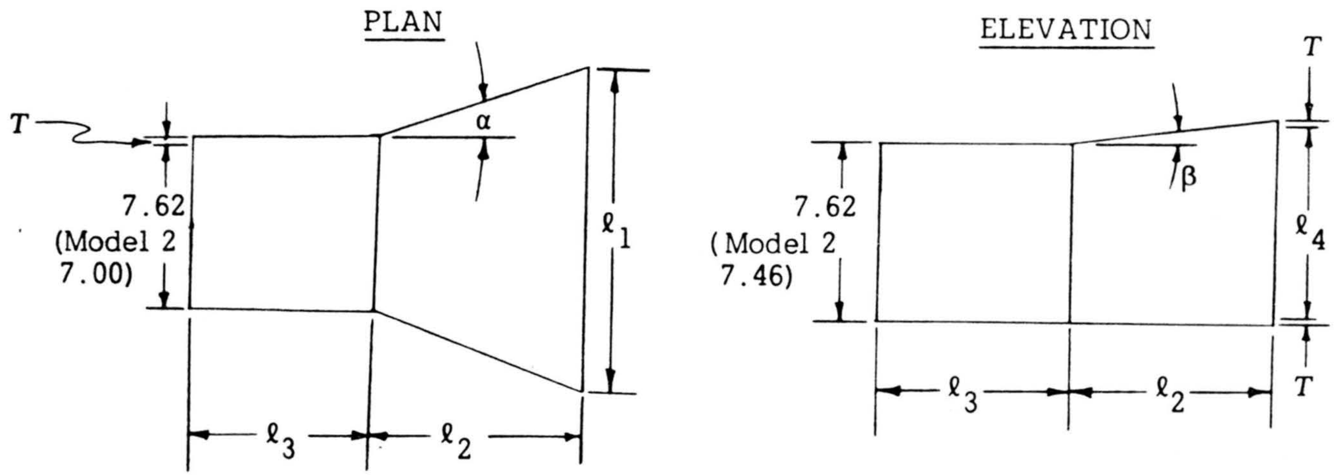
The velocities were obtained in a manner similar to test series 1. All nozzless were tested with the same hydraulic conditions (flow condition G), therefore, only one undisturbed velocity profile was required. The undisturbed profile was taken at the test section without the sampler in place. The nozzle velocity profiles were collected 1 cm upstream of the nozzle entrance. Three vertical velocity profiles were acquired in the nozzle, one at the nozzle centerline, and one each as close to the sidewalls as possible.

The velocity data were used to compute the hydraulic efficiency of each nozzle and determine the relation between the geometry of the sampler, specifically exit-entrance ratio, and the hydraulic efficiency.

Test Series 3

Test series 3 was divided into two parts. Part one of the series determined the effects of sediment in the sample bag on hydraulic efficiency. In the second part of the series, the sample bag area was systematically

Table 2.--Dimensions of nozzles



Nozzle	Dimensions in centimeters							
	α	β	ℓ_1	ℓ_2	ℓ_3	ℓ_4	T	Exit to entrance ratio
7.62 cm Helley-Smith standard	26.6°	15.5°	19.05	11.43	8.89	10.80	0.64	3.22
1	7.1°	7.9°	10.48	11.43	7.62	9.21	0.64	1.66
2	1.36°	0	8.57	$\ell_2 + \ell_3 = 20.32$		7.62	0.32	1.13
3	1.15°	0	7.78	$\ell_2 + \ell_3 = 20.16$		7.46	0.32	1.11
4	10.2°	0	14.92	$\ell_2 + \ell_3 = 20.32$		7.62	0.32	1.96
5	0	0	7.62	$\ell_2 + \ell_3 = 20.00$		7.62	0.32	1.00
6	22.4°	8.4°	16.51	10.80	8.89	9.21	0.64	2.62

reduced to ascertain when the total surface area of the bag was small enough to reduce the hydraulic efficiency.

The sediment tests in part one of series 3 were conducted in flume 1 with flow condition F and used the 7.62-cm Helley-Smith sampler with a 0.2-mm sample bag. Three sediment sizes were employed with mean diameters of 0.2 mm, 1.2 mm, and 10 mm. For each sediment size, the sample bag was loaded with sediment, installed on the sampler, and the sampler placed at the test section. The sample bag was first filled to 20 percent and then 40 percent by volume. For each sediment size and sample bag volume, velocity profiles were acquired in the undisturbed and nozzle flow. The velocities were determined using the same procedure described in test series 1.

The second part of test series 3 was conducted in flume 2 with flow condition G. Nozzle 2, with a 1-mm mesh sample bag attached, was used. In this test, the surface area of the sample bag was reduced in five steps from an area of 1030 cm^2 to 58 cm^2. At each step, velocity profiles inside the nozzle were collected. The velocities were collected using the same procedure described in test series 2. With the velocity data, a relation between sample bag area and the hydraulic efficiency of nozzle 2 could be determined.

Test Series 4

Test series 4 was a dye injection experiment to determine how the sampler influenced the flow upstream from it. The 7.62-cm Helley-Smith sampler was placed in front of the plexiglass observation window of flume 1. Flow condition F was used during the dye test. To inject the dye, a thin brass tube connected to a dye source was mounted on a point gage. The point gage enabled the position of the dye injection to be accurately located. Dye was injected at various points in front of the sampler and the dye streaks were observed and mapped. A flow net depicting the transition of the flow from the undisturbed velocity field into the orifice was constructed from the dye data.

RESULTS

Point velocities were the basic data collected in all tests. The velocity data are listed in tables 6-13 according to the flow conditions in the flume at the time of their collection. The data are grouped into velocity profiles and annotated in order to reference them to a particular test series.

The results of each test series are presented below.

Test Series 1

The hydraulic efficiency of the 7.62-cm and 15.24-cm Helley-Smith samplers was determined. Three vertical-velocity profiles collected during flow condition F are presented in figure 5. Vertical and lateral nozzle velocity profiles for the 7.62-cm and 15.24-cm samplers are shown in figures 6 and 7. The velocity profiles in figures 5, 6, and 7 are typical of all profiles taken in test series 1.

The velocities taken approximately 0.6 cm inside the nozzle entrance had the following characteristics. In the center of the nozzle, away from the boundary effects of the sidewalls and roof of the nozzle, the vertical velocity profile has the same general shape as the undisturbed vertical profile. However, the velocity at each point on the nozzle profile has increased substantially from the undisturbed profile. Near the nozzle sides and

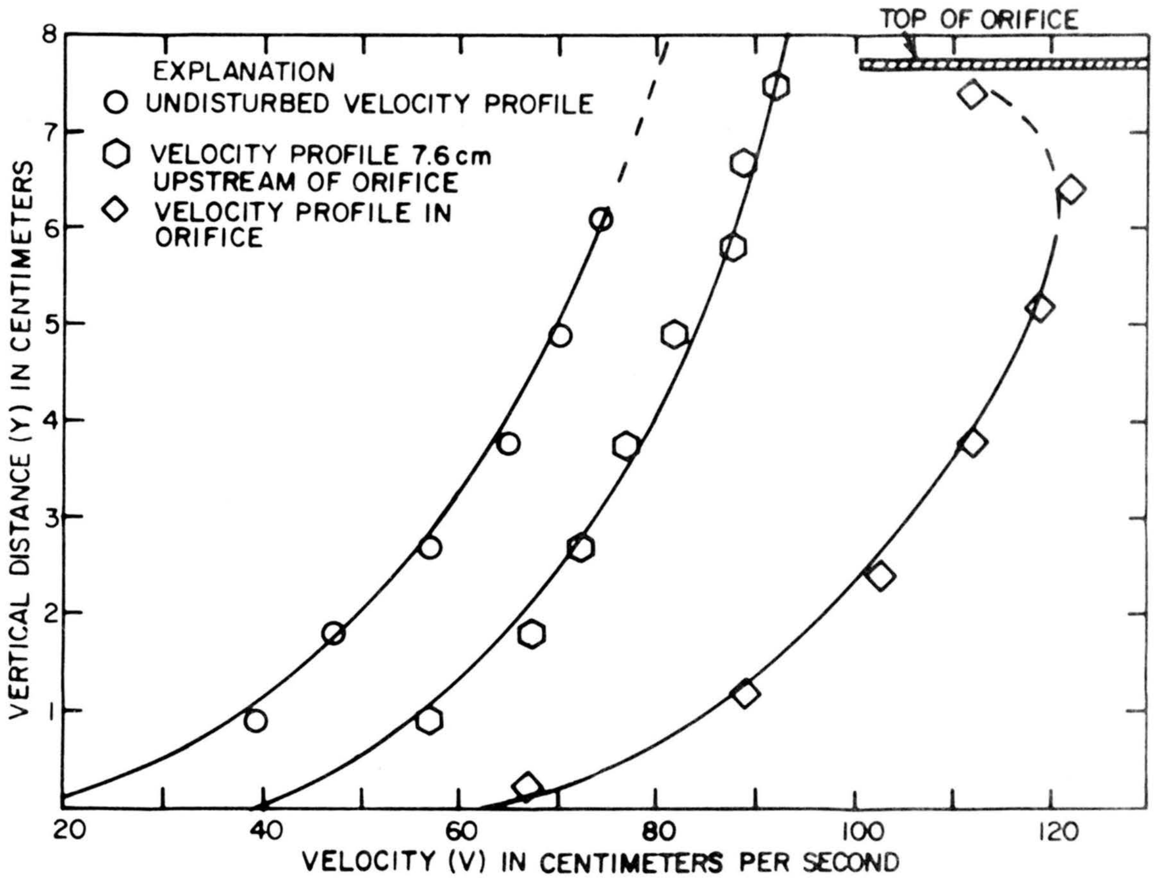


Figure 5. Velocity profiles 1.52 and 7.62 cm upstream of sampler, and in sampler orifice of 7.62-cm Helley-Smith sampler with flow condition F

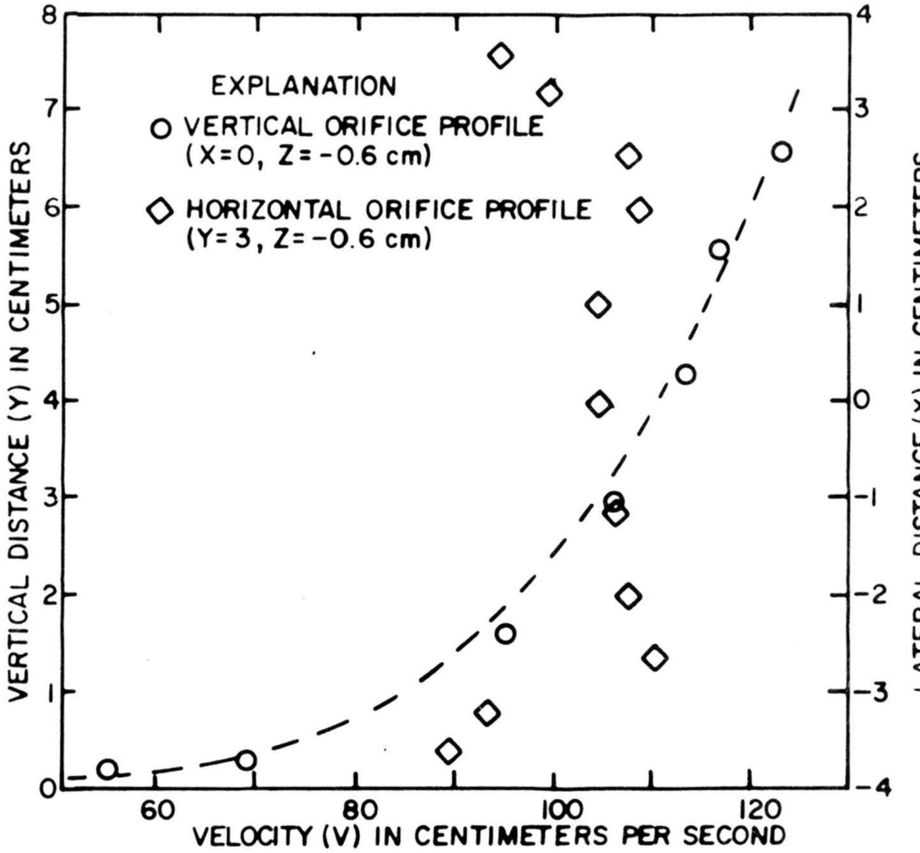


Figure 6. Vertical and horizontal velocity profiles in orifice of 7.62-cm Helley-Smith bedload sampler with flow condition E

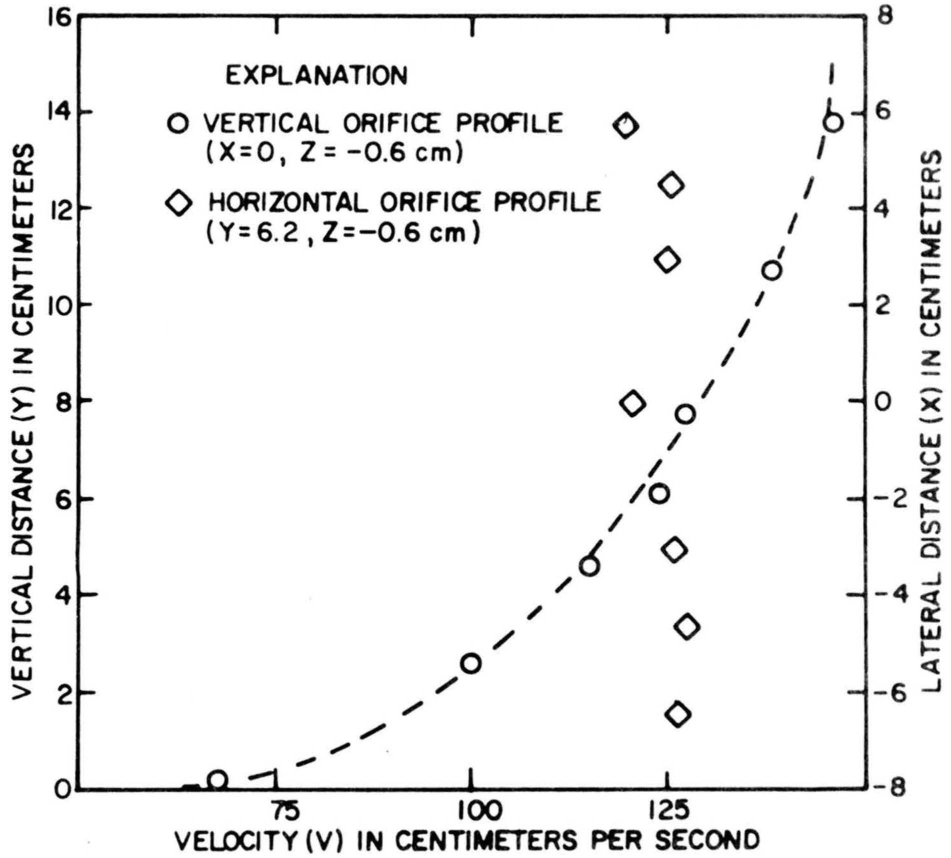


Figure 7. Vertical and horizontal velocity profiles in nozzle of 15.24-cm Helley-Smith bedload sampler with flow condition C

roof, boundary effects cause a reduction in the velocity. Very close to the sidewalls and roof, separation of the flow made determining the velocities impossible. This zone of separation was approximately 5-mm wide; and beyond this zone the velocity increased rapidly to the velocity in the nonboundary affected area. The velocity at a particular elevation above the nozzle floor was almost constant laterally, except for a slight reduction in the center of the nozzle and close to the sidewalls.

The velocity profiles shown in figure 5 are an undisturbed velocity profile 152 cm upstream of orifice entrance, a velocity profile 7.6 cm upstream of the orifice entrance, and a nozzle profile for the 7.62-cm sampler. The velocity profile taken 7.6 cm upstream of the nozzle is mid-way between the undisturbed and nozzle velocity profiles. Another velocity profile (not shown) taken 20 cm upstream of the sampler is identical to the undisturbed profile. These profiles indicate the flow into the nozzle does accelerate and the zone of acceleration extends between 7.6 cm and 20 cm upstream of the sampler.

The mean ambient and orifice velocities were determined by averaging and integrating the vertical velocity profiles. The hydraulic efficiency was computed by dividing the mean nozzle velocity by the mean ambient velocity. The mean velocities and corresponding hydraulic efficiency are listed according to flow condition in table 3.

For the 15.24-cm sampler (flow conditions A, B, C, and D), the mean ambient velocity ranged from 0.72 to 1.00 m/s, the mean orifice velocity ranged from 1.13 to 1.55 m/s, and the hydraulic efficiency remained relatively constant with a mean of 1.54. Flow conditions E and F for the

Table 3.--Mean undisturbed and nozzle velocities and hydraulic efficiencies for 7.62-cm and 15.24-cm Helley-Smith bedload sampler

	Flow condition					
	A	B	C	D	E	F
Nozzle	15.24	15.24	15.24	15.24	7.62	7.62
Mean undisturbed velocity, V_a	0.77	0.72	0.81	1.00	0.87	0.69
Mean nozzle velocity, V_o	1.16	1.13	1.25	1.55	1.32	1.06
Hydraulic efficiency, H.E.	1.51	1.57	1.54	1.55	1.52	1.54

7.62-cm sampler had mean ambient velocities of 0.69 and 0.87 m/s, mean orifice velocities of 1.06 and 1.32 m/s, and hydraulic efficiencies of 1.52 and 1.54. The flow conditions C and D for the 15.24-cm sampler are equivalent to flow conditions E and F for the 7.62-cm sampler.

The hydraulic efficiencies of both samplers for all flow conditions have a mean of 1.54 (standard deviation of 0.02) and within the accuracy of the testing can be considered equal. For the range of hydraulic conditions of these tests, the 7.62-cm and 15.24-cm samplers are hydraulically similar.

Test Series 2

The relation between the exit-entrance area ratio of the sampler nozzle and the hydraulic efficiency was measured in test series 2. This series was conducted in flume 2 with flow condition G. Nozzles tested in this series had entrance and length dimensions equal to the nozzle of the 7.62-cm sampler, but the exit area was varied from 58 to 152 cm^2. The velocity data were handled in a manner similar to test series 1.

Since the hydraulic flow conditions were not varied for series 2, only one mean undisturbed velocity determination was required. The mean undisturbed velocity for this test series was 0.75 m/s. Other data for the test series, including orifice exit-entrance area ratio (ex/en ratio), mean nozzle velocity, and hydraulic efficiency, are listed in table 4. Figure 8 shows the relation between ex/en ratio and hydraulic efficiency. Also included in table 4 and figure 8 are the 7.62-cm sampler data from test series 1.

The hydraulic efficiency increases from 1.06 for an ex/en ratio of 1.00 to a maximum of 1.55 for an ex/en ratio of 2.62. For an ex/en ratio of 2.62

Table 4.--Exit to entrance area ratios, mean undisturbed and nozzle velocities, and hydraulic efficiencies for nozzles

Orifice	7.62 cm Helley-Smith	1	2	3	4	5	6
Exit to entrance ratio	3.22	1.66	1.13	1.11	1.96	1.00	2.62
Mean undisturbed velocity, V_a, m/s	0.69	0.75	0.75	0.75	0.75	0.75	0.75
Mean nozzle velocity, V_o, m/s	1.06	1.10	0.89	0.89	1.06	0.80	1.16
Hydraulic efficiency, H.E.	1.54	1.47	1.18	1.18	1.41	1.06	1.55

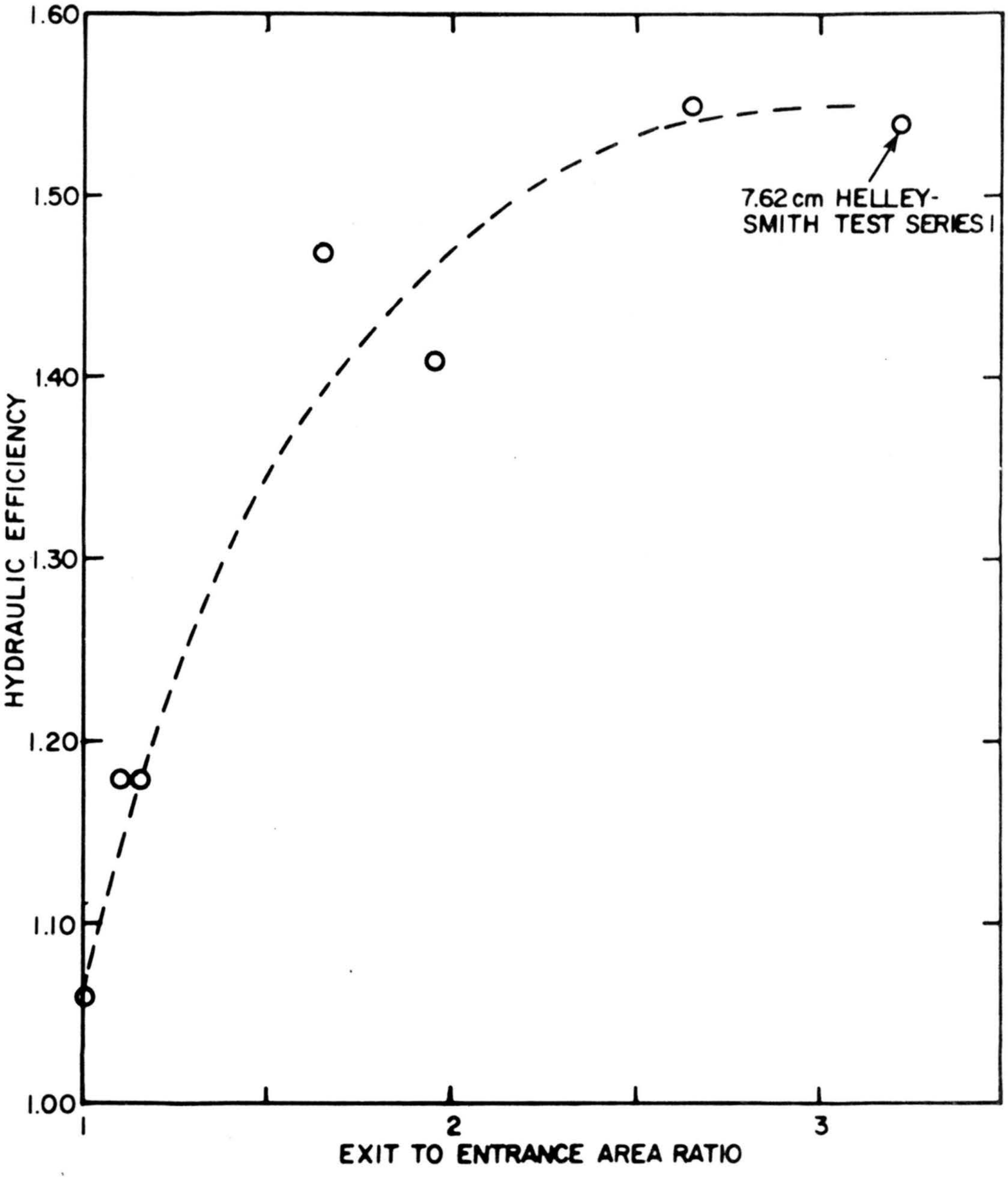


Figure 8. Exit to entrance area ratio and hydraulic efficiency relation

to 3.22 the hydraulic efficiency does not vary. Although the work by Helley and Smith (1971) is not directly comparable, their finding that an ex/en ratio change from 2.00 to 3.50 has no effect on hydraulic efficiency, parallels the findings of test series 2.

The ex/en ratio has a definite relation to the hydraulic efficiency. The results of test series 2 indicate the simplest way to change the efficiency of the Helley-Smith sampler is to change the exit-entrance area ratio.

Test Series 3

The effects of sediment in the sample bag and reduction of sampler bag area on hydraulic efficiency are defined. The velocities and hydraulic efficiency for test series 3 were obtained in a manner similar to test series 1. The sediment part of test series 3 was conducted in flume 1 with flow condition F using the 7.62-cm sampler with the standard 0.2- mm mesh sample bag. The three sediment sizes placed in the sample bag have the following effects on hydraulic efficiency.

When the sampler bag was filled to 20 or 40 percent capacity with either 1.2-mm or 10-mm sediment, the hydraulic efficiency was not altered and the 7.62-cm sampler performed as it did with no sediment in the sample bag. Again, although the results are not directly comparable, this result agrees with Helley and Smith's (1971) observation that the sampler bag could be filled to 66 percent capacity with 10-mm sediment and no change in hydraulic efficiency would be noted.

The 0.2-mm sediment did affect the hydraulic efficiency. Several identical tests were conducted with the sample bag filled to 20 and 40 percent capacity. In each test a different nozzle velocity profile and thus hydraulic efficiency was obtained. The hydraulic efficiency varied from 1.00 to 1.45. The efficiency of the sampler without the sediment was 1.55.

In addition to the loss in efficiency, the amount of sediment in the sample bag decreased as a particular test progressed. The 0.2-mm sediment was the same size as the 0.2-mm mesh of the sample bag. The sediment appeared to plug the mesh in the sample bag and then work its way out. The rate of sediment loss was impossible to determine.

The second part of series 3 was the sample bag area reduction test conducted in flume 2 with nozzle 2.

Initially a 0.2-mm mesh sample bag was fitted to the sampler. Organic matter in the flume system plugged the net immediately after the run started. To eliminate the effects of organic matter, a sample bag with a 1-mm mesh was used. The bag surface area and corresponding hydraulic efficiency for each area are listed in table 5. Figure 9 illustrates the variation of hydraulic efficiency with total bag area and indicates that approximately 600 cm^2 of bag surface area is required to keep the hydraulic efficiency from decreasing. This particular test is limited in scope but illustrates the effects of restricting the sample bag area.

Test Series 4

A dye-streak test was made to acertain the region upstream of the sampler influenced by the sampler's presence. The dye test determined the area of flow affected by the 7.62-cm sampler with standard 0.2-mm mesh sample bag attached. The test was conducted in flume 1 with flow condition F.

An isometric drawing of the streamlines entering the nozzle was constructed from the dye streaks (fig. 10). The streamlines begin curving

Table 5. Sample bag surface area, mean undisturbed and nozzle velocity, and hydraulic efficiency for nozzle 2

Bag area, cm^2	No bag	1030	516	260	194	58
Mean undisturbed velocity, m/s	0.75	0.75	0.75	0.75	0.75	0.75
Mean nozzle velocity, m/s	0.89	0.87	0.92	0.80	0.69	0.54
Hydraulic efficiency, H.E.	1.18	1.16	1.22	1.07	0.92	0.72

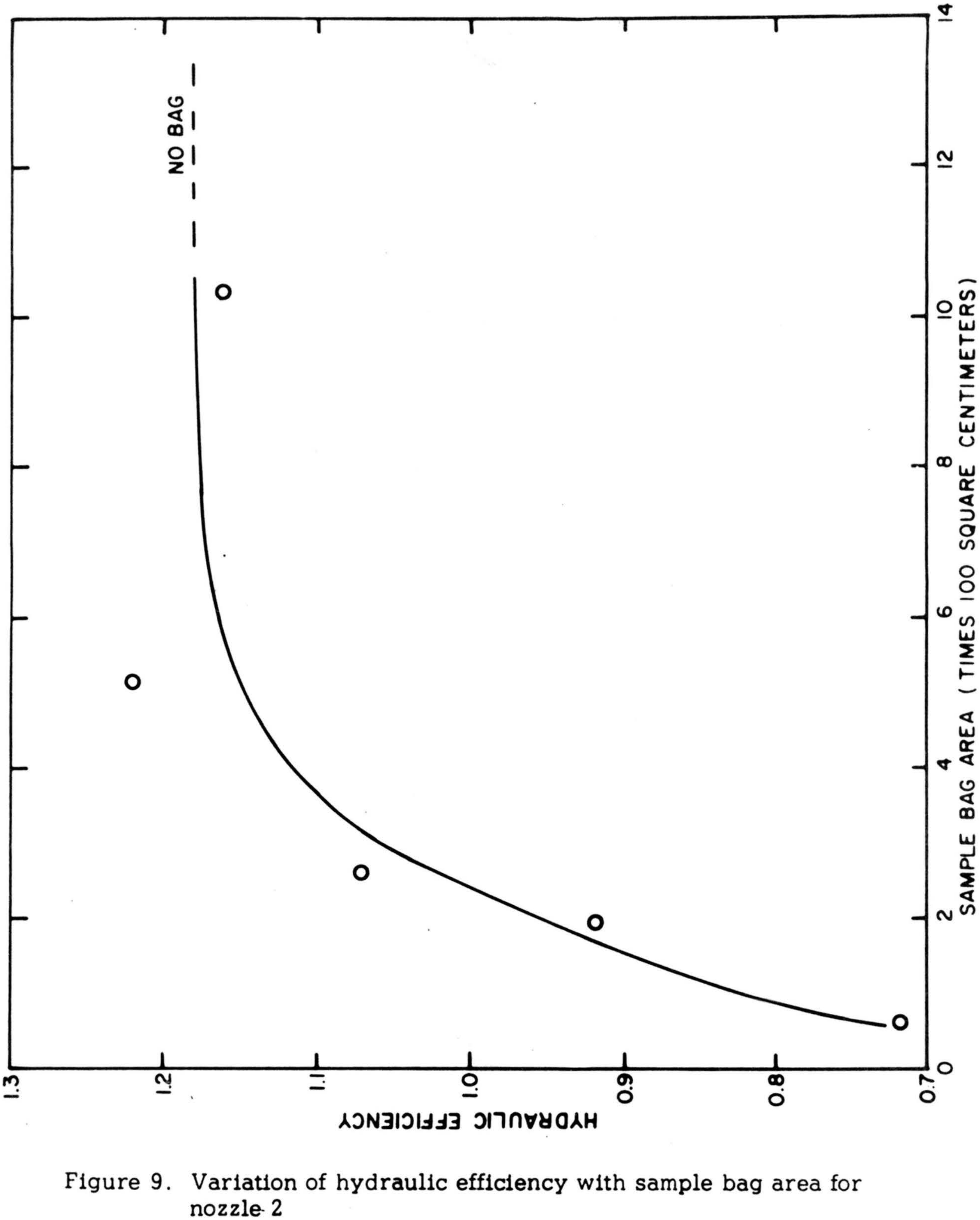


Figure 9. Variation of hydraulic efficiency with sample bag area for nozzle 2

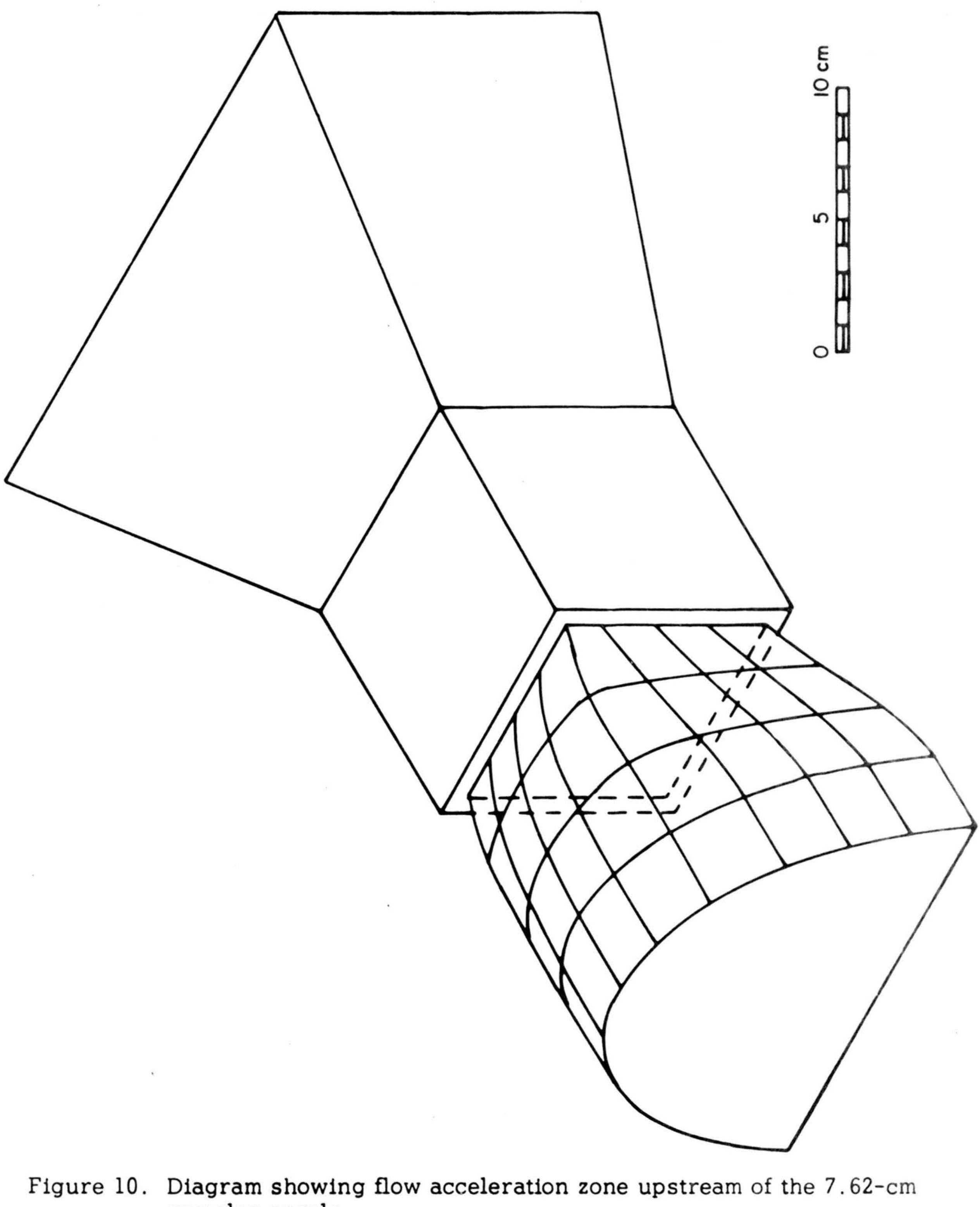


Figure 10. Diagram showing flow acceleration zone upstream of the 7.62-cm sampler nozzle

towards the orifice entrance approximately 10 cm upstream of the nozzle. The maximum width of the influenced area is approximately 14 cm, and the maximum height is approximately 9 cm. The maximum cross-sectional area of flow entering the nozzle is approximately 1.7 times the area of the sampler nozzle.

The flow net shown in figure 10 can give a qualitative indication of what could occur in sampling sediment. If the sediment could be influenced by the flow accelerating into the orifice of the sampler, sediment particles inside the flow net, but not directly in the path of the nozzle, could be included in the sample collected. These sediment particles would give an erroneous amount and size distribution for the sample.

CONCLUSIONS

The hydraulic efficiency of the 7.62-cm and 15.24-cm Helley-Smith bedload sampler is approximately 1.54. This value of hydraulic efficiency was found to be constant for the range of flow conditions in this experiment.

The hydraulic efficiency of the sampler can be regulated by changing the exit-entrance area ratio of the nozzle. The efficiency for a nozzle with a 7.62-cm opening increased from 1.06 to 1.54 as the exit-entrance area ratio increased from 1.00 to 2.62. With an exit to entrance ratio greater than 2.62 but less than 3.22, the efficiency remains constant.

The sample bag can be filled to 40 percent capacity with sediment whose diameter is larger than the 0.2-mm mesh size of the bag without reduction in hydraulic efficiency. However, sediment whose diameter is close to the 0.2-mm mesh size of the sample bag, plugs the sample bag and escapes through the mesh causing an unpredictable decrease in hydraulic efficiency and loss of the sample.

The dye-streak test delineated the point at which the streamlines of the flow net start to curve into the nozzle at approximately 10 cm upstream of the nozzle entrance. The maximum width of the area of influence is 14 cm and the height 9 cm.

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Table 6.-- Velocity data for test series A with 15.24 cm Helley-Smith bedload sampler with flume discharge 0.98 m^3/s; normal depth 0.57 m; slope 0.0015; and width 1.83 m.

Profile	Location (cm)			V, velocity (cm/s)	Profile	Location (cm)			V, velocity (cm/s)
	X	Y	Z			X	Y	Z	
A1: Undisturbed velocity profile 152 cm upstream of the sampler									
	0	-1.3	152	12	A1	7.6	-1.3	152	12
	0	0	152	14		7.6	0	152	16
	0	0.6	152	42		7.6	0.6	152	42
	0	2.2	152	57		7.6	2.2	152	57
	0	5.3	152	74		7.6	5.3	152	74
	0	8.4	152	84		7.6	8.4	152	84
	0	11.5	152	88		7.6	11.5	152	89
	0	14.6	152	92		7.6	14.6	152	93
	0	17.7	152	96		7.6	17.7	152	98
	0	23.9	152	105		7.6	23.9	152	105
	0	30.0	152	111		7.6	30.0	152	111
	0	36.2	152	116		7.6	36.2	152	116
	0	45.5	152	121		7.6	45.5	152	121
	0	50.4	152	123		7.6	50.4	152	123
	15.2	0.6	152	43					
	15.2	5.3	152	72					
	15.2	14.6	152	95					
	15.2	30.0	152	113					
	15.2	45.5	152	124					

Table 6.--(Continued).

Profile	Location (cm)			V, velocity (cm/s)	Profile	Location (cm)			V, velocity (cm/s)
	X	Y	Z			X	Y	Z	
A2: Velocity profile 0.6 cm inside									
	0	0.2	≅-.6	72		3.8	0.2	≅-.6	74
	0	2.0	≅-.6	97		3.8	2.0	≅-.6	102
	0	5.2	≅-.6	107		3.8	5.2	≅-.6	115
	0	6.7	≅-.6	112		3.8	6.7	≅-.6	117
	0	8.3	≅-.6	117		3.8	8.3	≅-.6	120
	0	11.4	≅-.6	124		3.8	11.4	≅-.6	128
	0	14.2	≅-.6	142		3.8	14.2	≅-.6	140
	7.4	0.2	≅-.6	98					
	7.4	2.0	≅-.6	74					
	7.4	5.2	≅-.6	106					
	7.4	6.7	≅-.6	113					
	7.4	8.3	≅-.6	116					
	7.4	11.4	≅-.6	131					
	7.4	14.2	≅-.6	141					

Table 7.-- Velocity data for test series B with 15.24 cm Helley-Smith bedload sampler with flume discharge 0.69 m^3/s; normal depth 0.45 m; slope 0.0015; and width 1.83 m.

Profile	Location (cm) X	Y	Z	V, velocity (cm/s)	Profile	Location (cm) X	Y	Z	V, velocity (cm/s)
B1:	Undisturbed velocity profile 152 cm upstream of the sampler								
	0	-1.3	152	16	B1	7.6	-1.3	152	16
	0	0	152	20		7.6	0	152	20
	0	0.6	152	42		7.6	0.6	152	43
	0	2.2	152	57		7.6	2.2	152	57
	0	5.2	152	71		7.6	5.2	152	72
	0	8.4	152	79		7.6	8.4	152	79
	0	11.5	152	85		7.6	11.5	152	85
	0	14.6	152	87		7.6	14.6	152	91
	0	17.7	152	92		7.6	17.7	152	95
	0	24.0	152	98		7.6	24.0	152	100
	0	30.2	152	101		7.6	30.2	152	105
	0	36.4	152	105		7.6	36.4	152	107
	0	41.1	152	108		7.6	41.1	152	111
	15.2	-1.3	152	12		15.2	4.5	152	87
	15.2	0	152	19		15.2	14.6	152	91
	15.2	0.6	152	45		15.2	17.7	152	96
	15.2	2.2	152	57		15.2	24.0	152	102
	15.2	5.2	152	74		15.2	30.2	152	106
	15.2	8.4	152	79		15.2	36.4	152	107
						15.2	41.1	152	112

Table 7.--(Continued)

Profile	Location (cm) X	Y	Z	V, velocity (cm/s)	Profile	Location (cm) X	Y	Z	V, velocity (cm/s)
B2: Velocity profile 0.6 cm inside nozzle									
	0	0.2	≅-.6	63		3.8	0.2	≅-.6	79
	0	0.2	≅-.6	77		3.8	0.6	≅-.6	84
	0	2.2	≅-.6	93		3.8	2.2	≅-.6	98
	0	5.3	≅-.6	102		3.8	5.3	≅-.6	115
	0	6.9	≅-.6	107		3.8	6.9	≅-.6	122
	0	8.4	≅-.6	109		3.8	8.4	≅-.6	127
	0	11.5	≅-.6	119		3.8	11.5	≅-.6	137
	0	14.4	≅-.6	140		3.8	14.4	≅-.6	154
	7.4	0.2	≅-.6	79					
	7.4	0.6	≅-.6	84					
	7.4	2.2	≅-.6	98					
	7.4	5.3	≅-.6	115					
	7.4	6.0	≅-.6	122					
	7.4	8.4	≅-.6	127					
	7.4	11.5	≅-.6	137					
	7.4	14.4	≅-.6	154					

Table 8.-- Velocity data for test series C with 15.24 cm Helley-Smith bedload sampler with flume discharge 1.35 m^3/s; normal depth 0.67 m; slope 0.0015; and width 1.83 m.

Profile	Location (cm) X	Y	Z	V, velocity (cm/s)	Profile	Location (cm) X	Y	Z	V, velocity (cm/s)
C1: Undisturbed velocity profile 152 cm upstream of the sampler									
	0	-1.3	152	10	C1	7.6	-1.3	152	16
	0	0	152	17		7.6	0	152	16
	0	0.6	152	39		7.6	0.6	152	42
	0	2.2	152	55		7.6	2.2	152	59
	0	5.3	152	77		7.6	5.3	152	79
	0	8.4	152	91		7.6	8.4	152	91
	0	11.4	152	98		7.6	11.4	152	98
	0	14.5	152	105		7.6	14.5	152	105
	0	17.6	152	108		7.6	17.6	152	108
	0	23.8	152	118		7.6	23.8	152	126
	0	30.0	152	125		7.6	30.0	152	
	0	36.1	152	132		7.6	36.1	152	132
	0	45.4	152	139		7.6	45.4	152	139
	15.2	-1.3	152	12		15.2	11.4	152	98
	15.2	0	152	12		15.2	14.5	152	105
	15.2	0.6	152	42		15.2	17.6	152	108
	15.2	2.2	152	59		15.2	23.8	152	117
	15.2	5.3	152	76		15.2	30.0	152	126
	15.2	8.4	152	91		15.2	36.1	152	132
						15.2	45.4	152	138

Table 8.-- (Continued)

Profile	Location (cm) X	Y	Z	V, velocity (cm/s)	Profile	Location (cm) X	Y	Z	V, velocity (cm/s)
C2: Velocity profile 0.6 cm inside nozzle									
	0	0.2	≅-.6	65		3.8	0.2	≅-.6	65
	0	0.2	≅-.6	72		3.8	0.2	≅-.6	63
	0	1.6	≅-.6	100		3.8	1.6	≅-.6	101
	0	4.7	≅-.6	115		3.8	4.7	≅-.6	122
	0	6.2	≅-.6	124		3.8	6.2	≅-.6	128
	0	7.8	≅-.6	127		3.8	7.8	≅-.6	128
	0	10.9	≅-.6	138		3.8	10.9	≅-.6	137
	0	13.8	≅-.6	147		3.8	13.8	≅-.6	150
	-6.4	6.2	≅-.6	126					
	-4.6	6.2	≅-.6	128					
	-3.0	6.2	≅-.6	126					
	0	6.2	≅-.6	120					
	3.0	6.2	≅-.6	124					
	4.6	6.2	≅-.6	125					
	5.8	6.2	≅-.6	119					
	6.4	6.2	≅-.6	89					
	7.0	6.2	≅-.6	55					
	7.4	6.2	≅-.6	22					

Table 8.--(Continued)

Profile	Location (cm) X	Y	Z	V, velocity (cm/s)	Profile	Location (cm) X	Y	Z	V, velocity (cm/s)
C3: Velocity profile 0.6 cm inside nozzle in area of flow separation									
	0	0	-.01	80		7.4	0.2	≅-.6	-50
	0	1.1	-.01	63		7.4	0.2	≅-.6	-35
	0	2.3	-.01	91		7.4	1.6	≅-.6	-39
	0	3.0	-.01	100		7.4	4.7	≅-.6	-22
	0	3.4	-.01	102		7.4	6.2	≅-.6	27
	0	4.5	-.01	115		7.4	7.8	≅-.6	32
	0	5.6	-.01	117		7.4	10.9	≅-.6	74
	0	6.8	-.01	121		7.4	13.8	≅-.6	128
C4: Velocity profile for 7.62 cm Helley-Smith sampler									
	-3.7	3.0	-.01	100					
	-2.7	3.0	-.01	98					
	-1.8	3.0	-.01	115					
	0	3.0	-.01	100					
	1.5	3.0	-.01	102					
	2.5	3.0	-.01	102					
	3.4	3.0	-.01	100					

Table 8.--(Continued)

Profile	Location (cm) X	Y	Z	V, velocity (cm/s)	Profile	Location (cm) X	Y	Z	V, velocity (cm/s)
C5: Velocity profile for sampler Model 7									
	0	0.2	-.01	70		-3.4	1.9	-.01	109
	0	0.2	-.01	87		-2.0	1.9	-.01	105
	0	3.0	-.01	101		-0.6	1.9	-.01	106
	0	3.5	-.01	104		0	1.9	-.01	105
	0	4.4	-.01	109		0.1	1.9	-.01	104
	0	5.9	-.01	115		2.1	1.9	-.01	105
	0	7.3	-.01	117		3.7	1.9	-.01	93
C6: Velocity profile for sampler model 1									
	0	0.1	-.01	80		0	0.1	-6.1	90
	0	0.2	-.01	84		0	1.2	-6.1	74
	0	3.0	-.01	106		0	3.0	-6.1	91
	0	3.4	-.01	112		0	3.4	-6.1	96
	0	4.4	-.01	118		0	4.4	-6.1	106
	0	5.8	-.01	125		0	5.8	-6.1	114
	0	7.2	-.01	134		0	7.2	-6.1	120

Table 9.-- Velocity data for test series D with 15.24 cm Helley-Smith bedload sampler with flume discharge 1.38 m^3/s; normal depth 0.54 m; slope 0.0028; and width 1.83 m.

Profile	Location (cm) X	Y	Z	V, velocity (cm/s)	Profile	Location (cm) X	Y	Z	V, velocity (cm/s)
D1: Undisturbed velocity profile 152 cm upstream of sampler									
	0	-1.3	152	12	D1	7.6	-1.3	152	10
	0	0	152	12		7.6	0	152	14
	0	0.6	152	47		7.6	0.6	152	50
	0	2.2	152	72		7.6	2.2	152	71
	0	5.3	152	100		7.6	5.3	152	101
	0	8.4	152	113		7.6	8.4	152	112
	0	11.5	152	119		7.6	11.5	152	120
	0	14.6	152	127		7.6	14.6	152	127
	0	17.7	152	134		7.6	17.7	152	136
	0	23.9	152	146		7.6	23.9	152	146
	0	30.1	152	155		7.6	30.1	152	155
	0	36.2	152	163		7.6	36.2	152	162
	0	42.4	152	169		7.6	42.4	152	168
	15.2	-1.3	152	16		15.2	11.5	152	119
	15.2	0	152	19		15.2	14.6	152	129
	15.2	0.6	152	47		15.2	17.7	152	135
	15.2	2.2	152	71		15.2	23.9	152	144
	15.2	5.3	152	97		15.2	30.1	152	155
	15.2	8.4	152	107		15.2	36.2	152	162
						15.2	42.4	152	168

Table 9.--(Continued)

Profile	Location (cm) X	Y	Z	V, velocity (cm/s)	Profile	Location (cm) X	Y	Z	V, velocity (cm/s)
D2: Velocity profile 0.6 cm inside orifice									
	0	0.2	≅-.6	84		3.8	0.2	≅-.6	101
	0	0.2	≅-.6	74		3.8	0.2	≅-.6	92
	0	1.2	≅-.6	104		3.8	1.2	≅-.6	105
	0	4.3	≅-.6	143		3.8	4.3	≅-.6	146
	0	5.9	≅-.6	152		3.8	5.9	≅-.6	159
	0	7.5	≅-.6	159		3.8	7.5	≅-.6	162
	0	10.6	≅-.6	169		3.8	10.6	≅-.6	172
	0	12.2	≅-.6	--		3.8	12.2	≅-.6	176
	0	13.5	≅-.6	183		3.8	13.5	≅-.6	185
	7.4	0.2	≅-.6	111		-6.4	5.9	≅-.6	159
	7.4	0.2	≅-.6	111		-4.6	5.9	≅-.6	158
	7.4	1.2	≅-.6	52		-3.0	5.9	≅-.6	155
	7.4	4.3	≅-.6	123		0	5.9	≅-.6	151
	7.4	5.9	≅-.6	151		3.0	5.9	≅-.6	155
	7.4	7.5	≅-.6	161		4.6	5.9	≅-.6	159
	7.4	10.6	≅-.6	176		5.8	5.9	≅-.6	158
	7.4	12.2	≅-.6	184		6.4	5.9	≅-.6	137
	7.4	13.5	≅-.6	195		7.0	5.9	≅-.6	145
						7.4	5.9	≅-.6	148

Table 10.-- Velocity data for test series E with 7.62 cm Helley-Smith bedload sampler with flume discharge 1.37 m^3/s; normal depth 0.56 m; slope 0.0028; and width 1.83 m.

Profile	Location (cm) X	Y	Z	V, velocity (cm/s)	Profile	Location (cm) X	Y	Z	V, velocity (cm/s)
E1: Undisturbed velocity profile 152 cm upstream of sampler									
	0	-1.3	152	20	E1	7.6	-1.3	152	20
	0	0	152	21		7.6	0	152	19
	0	0.6	152	52		7.6	0.6	152	55
	0	2.2	152	79		7.6	2.2	152	80
	0	5.3	152	101		7.6	5.3	152	102
	0	8.4	152	117		7.6	8.4	152	117
	0	11.5	152	129		7.6	11.5	152	126
	0	14.6	152	133		7.6	14.6	152	134
	0	17.7	152	141		7.6	17.7	152	140
	0	23.9	152	151		7.6	23.9	152	155
	0	30.1	152	161		7.6	30.1	152	161
	0	36.2	152	171		7.6	36.2	152	170
	0	42.4	152	175		7.6	42.4	152	175
	15.2	-1.3	152	20		15.2	11.5	152	124
	15.2	0	152	21		15.2	14.6	152	135
	15.2	0.6	152	55		15.2	17.7	152	143
	15.2	2.2	152	80		15.2	23.9	152	154
	15.2	5.3	152	104		15.2	30.1	152	161
	15.2	8.4	152	118		15.2	36.2	152	169
						15.2	42.4	152	175

Table 10.--(Continued)

Profile	Location (cm) X	Y	Z	V, velocity (cm/s)	Profile	Location (cm) X	Y	Z	V, velocity (cm/s)
E2: Velocity profile 0.6 cm inside orifice									
	0	0.2	≅-.6	111		1.9	0.2	≅-.6	121
	0	0.2	≅-.6	77		1.9	0.2	≅-.6	95
	0	1.3	≅-.6	113		1.9	1.3	≅-.6	119
	0	2.7	≅-.6	128		1.9	2.7	≅-.6	129
	0	4.1	≅-.6	139		1.9	4.1	≅-.6	138
	0	5.3	≅-.6	145		1.9	5.3	≅-.6	144
	0	6.3	≅-.6	147		1.9	6.3	≅-.6	147
	3.6	0.2	≅-.6	85		-3.6	2.7	≅-.6	91
	3.6	0.2	≅-.6	45		-3.2	2.7	≅-.6	2
	3.6	1.3	≅-.6	77		-2.6	2.7	≅-.6	112
	3.6	2.7	≅-.6	84		-2.0	2.7	≅-.6	130
	3.6	4.1	≅-.6	97		-1.1	2.7	≅-.6	128
	3.6	5.3	≅-.6	116		0	2.7	≅-.6	129
	3.6	6.3	≅-.6	136		1.1	2.7	≅-.6	128
						2.0	2.7	≅-.6	131
						2.1	2.7	≅-.6	124
						3.2	2.7	≅-.6	97
						3.6	2.7	≅-.6	92

Table 11.-- Velocity data for test series F with 7.62 cm Helley-Smith bedload sampler with flume discharge 1.37 m^3/s; normal depth 0.67 m; slope 0.0015; and width 1.83 m.

Profile	Location (cm) X	Y	Z	V, velocity (cm/s)	Profile	Location (cm) X	Y	Z	V, velocity (cm/s)
F1: Undisturbed velocity profile 152 cm upstream of sampler									
	0	-1.3	152	0	F1	7.6	-1.3	152	7
	0	0	152	7		7.6	0	152	16
	0	0.6	152	39		7.6	0.6	152	45
	0	2.2	152	61		7.6	2.2	152	63
	0	5.3	152	82		7.6	5.3	152	82
	0	8.4	152	95		7.6	8.4	152	95
	0	11.4	152	104		7.6	11.4	152	102
	0	14.5	152	107		7.6	14.5	152	109
	0	17.6	152	113		7.6	17.6	152	113
	0	23.8	152	123		7.6	23.8	152	123
	0	30.0	152	132		7.6	30.0	152	131
	0	36.1	152	139		7.6	36.1	152	138
	0	42.3	152	142		7.6	42.3	152	141
	15.2	-1.3	152	10			11.4	152	101
	15.2	0	152	14			14.5	152	107
	15.2	0.6	152	45			17.6	152	112
	15.2	2.2	152	61			23.8	152	123
	15.2	5.3	152	82			30.0	152	131
	15.2	8.4	152	93			36.1	152	138
							42.3	152	142

Table 11.--(Continued)

Profile	Location (cm) X	Y	Z	V, velocity (cm/s)	Profile	Location (cm) X	Y	Z	V, velocity (cm/s)
F2: Velocity profile 0.6 inside nozzle									
	0	0.2	≅-.6	55		1.9	0.2	≅-.6	72
	0	0.3	≅-.6	69		1.9	0.3	≅-.6	76
	0	1.6	≅-.6	95		1.9	1.6	≅-.6	95
	0	3.0	≅-.6	106		1.9	3.0	≅-.6	107
	0	4.3	≅-.6	113		1.9	4.3	≅-.6	113
	0	5.6	≅-.6	117		1.9	5.6	≅-.6	119
	0	6.6	≅-.6	123		1.9	6.6	≅-.6	122
	3.6	0.2	≅-.6	47		0	0.2	≅-.6	77
	3.6	0.3	≅-.6	52		0	0.3	≅-.6	65
	3.6	1.6	≅-.6	72		0	1.6	≅-.6	91
	3.6	3.0	≅-.6	79		0	3.0	≅-.6	101
	3.6	4.3	≅-.6	91		0	4.3	≅-.6	109
	3.6	5.6	≅-.6	105		0	5.6	≅-.6	117
	3.6	6.6	≅-.6	118		0	6.6	≅-.6	120
	1.9	0.2	≅-.6	85		3.6	0.2	≅-.6	93
	1.9	0.3	≅-.6	76		3.6	0.3	≅-.6	79
	1.9	1.6	≅-.6	92		3.6	1.6	≅-.6	80
	1.9	3.0	≅-.6	106		3.6	3.0	≅-.6	92
	1.9	4.3	≅-.6	113		3.6	4.3	≅-.6	102
	1.9	5.6	≅-.6	117		3.6	5.6	≅-.6	111
	1.9	6.6	≅-.6	120		3.6	6.6	≅-.6	121

Table 11.--(Continued)

Profile	Location (cm) X	Y	Z	V, velocity (cm/s)	Profile	Location (cm) X	Y	Z	V, velocity (cm/s)
F2: (Continued).									
	-3.6	3.0	≅-.6	76		-3.6	3.0	≅-.6	87
	-3.2	3.0	≅-.6	80		-3.2	3.0	≅-.6	91
	-2.6	3.0	≅-.6	104		-2.6	3.0	≅-.6	108
	-2.0	3.0	≅-.6	107		-2.0	3.0	≅-.6	105
	-1.1	3.0	≅-.6	106		-1.1	3.0	≅-.6	104
	0	3.0	≅-.6	106		0	3.0	≅-.6	102
	1.1	3.0	≅-.6	106		1.1	3.0	≅-.6	102
	2.0	3.0	≅-.6	105		2.0	3.0	≅-.6	106
	2.1	3.0	≅-.6	106		2.6	3.0	≅-.6	105
	3.2	3.0	≅-.6	89		3.2	3.0	≅-.6	97
	3.6	3.0	≅-.6	82		3.6	3.0	≅-.6	92
F3: Velocity profile 0.6 cm inside nozzle with no bag attached									
	0	0.2	-3.0	69					
	0	0.3	-3.0	72					
	0	0.9	-3.0	85					
	0	1.6	-3.0	93					
	0	3.0	-3.0	109					
	0	4.3	-3.0	116					
	0	5.6	-3.0	120					
	0	6.6	-3.0	124					

Table 11.-- (Continued)

Profile	Location (cm) X	Y	Z	V, velocity (cm/s)	Profile	Location (cm) X	Y	Z	V, velocity (cm/s)
F4: Velocity profile 0.6 cm inside nozzle with 1.5 cm x 10 cm slot in the bag for pitot tube									
	0	0.2	0	55		0	0.2	-3.0	77
	0	0.3	0	69		0	0.3	-3.0	65
	0	0.9	0			0	0.9	-3.0	
	0	1.6	0	95		0	1.6	-3.0	91
	0	3.0	0	106		0	3.0	-3.0	101
	0	4.3	0	113		0	4.3	-3.0	109
	0	5.6	0	117		0	5.6	-3.0	117
	0	6.6	0	123		0	6.6	-3.0	120
F5: Velocity profile 0.6 cm inside nozzle with the slot in the bag for the pitot tube same size as the pitot tube									
	0	0.2	-3.0	61					
	0	0.8	-3.0	88					
	0	1.4	-3.0	87					
	0	2.0	-3.0	106					
	0	3.4	-3.0	113					
	0	4.8	-3.0	118					
	0	6.0	-3.0	119					
	0	7.0	-3.0	123					

Table 11.--(Continued)

Profile	Location (cm) X	Y	Z	V, velocity (cm/s)	Profile	Location (cm) X	Y	Z	V, velocity (cm/s)
F6: Velocity profile 0.6 cm inside nozzle with bag 20% full by volume of 10 mm sediment									
	0	0.2	≅-.6	64		0	0.2	-1.2	74
	0	0.8	≅-.6	91		0	1.2	-1.2	89
	0	1.4	≅-.6	93		0	2.4	-1.2	103
	0	2.0	≅-.6	101		0	3.8	-1.2	110
	0	3.4	≅-.6	111		0	5.2	-1.2	117
	0	4.8	≅-.6	114		0	6.4	-1.2	123
	0	6.0	≅-.6	120		0	7.4	-1.2	114
	0	7.0	≅-.6	121					
	2.9	0	-1.2	113					
	2.9	0	-1.2	113					
	2.9	0	-1.2	112					
	2.9	0	-1.2	113					
	2.9	0	-1.2	112					
	2.9	0	-1.2	114					
	2.9	0	-1.2	112					
	2.9	0	-1.2	114					
	2.9	0	-1.2	114					

Table 11.--(Continued)

Profile	Location (cm) X	Y	Z	V, velocity (cm/s)	Profile	Location (cm) X	Y	Z	V, velocity (cm/s)
F7: Velocity profile 0.6 cm inside nozzle with bag 20 percent full by volume of 10-mm sediment									
	0	0.2	=-.6	76					
	0	0.8	=-.6	84					
	0	1.4	=-.6	89					
	0	2.0	=-.6	97					
	0	3.4	=-.6	107					
	0	4.8	=-.6	116					
	0	6.0	=-.6	120					
	0	7.0	=-.6	118					
F8: Velocity profile 0.6 cm inside nozzle with bag 20 percent full by volume of 0.2-mm sediment									
	0	0.2	=-.6	0		0	0.2	-1.2	85
	0	0.8	=-.6	0		0	1.2	-1.2	97
	0	1.4	=-.6	0		0	2.4	-1.2	108
	0	2.0	=-.6	10		0	3.8	-1.2	115
	0	3.4	=-.6	30		0	5.2	-1.2	121
	0	4.8	=-.6	44		0	6.4	-1.2	125
	0	6.0	=-.6	53		0	7.4	-1.2	100
	0	7.0	=-.6	60					

Table 11.--(Continued)

Profile	Location (cm) X	Y	Z	V, velocity (cm/s)	Profile	Location (cm) X	Y	Z	V, velocity (cm/s)
F8: (Continued).									
	0	0.2	-1.2	80					
	0	1.2	-1.2	95					
	0	2.4	-1.2	106					
	0	3.8	-1.2	115					
	0	5.2	-1.2	119					
	0	6.4	-1.2	123					
	0	7.4	-1.2	95					
F9: Velocity profile 0.6 cm inside nozzle with bag 40 percent full by volume of 0.2-mm sediment									
	0	0.2	≅-.6	22					
	0	0.8	≅-.6	27					
	0	1.4	≅-.6	35					
	0	2.0	≅-.6	42					
	0	3.4	≅-.6	55					
	0	4.8	≅-.6	61					
	0	6.0	≅-.6	69					
	0	7.0	≅-.6	71					

Table 11.-- (Continued)

Profile	Location (cm) X	Y	Z	V, velocity (cm/s)	Profile	Location (cm) X	Y	Z	V, velocity (cm/s)
F10: Velocity profiles 8 cm upstream of sampler									
	-3	-.3	8	27		-1.9	-.3	8	27
	-3	0	8	32		-1.9	0	8	35
	-3	.9	8	47		-1.9	.9	8	52
	-3	1.8	8	67		-1.9	1.8	8	61
	-3	2.7	8	69		-1.9	2.7	8	69
	-3	3.8	8	77		-1.9	3.8	8	76
	-3	4.9	8	84		-1.9	4.9	8	84
	-3	5.8	8	84		-1.9	5.8	8	87
	-3	6.7	8	89		-1.9	6.7	8	89
	-3	7.6	8	91		-1.9	7.6	8	92
	0	0	8	42		1.9	0	8	42
	0	.9	8	57		1.9	.9	8	55
	0	1.8	8	67		1.9	1.8	8	65
	0	2.7	8	72		1.9	2.7	8	70
	0	3.8	8	77		1.9	3.8	8	77
	0	4.9	8	82		1.9	4.9	8	84
	0	5.8	8	88		1.9	5.8	8	88
	0	6.7	8	89		1.9	6.7	8	91
	0	7.6	8	92		1.9	7.6	8	92

Table 11.--(Continued)

Profile	Location (cm) X	Y	Z	V, velocity (cm/s)	Profile	Location (cm) X	Y	Z	V, velocity (cm/s)
F10: (Continued).									
	3	0	8	32		6.1	0	8	16
	3	.9	8	39		6.1	.9	8	39
	3	1.8	8	52		6.1	1.8	8	50
	3	2.7	8	61		6.1	2.7	8	63
	3	3.8	8	76		6.1	3.8	8	65
	3	4.9	8	77		6.1	4.9	8	69
	3	5.8	8	85		6.1	5.8	8	72
	3	6.7	8	88		6.1	6.7	8	76
	3	7.6	8	85		6.1	7.6	8	80
	9.1	0	8	0		12.2	0	8	0
	9.1	.9	8	32		12.2	.9	8	32
	9.1	1.8	8	47		12.2	1.8	8	45
	9.1	2.7	8	59		12.2	2.7	8	55
	9.1	3.8	8	63		12.2	3.8	8	61
	9.1	4.9	8	70		12.2	4.9	8	67
	9.1	5.8	8	72		12.2	5.8	8	74
	9.1	6.7	8	76		12.2	6.7	8	77
	9.1	7.6	8	77		12.2	7.6	8	80

Table 11.--(Continued)

Profile	Location (cm) X	Y	Z	V, velocity (cm/s)	Profile	Location (cm) X	Y	Z	V, velocity (cm/s)
F10: (Continued).									
	0	9.1	8	85					
	0	10.7	8	87					
	0	12.2	8	91					
	0	13.7	8	93					
	0	15.2	8	98					
	0	21.3	8	110					
	0	22.9	8	115					
	0	30.5	8	132					
	0	38.1	8	137					
	0	45.7	8	146					

Table 12.-- Velocity data for test series G with nozzle models 1 to 6 with flume discharge 0.1 m^3/s ; normal depth 0.25 m; slope 0.000; and width 0.51 m.

Profile	Location (cm) X	Y	Z	V, velocity (cm/s)	Profile	Location (cm) X	Y	Z	V, velocity (cm/s)
G1: Undisturbed velocity profiles 152 cm upstream 30.5 cm downstream and at the location of the samplers									
	0	0.0	-30.5	63	G1	0	0.0	152	56
	0	2.8	-30.5	78		0	2.8	152	68
	0	5.8	-30.5	80		0	5.8	152	69
	0	8.8	-30.5	79		0	8.8	152	71
	0	11.9	-30.5	80		0	11.9	152	75
	0	14.9	-30.5	80		0	14.9	152	77
	0	18.0	-30.5	82		0	18.0	152	83
	0	21.0	-30.5	86		0	21.0	152	85
	0	24.1	-30.5	87		0	24.1	152	89
	0	0.0	14	57		0	0.0	0	67
	0	1.5	14	68		0	2.8	0	74
	0	3.1	14	73		0	5.8	0	75
	0	6.1	14	74		0	8.8	0	75
	0	9.1	14	74		0	11.9	0	77
	0	12.2	14	74		0	14.9	0	78
	0	15.2	14	75		0	18.0	0	84
	0	18.3	14	76		0	21.0	0	85
	0	21.0	14	80		0	24.1	0	88
	0	24.5	14	82					

Table 12.-- (Continued)

Profile	Location (cm) X	Y	Z	V, velocity (cm/s)	Profile	Location (cm) X	Y	Z	V, velocity (cm/s)
G1: (Continued).									
	23.5	5.5	14	70					
	17.8	5.5	14	70					
	11.4	5.5	14	69					
	7.6	5.5	14	71					
	1.3	5.5	14	73					
	-11.4	5.5	14	78					
	-17.8	5.5	14	78					
	-21.6	5.5	14	74					
G2: Velocity for model sampler 1 with no bag									
	3.2	0.3	1.0	90		0	0.4	1.0	102
	3.2	1.4	1.0	91		0	1.9	1.0	110
	3.2	2.9	1.0	92		0	3.2	1.0	112
	3.2	4.3	1.0	96		0	5.0	1.0	112
	3.2	6.1	1.0	103		0	6.5	1.0	113
	3.2	7.0	1.0	109		0	6.8	1.0	114
	-3.2	0.3	1.0	116					
	-3.2	1.4	1.0	117					
	-3.2	2.9	1.0	120					
	-3.2	4.3	1.0	122					
	-3.2	7.0	1.0	122					

Table 12.--(Continued)

Profile	Location (cm) X	Y	Z	V, velocity (cm/s)	Profile	Location (cm) X	Y	Z	V, velocity (cm/s)
G3: Velocity for model sampler 2 with no bag									
	3.2	0.3	1.0	65		0	0.3	1.0	78
	3.2	1.8	1.0	76		0	1.8	1.0	86
	3.2	3.4	1.0	82		0	3.4	1.0	88
	3.2	4.9	1.0	85		0	4.9	1.0	89
	3.2	6.4	1.0	87		0	6.4	1.0	91
	3.2	7.0	1.0	88		0	7.0	1.0	91
	-3.2	0.3	1.0	88					
	-3.2	1.8	1.0	91					
	-3.2	3.4	1.0	94					
	-3.2	4.9	1.0	95					
	-3.2	6.4	1.0	96					
	-3.2	7.0	1.0	96					
G4: Velocity for model sampler 2 with a plastic bag of 1 mm mesh.									
	Bag area 1030 cm^2					Bag area 520 cm^2			
	0	0.3	1.0	76		0	.3	1.0	81
	0	1.8	1.0	85		0	1.8	1.0	88
	0	3.4	1.0	87		0	3.4	1.0	92
	0	4.9	1.0	89		0	4.9	1.0	92
	0	6.4	1.0	90		0	6.4	1.0	90

Table 12.-- (Continued)

Profile	Location (cm) X	Y	Z	V, velocity (cm/s)	Profile	Location (cm) X	Y	Z	V, velocity (cm/s)
G4: (Continued).									
	Bag area 260 cm^2					Bag area 170 cm^2			
	0	.3	1.0	65		0	.3	1.0	57
	0	1.8	1.0	74		0	1.8	1.0	63
	0	3.4	1.0	80		0	3.4	1.0	69
	0	4.9	1.0	80		0	4.9	1.0	71
	0	6.4	1.0	83		0	6.4	1.0	71
	Bag area 60 cm^2								
	0	.3	1.0	31					
	0	1.8	1.0	45					
	0	3.4	1.0	51					
	0	4.9	1.0	54					
	0	6.4	1.0	54					
G5: Velocity for model sampler 3									
	3.2	0.3	1.0	66		0	0.3	1.0	81
	3.2	1.8	1.0	77		0	1.8	1.0	86
	3.2	3.4	1.0	79		0	3.4	1.0	90
	3.2	4.9	1.0	84		0	4.9	1.0	91
	3.2	6.4	1.0	87		0	6.4	1.0	91
	3.2	6.7	1.0	87		0	6.7	1.0	91
	-3.2	0.3	1.0	83					
	-3.2	1.8	1.0	94					
	-3.2	3.4	1.0	99					
	-3.2	4.9	1.0	100					
	-3.2	6.4	1.0	101					
	-3.2	6.7	1.0	101					

Table 12.--(Continued)

Profile	Location (cm) X	Y	Z	V, velocity (cm/s)	Profile	Location (cm) X	Y	Z	V, velocity (cm/s)
G6: Velocity for model sampler 4									
	3.2	0.3	1.0	90		0	0.3	1.0	95
	3.2	1.8	1.0	98		0	1.8	1.0	100
	3.2	3.4	1.0	101		0	3.4	1.0	102
	3.2	4.9	1.0	100		0	4.9	1.0	102
	3.2	6.4	1.0	100		0	6.4	1.0	106
	-3.2	0.3	1.0	101					
	-3.2	1.8	1.0	106					
	-3.2	3.4	1.0	110					
	-3.2	4.9	1.0	112					
	-3.2	6.4	1.0	112					
G7: Velocity for model sampler 5									
	3.2	0.3	1.0	60		0	0.3	1.0	71
	3.2	1.8	1.0	68		0	1.8	1.0	76
	3.2	3.4	1.0	72		0	3.4	1.0	79
	3.2	4.9	1.0	74		0	4.9	1.0	81
	3.2	6.4	1.0	77		0	6.4	1.0	82
	3.2	7.0	1.0	77		0	7.0	1.0	82

Table 12.--(Continued)

Profile	Location (cm) X	Y	Z	V, velocity (cm/s)	Profile	Location (cm) X	Y	Z	V, velocity (cm/s)
G7: (Continued).									
	-3.2	0.3	1.0	76					
	-3.2	1.8	1.0	84					
	-3.2	3.4	1.0	87					
	-3.2	4.9	1.0	87					
	-3.2	6.4	1.0	88					
	-3.2	7.0	1.0	87					
G8: Velocity for model sampler 6									
	3.2	0.3	1.0	96		0	0.3	1.0	98
	3.2	1.8	1.0	96		0	1.8	1.0	113
	3.2	3.4	1.0	102		0	3.4	1.0	120
	3.2	4.9	1.0	107		0	4.9	1.0	121
	3.2	6.4	1.0	113		0	6.4	1.0	126
	3.2	7.0	1.0	112		0	7.0	1.0	127
	-3.2	0.3	1.0	121					
	-3.2	1.8	1.0	126					
	-3.2	3.4	1.0	131					
	-3.2	4.9	1.0	134					
	-3.2	6.4	1.0	138					
	-3.2	7.0	1.0	138					

Table 13.-- Velocity data for test series H with 7.62 cm Helley-Smith bedload sampler with flume discharge 0.98 m^3/s; normal depth 0.52 m; slope 0.002; and width 1.83 m.

Profile	Location (cm) X	Y	Z	V, velocity (cm/s)	Profile	Location (cm) X	Y	Z	V, velocity (cm/s)
H1: Undisturbed velocity profile 152 cm upstream of sampler									
	0	0	152	32	H1	0	0	152	16
	0	1.5	152	55		0	1.2	152	45
	0	3.0	152	69		0	2.4	152	63
	0	4.6	152	80		0	3.8	152	74
	0	6.1	152	87		0	5.2	152	88
	0	9.1	152	98		0	6.4	152	91
	0	12.2	152	103		0	7.4	152	95
	0	15.2	152	112		0	9.1	152	102
	0	22.9	152	126		0	12.2	152	112
	0	30.5	152	132		0	15.2	152	119
	0	33.4	152	136		0	22.9	152	127
						0	30.5	152	137
						0	38.1	152	144
						0	39.3	152	144

Table 13.--(Continued)

Profile	Location (cm) X	Y	Z	V, velocity (cm/s)	Profile	Location (cm) X	Y	Z	V, velocity (cm/s)
H2: Velocity profile 1.2 cm inside nozzle									
	0	0.2	-1.2	70					
	0	1.2	-1.2	93					
	0	2.4	-1.2	103					
	0	3.8	-1.2	112					
	0	5.2	-1.2	117					
	0	6.4	-1.2	122					
	0	7.4	-1.2	109					
H3: Velocity profile 1.2 cm inside nozzle with bag 20 percent full by volume of 10-mm sediment									
	2.9	3.8	-1.2	116		0	0.2	-1.2	70
	2.6	3.8	-1.2	114		0	1.2	-1.2	92
	2.0	3.8	-1.2	113		0	2.4	-1.2	107
	1.0	3.8	-1.2	114		0	3.8	-1.2	114
	0	3.8	-1.2	113		0	5.2	-1.2	123
	-1.0	3.8	-1.2	114		0	6.4	-1.2	126
	-2.0	3.8	-1.2	117		0	7.4	-1.2	110
	-2.6	3.8	-1.2	112					
	-2.9	3.8	-1.2	103					

Table 13.-- (Continued)

Profile	Location (cm) X	Y	Z	V, velocity (cm/s)	Profile	Location (cm) X	Y	Z	V, velocity (cm/s)
H4: Velocity profile 1.2 cm inside nozzle with bag 40 percent full by volume of 1.2-mm sediment									
	0	0.2	-1.2	79					
	0	1.2	-1.2	89					
	0	2.4	-1.2	103					
	0	3.8	-1.2	115					
	0	5.2	-1.2	120					
	0	6.4	-1.2	127					
	0	7.4	-1.2	109					