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Determination of Sediment Filtration Efficiency of Grass Media

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David T. Kao
University of Kentucky

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DETERMINATION OF SEDIMENT FILTRATION EFFICIENCY OF GRASS MEDIA

(Volume I) SEDIMENT FILTRATION EFFICIENCY OF CONTINUOUS GRASS MEDIA

by
David T. Kao
Principal Investigator

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University of Kentucky
Water Resources Research Institute
Lexington, Kentucky

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DISCLAIMER

ABSTRACT

Vegetative filters serve the purpose of retarding flow. As a result the sediment carrying power of flowing water in a vegetated channel is greatly reduced and silting takes place along the section where the vegetation is planted.

The mechanism of the filtering action of real or artifical vegetation can be described by a simplified principle, in that a gross reduction of turbulent fluctuation of the fluid is involved. This in turn allows the sediment particles to settle under the force of gravity more readily. In the case of nonsubmerged flow, solid particles may settle out even faster due to the lengthening of the path the particles travel as they move with the fluid around the vegetation blades and the creation of zero velocity regions in front and behind the vegetation stems.

In order to determine the actual sediment trapping efficiency, a series of experimental tests were conducted under various flow conditions in a channel with continuous and discrete vegetative covers. The research results will be presented in three parts: (1) sediment filtration efficiency of continuous grass media; (2) bedload behavior in continuous and discrete vegetative filters; and (3) trapping of suspended solids by diecrete vegetative filters. This research report addressed the effectiveness of the vegetative filter in trapping suspended solids when the filter is arranged in a continuous manner.

Descriptors: Sediment Transport*, Suspended Load, Bed Load, Grassed Waterway*, Trapping Efficiency*

Identifiers: Grass Filter, Sediment Filtration, Filtration Efficiency

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TABLE OF CONTENTS

Title Page i
Disclaimer ii
Abstract iii
Acknowledgment iv
List of Tables vi
List of Figures vii
Introduction 1
Chapter I Research Procedures 5
Experimental Facilities 5
Experimental Procedures 9
Chapter II Data and Results 13
Filtration Efficiency 13
Sediment Size Distribution 22
Bed Load Profile 29
Chapter III Conclusions 42
References 44

LIST OF FIGURES

page

Fig. 1 Schematic drawing of the experimental facility 6

Fig. 2 General arrangement of the laboratory set-up...................7

Fig. 3 Three different types of simulated vegetation and two..........
different blade densities 8

Fig. 4 Dry sediment feeding box 10

Fig. 5 Microscope picture of sediment samples taken at 0.3 m
(1 foot), 1.5 m (5 feet) and 2.7 m (9 feet), respectively 12

Fig. 6 Sediment filtration efficiency for stiff, less dense
vegetation with uniform particle size 17

Fig. 7 Sediment filtration efficiency for stiff, less dense
vegetation with mixed particle size. 18

Fig. 8 Sediment filtration efficiency for stiff, dense vegetation
with mixed particle size 19

Fig. 9 Sediment filtration efficiency for less stiff vegetation
with mixed particle size 20

Fig. 10 Sediment filtration efficiency for least stiff vegetation
with mixed particle size.....................................21

Fig. 11 Typical sediment bed profile and its forward progress
pattern...31

Fig. 12 Typical sediment bed profile and its forward progress
pattern 32

Fig. 13 Typical sediment bed profile and its forward progress
pattern...33

Fig. 14 Typical sediment bed profile and its forward progress
pattern...34

Fig. 15 Typical sediment bed profile and its forward progress
pattern...35

Fig. 16 Typical sediment bed profile and its forward progress
pattern 36

Fig. 17 Sediment bed formed by trapped sediment in stiff and
flexible simulated grass.....................................41

LIST OF TABLES

Table I Sieve Analysis of Sediment Material Used 14
Table II Sediment Filtration Efficiency for Various Flow Conditions 15
Table III Size Range of Sediment Samples 14
Table IV Percentage of Sediment Type Presented Along Flume 23
Table V Bed Load Progression with Time and Maximum Height of Progression 37

CHAPTER I

INTRODUCTION

Erosion is a process of soil detachment by impact of rain drops and by the shear force due to moving water. Although such a process is a natural one, in areas where soil disturbance is taking place the erosion process becomes more severe and large volumes of sediment are produced.

The sediment particles are then transported by the concentrated water to a place of deposition. In the process, it pollutes the nation's streams and silts reservoirs and waterways. The adverse effects from sediment pollution on water resources are well documented and various control measures are implemented, most of which require expensive capital construction and are subject to difficult maintainence procedures.

Some relatively economical sediment control methods are therefore needed in order to provide increased protection and additional preservation of the nation's water resources. One of such methods is the use of real or artificial vegetative filters to trap, on site, the excessive sediment load or to perform filtering action to the sediment concentrated runoff water near the sources of its production, which include sites of urban construction and land involved with active mining activities.

In 1967 Freeman (1) stated that farm land with good vegetation has erosion ranging up to 50 $T/m^2/yr$. while land with no vegetation can have up to 2300 $T/m^2/yr$. This clearly indicates that vegetation prevents soil erosion. However, vegetation must be stripped away during construction, leaving the ground bare and susceptible to erosion. Therefore, some methods must be employed to stop the sediment from polluting our waterways.

The proposed EPA "Effluent Guidelines and Standards" (2) requires that the total suspended solids from coal mine land runoff should not exceed 70 mg/ℓ maximum concentration for any one day period. The guideline further states that untreated overflow from facilities designed, constructed and operated to treat the mine drainage and the runoff at the treatment facility, resulting from a ten year 24-hour precipitation event, shall not be subject to the limitations. This indicates the positive recognition by the guideline that to design and construct a control system for rainfall events which produce excessively large volume of runoff will be uneconomical and impractical. The control system is therefore designed, with a major aim, to insure clean effluent for daily drainage flow events.

One method employed for sediment removal from rain water is to construct sediment basins or diversions. This method is expensive to build and maintain, and it is sometimes difficult to find suitable sites.

Grass filters have previously been used in Bayard, Nebraska for treatment of sugar beet waste. The waste was passed through a 160 acre treatment field with up to 98% removal of suspended solids.

Transportation and dispersion of sediment are caused by forces of the carrying fluid acting on individual particles. Thus the process of filtration and retention is expected to be a function of the fluid power in transporting the particles. Such fluid power is normally present in the form of kinetic energy which is directly proportional to the square of the velocity of the moving fluid.

According to Brown (3), vegetation acts to reduce the velocity by retarding the flow. This causes the sediment to deposit around and between the plants.

L.G. Wilson (4) was one of the first to evaluate the removal of sediment from waters by grass filtration. He listed these requirements for a grass filter:

1. Deep root system to resist scouring if swift currents develop
2. Dense, well ramified top growth
3. Resistance to flooding and drought
4. Ability to recover growth subsequent to inundation with sediment
5. Yield economic returns either through the production of seed or hay.

Wilson indicated that grass filters promote mechanical sedimentation by retarding the flow velocity and thus enhancing particle settling. He states that when steady state conditions are approached, the most important parameters in sedimentation are: bed slope, quantity and quality of turbulence and vegetative characteristics such as density, height and flexibility.

Wilson found, working at San Jose, that bermuda grass was a good grass to use as opposed to various alfalfas. He indicated that bermuda grass had a greater removal efficiency due to a larger Manning's 'n' value than other grasses. Also, inundation would not inhibit growth of bermuda grass. In general Wilson found:

1. Continuous flooding did not appear to reduce filtration efficiency
2. When critical slope and critical velocity are exceeded, deposition rates are reduced
3. Longer filtration length is needed for colloidal size than silt size
4. Filtration length needed depends on sediment concentration, flowrate, channel bed and grass characteristics.

Kramer and Meyer (5), in working with surface mulches, stated that the quantity of material carried by flowing water is approximately proportional to $(V)^5$, and the size of particles moved is approximately proportional to $(V)^6$. Thus a small reduction in velocity will result in a great reduction in the amount and size of materials that can be carried. They found that slope steepness had the greatest effect on erosion rate and that mulch rate had the greatest effect on runoff velocity.

Podmore and Merva (6), in studying silt transportation by thin film flow, defined a quantity known as Critical Distance. The Critical Distance is the distance between the point of introduction of soil particles of a given size and the point at which the maximum percent of these particles is deposited. They determined Critical Distance for each range of particle size by plotting the number of particles retained on the surface vs distance from point of insertion into flow. The peak of the curve equaled the Critical Distance. Podmore and Merva in their study concluded:

1. Critical Distance slightly decreased with increased particle size
2. Critical Distance increased with increasing slope and increasing flowrate
3. Stokes' law was not valid because in thin film flow velocity fluctuations are present

Tollner, Barfield and Kao (7), in attempting to model the filtration capacity of simulated rigid vegetation, found that velocity was the most dominant parameter, followed by spacing hydraulic radius, flow depth, length, and particle fall velocity. The spacing hydraulic radius, R_s, was defined as vegetation spacing times flow depth divided by twice the flow depth plus the spacing or:

$$R_s = \frac{(S_s)\ (D_w)}{2\ D_w + S_s}$$

where: D_w = flow depth, and

S_s = space between simulated vegetation.

Their results allow one to approximate filtration efficiency as a function of flow characteristics for the same simulated flow conditions.

In the recent revival of research interest on the subject of sediment filtration by grass filters, Kao, et al (8) discussed the feasibility of on-site application of the grass filters at urban construction sites. Tollner, et al (9) presented a discussion of the sediment deposition pattern based on a bed load volume conservacion approach.

The application of sod strips as a filter to trap sediment produced by water drops from a rainfall simulator was reported by Neibling and Alberts (10). Their data provided much of the needed field confirmation of the possible application of the grass filter as a sediment control measure.

CHAPTER II

RESEARCH PROCEDURES

Experimental Facilities

The experimental apparatus consists of a 4.9 meter (16 feet) long rectangular flume which is 15 cm (.481 feet) wide by 45 cm (1.5 feet) deep. At one end is a 1.22 meter (4 feet) high by 0.3 meter (1 foot) long reservoir. A sluice gate with a 25.4 mm (1 inch) gate opening connects to the reservoir and produces a submerged hydraulic jump for mixing the sediment load before enterning the test section. Water was supplied into the reservoir from a constant head pit through a 50 mm (2 inch) pipe. Figure 1 is the schematic drawing of the facility.

One side wall of the flume is built of 12.7 mm (1/2 inch) plexiglass for visual observation while the other wall was made of plywood of the same thickness. The bottom was lined with 38 mm (1-1/2 inch) thick florist clay upon which the artificial vegetation was mounted. The flume rested on a 152 mm (6 inch) I-beam which was supported by a hinged plat at one end and a screw jack at the other. The jack could be adjusted to give slopes from 0% to 4.0%. Figure 2 shows the general arrangement of the laboratory setup.

Three types of artificial vegetation were used. Polypropylene coffee sticks with dimensions of 140 mm (5-1/4 inch) by 6.4 mm (1/4 inch) by 1.6 mm (1/16 inch) were used as one type. The other two types of artificial grasses were cut out of acetate films of 0.244 mm (0.0096 inch) and 0.09 mm (0.0036 inch) in thickness. The individual blades were embedded in paraffin by first heating the paraffin to a liquid state and pouring it into a 146 mm (5-3/4 inch) by 102 mm (4 inch) rectangular mold. The blades were held in place in the hot paraffin by means of two pieces of wire mesh fixed over the mold. The paraffin with the embedded artificial grasses was then cooled and fixed upon the modeling clay with screws. Figure 3 shows three types of artificial vegetation and two different simulated vegetation densities formed by stiff blades.

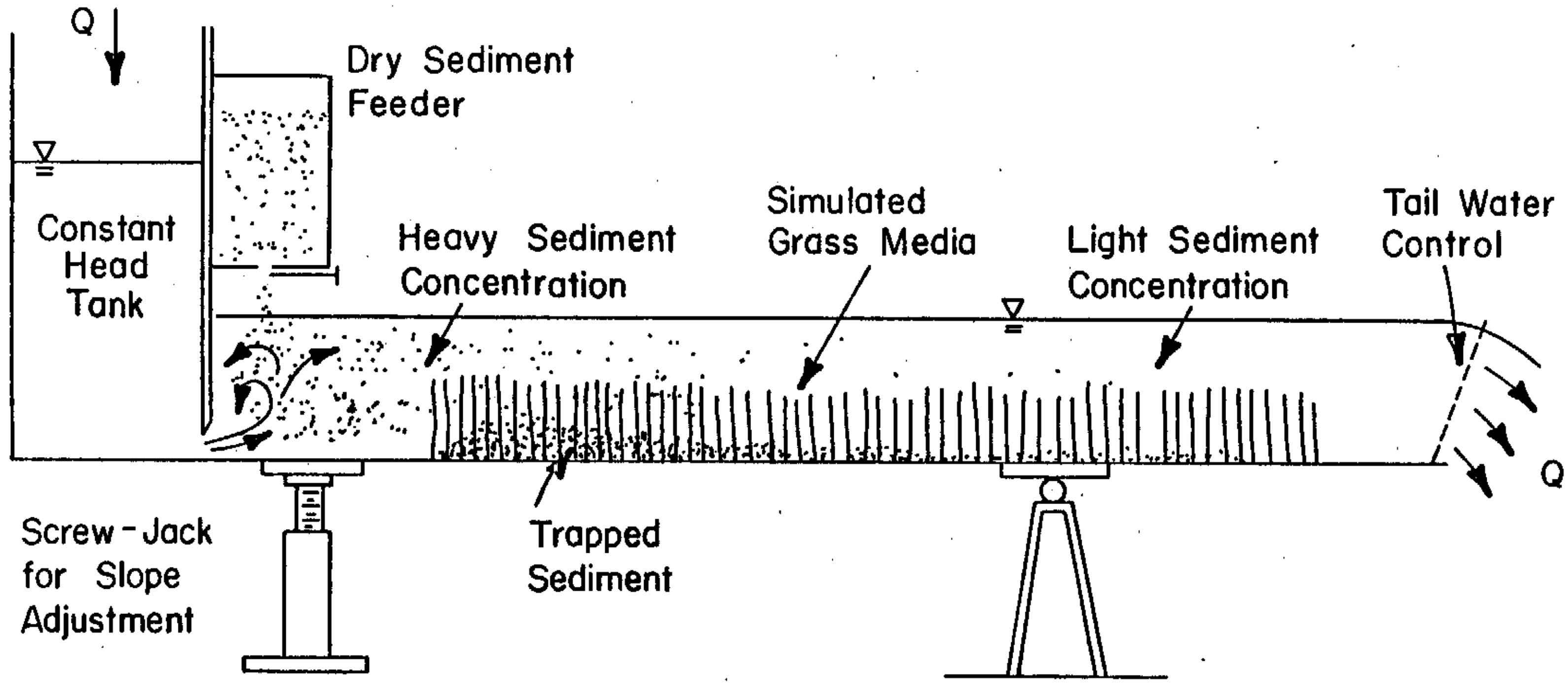

Fig. 1 Schematic drawing of the experimental facility

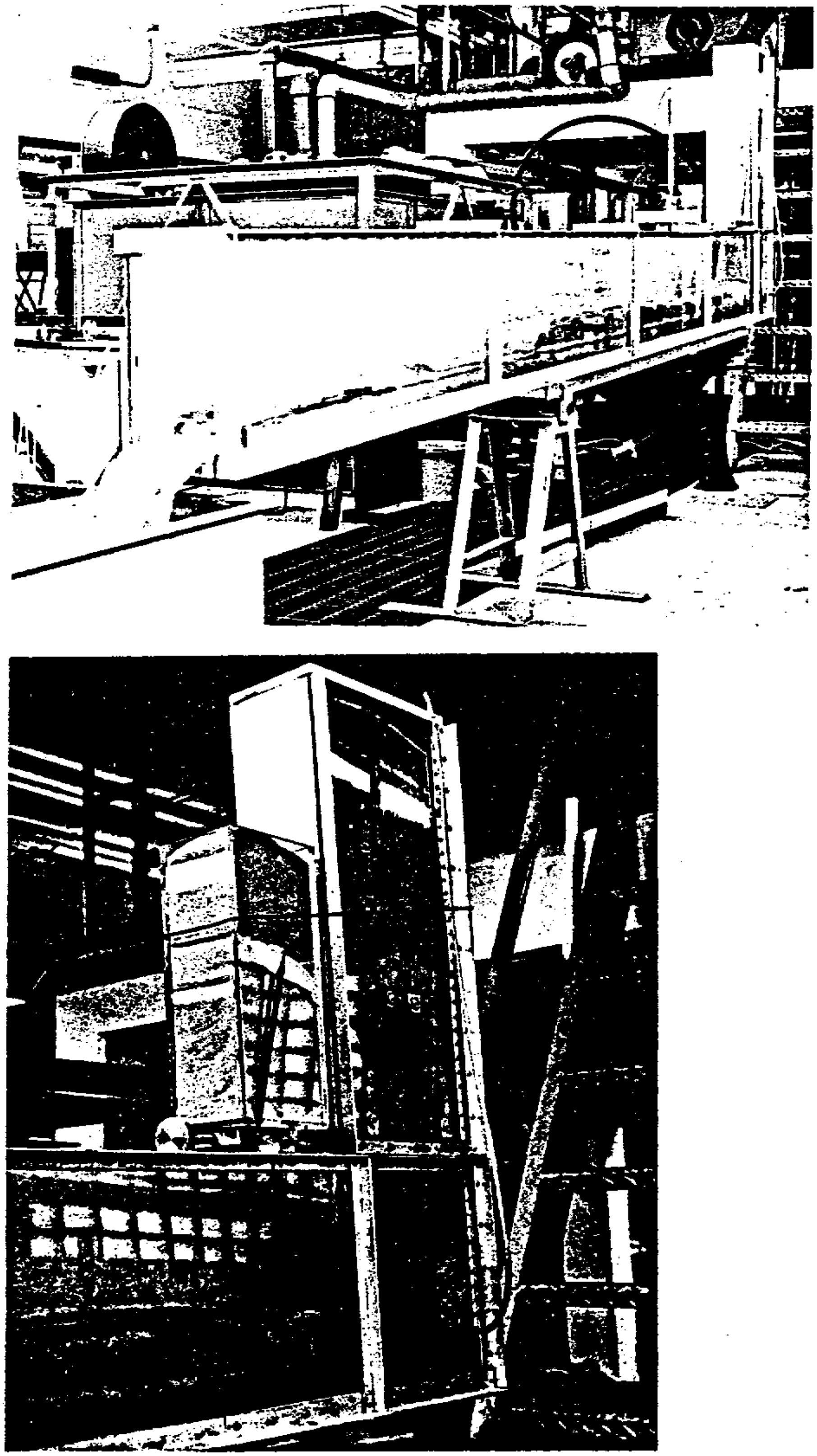

Fig. 2 General arrangement of the laboratory set-up

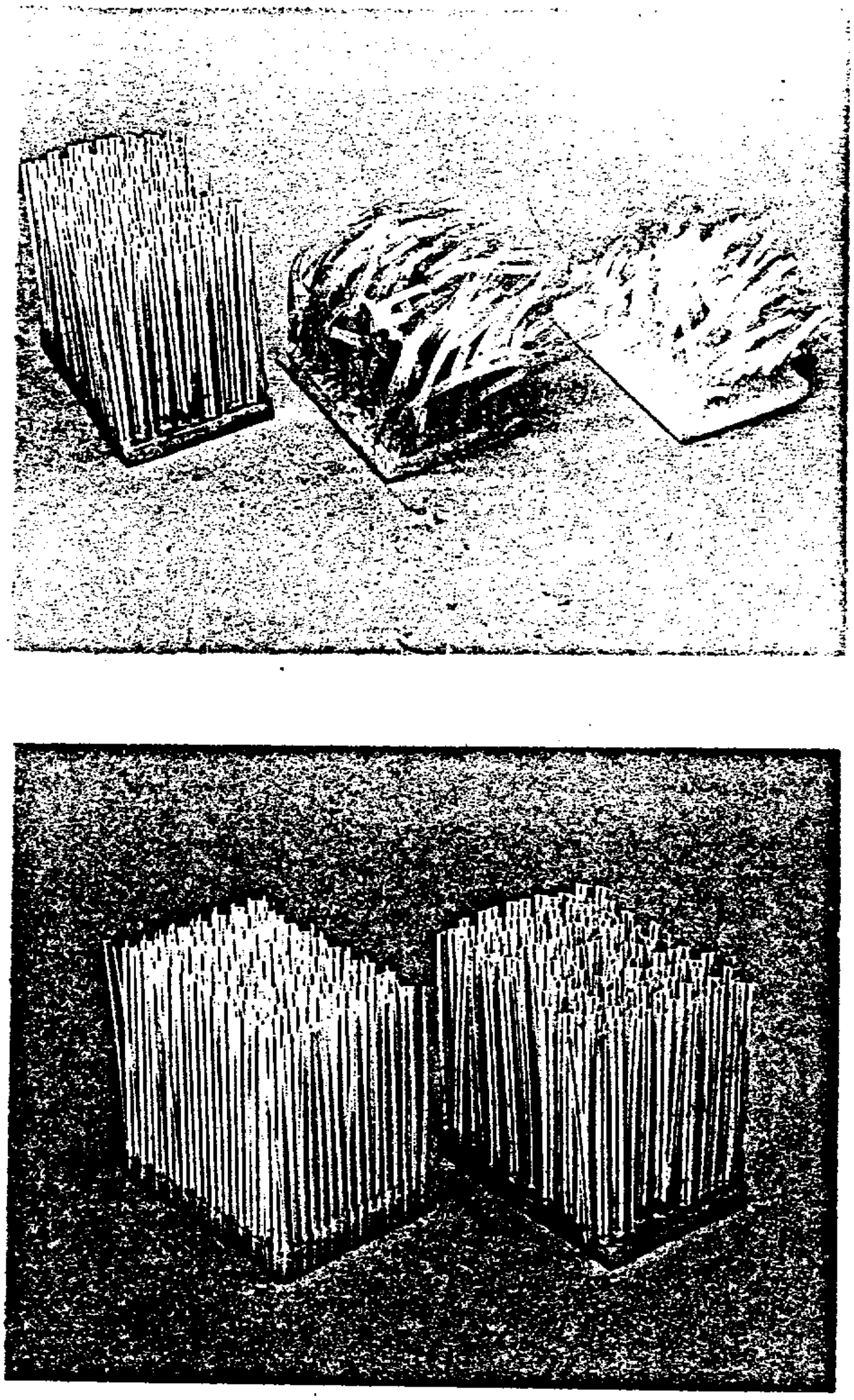

Fig. 3 Three diffent types of simulated vegetation (above) and diffent blade densities

In the phase - I experiments spherical glass beads were used to simulate various sediment sizes. The glass beads of diameters ranging from 0.025 mm (.001 inches) to 6.00 mm (.024 inches) were fed into the flume by means of a feeder box. The feeder box, which is 45.7 cm (18 inches) high, 17.7 (7 inches) long and 12.7 cm (5 inches) wide, (Fig. 4) was placed immediately after the sluice gate. The feeding rate of the sediment was controlled by adjusting the opening size of a control valve in the bottom of the feeder box. The dry sediment was then wetted and mixed with water at the submerged hydraulic jump produced by the sluice gate.

The flow discharge, which was controlled by a valve in the 50 mm (3 inch) pipe line, was measured by noting the water level on a precalibrated scale placed on the reservoir of the flume. Knowing the sediment feeding rate and the rate of clear water flow, the inflow sediment concentration can be determined.

Experimental Procedures

The independent variables used in the experimental analysis were slope, discharge, sediment feeding rate, grass desnity and grass stiffness. The dependent variables were water depth, the sediment inflow and outflow concentration, the time variation of the bedload profile and the particle size distribution along the flume.

The experiment was divided into A, B, C and D series. Series A experiments were conducted using the stiffest vegetal media (polypropylene sticks) with a density of 13,168 blades/m^2 (1224 blades/ft^2). Series B experiments were performed using the stiffest media with 24,009 blades/m^2 (2232 blades/ft^2). Series C and D experiments were completed using two other different stiffnesses with the same density as that used in series A.

For tests in each series, the flow depth measurements were taken first using an electronic point guage, as well as channel slope and flowrate measurements. In the series C and D experiments non-submerged flow condition was used first, followed by submerged flow with repeated non-submerged conditions afterward. The reason for the repetition was to observe the effect of possible bending of the artificial vegetation on trapping of sediments.

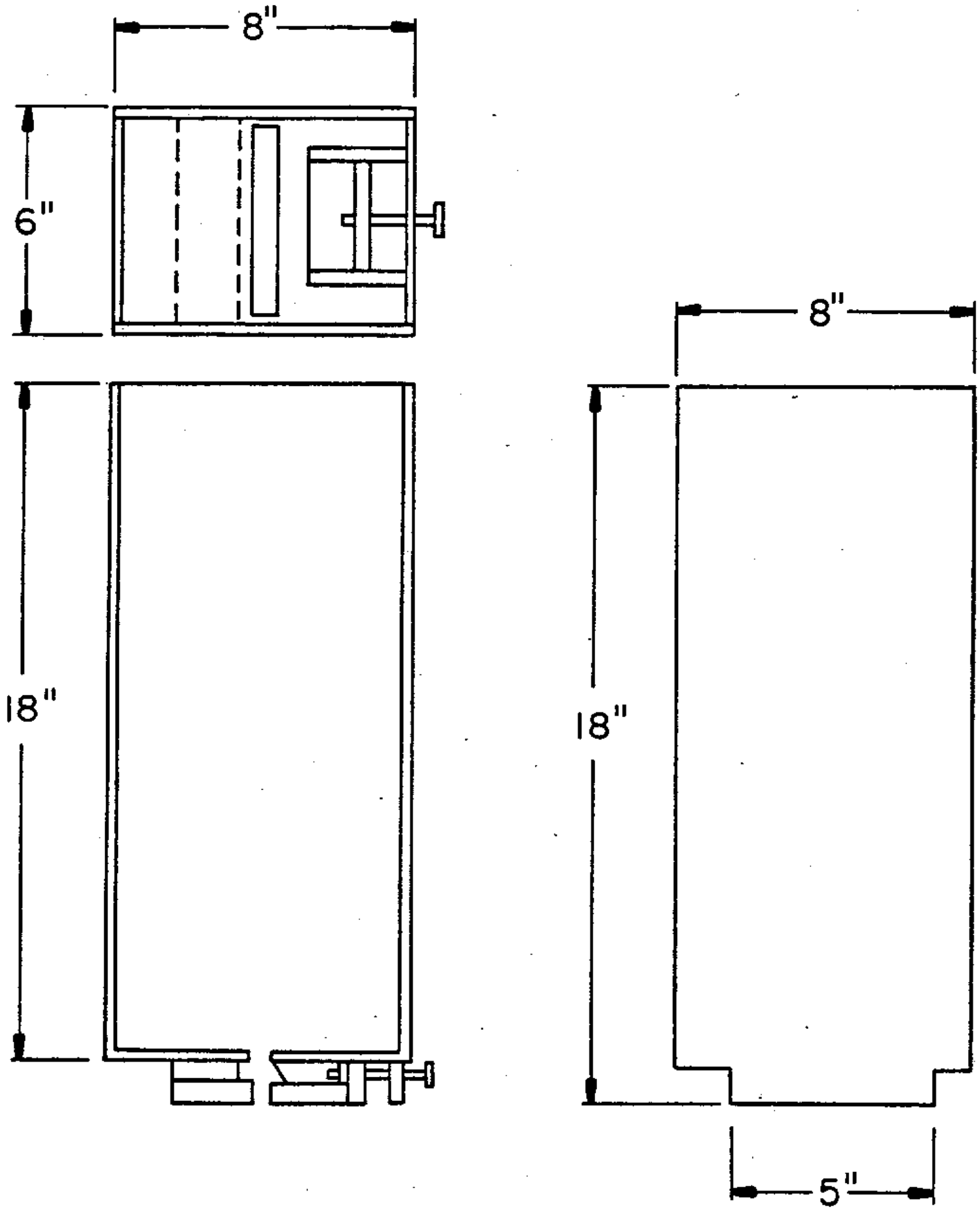

Fig 4. Dry sediment feeding box

In the filtration experiments, a constant flowrate was normally established first, and then sediment in the feeder box was allowed to flow out at a constant rate. With the time count to start at the beginning of the sediment feeding time, every ten minutes a water sample was taken at the end of the flume, and in the meantime, the bedload profile was marked. This procedure was repeated until the end of each test run which usually last approximately 40 minutes. After each run a sediment sample from the bottom of the flume was taken at 0.3 m (1 foot), 1.5 m (5 feet), and 2.7 m (9 feet) into the artificial grass section and at the end of the section. The water samples taken at the end of the flume were analyzed for sediment concentration. The weight of sediment per volume of fluid was found and the percent of sediment removed was then calculated using:

$$\text{\% Sediment Removed} = \frac{\text{Initial conc. - Final conc.}}{\text{Initial conc.}} \times 100$$

The sediment samples were analyzed for size distribution along the flume by means of photographic analysis with the pictures being taken under a microscope mounted with a camera. A small part of the sediment sample was placed on a slide and several random pictures of the samples were taken through a 50 and a 100 power magnification for determining the sediment size distribution. Figure 5 gives examples of pictures taken of sediment samples from 0.3 m (1 foot), 1.5 m (5 feet), and 2.7 (9 feet). The sediment range was divided into seven types and each picture was analyzed for size distribution based on numbers of each type present. The volumetric and weight percentages of the average sample analysis results were then computed accordingly.

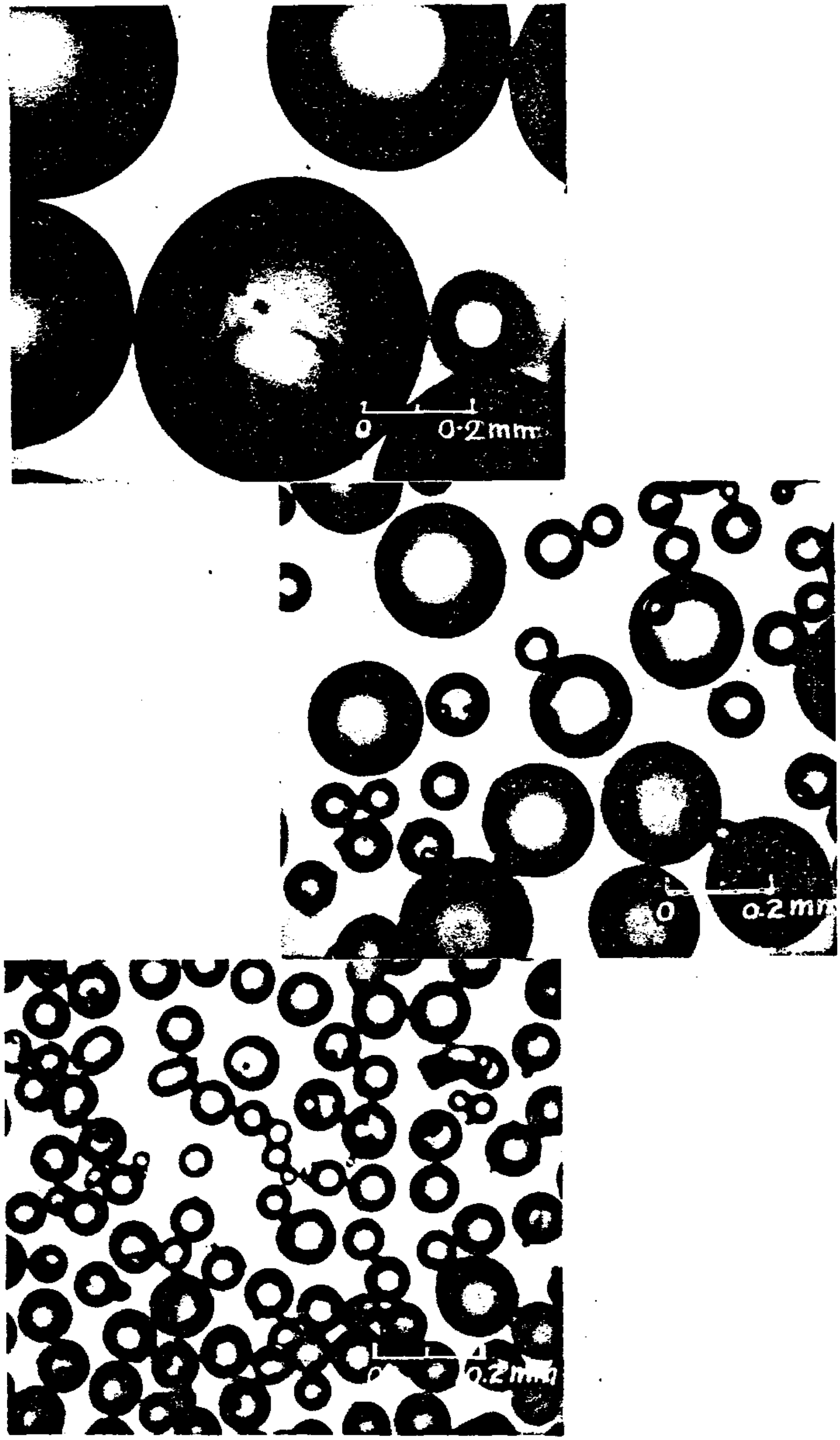

Fig. 5 Microscope photograph of sediment samples taken at 0.3 m (above), 1.5 m (middle), and 2.7 m (below) respectively

CHAPTER III

DATA AND RESULTS

The first few tests of the experimental analysis were run using two different uniform size glass beads, so as to examine solely the effect of particle size on filtration. In order to more closely simulate field conditions, the majority of the tests (Tests No. 8 through No. 44) were run with a mixed size distribution. The three types of glass beads were identified as d_{70}, d_{130} and d_{mix} and the sieve analysis of each is given in Table I.

Filtration Efficiency

The efficiency of the sediment removal was determined, as described in the previous section, for the channel section with the given length vegetative filter. An outflow sample from the channel was taken at every ten minute interval. The sediment concentrations of the samples were determined by weighing the mixture of the sample first and later the dried solids. Knowing the inflow concentration from the flow discharge and the solid feeding rate, the efficiency of filtration can thus be computed.

Table II lists the percent of sediment removal by the vegetative filter evaluated from samples taken for various flowrates, channel slopes and vegetation types. Three different simulated vegetation stiffnesses identified as stiff, medium stiff and least stiff were used in the analysis. The stiff type was made with two different blade desnities. The natural grasses which these artificial vegetations approximately simulate are identified by their corresponding flow resistance characteristics as reported by Kao and Barfield (11) earlier.

The filtration efficiency results are also presented graphically as shown in Figs. 6 through 10. The plots provide a clear indication of the general trend in which the trapping efficiencies, in almost all cases, tend to decline as time increases. This can be attributed to the effect of bedload movement, which causes some settled particles to be carried out of the channel test section. A detailed discussion of such bed load movement in both continuous and discrete filters will be discussed in volume II of this project on completion report.

TABLE I. SIEVE ANALYSIS OF SEDIMENT MATERIAL USED

Code Size	Average Diameter (mm)	U.S. Sieve No. (Percent Retained) 20	30	40	50	60	80	170	200	Pan
d_{70}	0.46	-	-	70	-	30	-	-	-	-
d_{130}	0.10	-	-	-	-	-	-	60	35	5
d_{mix}	-	-	5	-	30	-	40	-	20	5

TABLE III SIZE RANGE OF SEDIMENT SAMPLES

Size Type	Diameter
0	$\le$ .60 mm (.024 in.)
1	$\le$ .50 mm (.020 in.)
2	$\le$ .31 mm (.012 in.)
3	$\le$ .21 mm (.008 in.)
4	$\le$ .15 mm (.006 in.)
5	$\le$ .10 mm (.004 in.)
6	$\le$ .05 mm (.002 in.)

TABLE II. SEDIMENT FILTRATION EFFICIENCY FOR VARIOUS FLOW CONDITIONS

Test No.	Sediment Class	Discharge per foot (ℓ/s)	Discharge per foot (cfs)	Channel slope (%)	Water Depth (cm)	Water Depth (ft)	Flow Velocity (m/s)	Flow Velocity (fps)	Density # Blades per ft^2	Flexibility	Efficiency of Sediment Removal (%) Time (min) 10	20	30	40
-1	70	3.03	0.107	3.0	12.80	.420	.1435	.4709	1224	Stiff	100	100	100	100
-2	70	1.84	0.065	3.0	11.31	.371	.1075	.3528	1224	Stiff	100	100	100	100
-3	70	3.71	0.131	3.0	13.44	.441	.1613	.5292	1224	Stiff	100	100	100	100
-4	70	1.84	0.065	4.0	10.36	.340	.1157	.3795	1224	Stiff	100	100	100	100
-5	70	3.71	0.131	4.0	13.23	.434	.1714	.5623	1224	Stiff	100	100	100	100
-6	70	3.71	0.131	4.0	13.23	.434	.1714	.5623	1224	Stiff	100	100	100	100
-7	70	3.03	0.107	4.0	12.44	.408	.1524	.5000	1224	Stiff	100	100	100	100
-8	70	0.70	0.027	4.0	4.88	.16	.0914	.30	1224	Stiff	100	100	100	100
-9	70	3.03	0.107	2.0	12.95	.425	.1358	.4455	1224	Stiff	100	100	100	100
-10	70	3.71	0.131	2.0	13.72	.450	.1512	.4961	1224	Stiff	100	100	100	100
-11	70	1.84	0.065	2.0	11.49	.377	.1077	.3535	1224	Stiff	100	100	100	100
1	130	1.84	0.065	2.0	11.49	.377	.1077	.3535	1224	Stiff	100	100	98.1	93.9
2	130	3.03	0.107	2.0	12.95	.425	.1358	.4455	1224	Stiff	93.9	92.2	94.2	79.5
3	130	3.71	0.131	2.0	13.72	.450	.1512	.4961	1224	Stiff	92.1	89.6	86.2	92.5
4	130	1.84	0.065	3.0	11.31	.371	.1075	.3528	1224	Stiff	94.4	90.0	91.4	91.0
5	130	3.03	0.107	3.0	12.80	.420	.1435	.4709	1224	Stiff	73.6	65.7	70.3	68.0
6	130	1.84	0.065	4.0	10.36	.340	.1157	.3795	1224	Stiff	81.1	75.3	69.7	66.5
7	130	3.03	0.107	4.0	12.44	.408	.1524	.5000	1224	Stiff	72.4	71.8	72.7	58.1
8	Mix	1.84	0.065	4.0	10.36	.340	.1157	.3795	1224	Stiff	94.0	93.8	91.5	92.8
9	Mix	3.03	0.107	4.0	12.44	.408	.1524	.5000	1224	Stiff	94.9	90.5	86.1	85.7
10	Mix	3.71	0.131	4.0	13.23	.434	.1714	.5623	1224	Stiff	83.5	79.8	81.5	83.9
11	Mix	1.84	0.065	3.0	11.31	.371	.1075	.3528	1224	Stiff	95.2	93.7	91.2	88.6
12	Mix	3.71	0.131	3.0	13.44	.441	.1613	.5292	1224	Stiff	82.1	83.3	82.1	76.3
13	Mix	3.03	0.107	3.0	12.80	.420	.1435	.4709	1224	Stiff	96.4	93.6	94.1	90.8
14	Mix	1.84	0.065	2.0	11.49	.377	.1077	.3535	1224	Stiff	94.2	99.3	93.4	89.0
15	Mix	3.03	0.107	2.0	12.95	.425	.1358	.4450	1224	Stiff	95.8	87.2	89.0	-
16	Mix	3.71	0.131	2.0	13.72	.450	.1512	.4961	1224	Stiff	89.3	88.3	89.0	84.8

TABLE II. (continued)

Test No.	Sediment Class	Discharge per foot (ℓ/s)	Discharge per foot (cfs)	Channel slope (%)	Water Depth (cm)	Water Depth (ft)	Flow Velocity (m/s)	Flow Velocity (fps)	Density # Blades per ft^2	Flexibility	Efficiency of Sediment Removal (%) Time (min) 10	20	30	40
17	Mix	2.10	.074	4.0	12.10	.397	.1470	.4823	2232	Stiff	94.4	97.4	95.1	93.4
18	Mix	2.69	.095	4.0	13.01	.427	.1717	.5632	2232	Stiff	90.1	93.2	91.2	90.6
19	Mix	3.51	.124	4.0	13.93	.457	.2064	.6773	2232	Stiff	91.6	90.4	88.2	85.8
20	Mix	3.51	.124	3.0	14.20	.466	.1968	.6456	2232	Stiff	92.2	93.2	91.3	89.5
21	Mix	2.69	.095	3.0	13.01	.427	.1635	.5365	2232	Stiff	93.5	91.4	92.5	90.6
22	Mix	2.10	.074	3.0	11.80	.387	.1401	.4598	2232	Stiff	97.2	94.3	94.0	94.8
23	Mix	2.10	.074	2.0	11.98	.393	.1229	.4033	2232	Stiff	96.0	94.4	95.9	95.1
24	Mix	2.69	.095	2.0	13.01	.427	.1448	.4750	2232	Stiff	95.7	96.6	93.5	93.8
25	Mix	3.54	.125	2.0	14.48	.475	.1760	.5776	2232	Stiff	94.0	92.3	92.5	91.5
26	Mix	2.21	.078	4.0	8.50	.279	.1352	.4436	1224	Med.	92.6	91.4	91.3	84.9
27	Mix	2.21	.078	3.0	8.84	.290	.1274	.4179	1224	Med.	94.6	92.3	89.9	88.4
28	Mix	2.21	.078	2.0	10.06	.330	.1048	.3440	1224	Med.	92.6	91.5	87.2	87.1
29	Mix	2.83	.100	4.0	8.81	.289	.1637	.5370	1224	Med.	91.2	91.5	87.1	92.0
30	Mix	2.83	.100	3.0	9.33	.306	.1500	.4923	1224	Med.	94.2	90.6	86.3	89.5
31	Mix	2.83	.100	2.0	10.52	.345	.1261	.4137	1224	Med.	90.9	90.1	89.5	90.3
33	Mix	3.60	.127	4.0	9.24	.303	.1934	.6347	1224	Med.	88.6	90.3	87.6	84.3
34	Mix	3.60	.127	3.0	9.78	.321	.1772	.5814	1224	Med.	91.6	86.2	86.5	80.2
35	Mix	3.60	.127	2.0	10.67	.350	.1570	.5152	1224	Med.	90.5	91.6	89.7	85.8
36	Mix	1.98	.070	4.0	7.16	.235	.1273	.4177	1224	Least	92.0	88.6	85.9	69.7
37	Mix	1.98	.070	3.0	7.83	.257	.1186	.3892	1224	Least	92.4	89.7	89.1	83.7
38	Mix	1.98	.070	2.0	9.02	.296	.0934	.3066	1224	Least	92.6	90.4	91.7	76.0
39	Mix	2.55	.090	4.0	7.41	.243	.1565	.5135	1224	Least	87.0	85.6	65.1	
40	Mix	2.55	.090	3.0	8.35	.274	.1345	.4414	1224	Least	92.8	91.0	81.2	42.7
41	Mix	2.55	.090	2.0	9.78	.321	.0898	.2945	1224	Least	90.3	90.3	88.2	73.1
42	Mix	3.13	.1105	4.0	7.62	.250	.1844	.6051	1224	Least	93.1	91.9	89.7	82.7
43	Mix	3.13	.1105	3.0	8.11	.266	.1694	.5558	1224	Least	90.6	91.5	88.2	87.7
44	Mix	3.13	.1105	2.0	8.84	.290	.1510	.4953	1224	Least	92.0	91.0	85.2	86.5

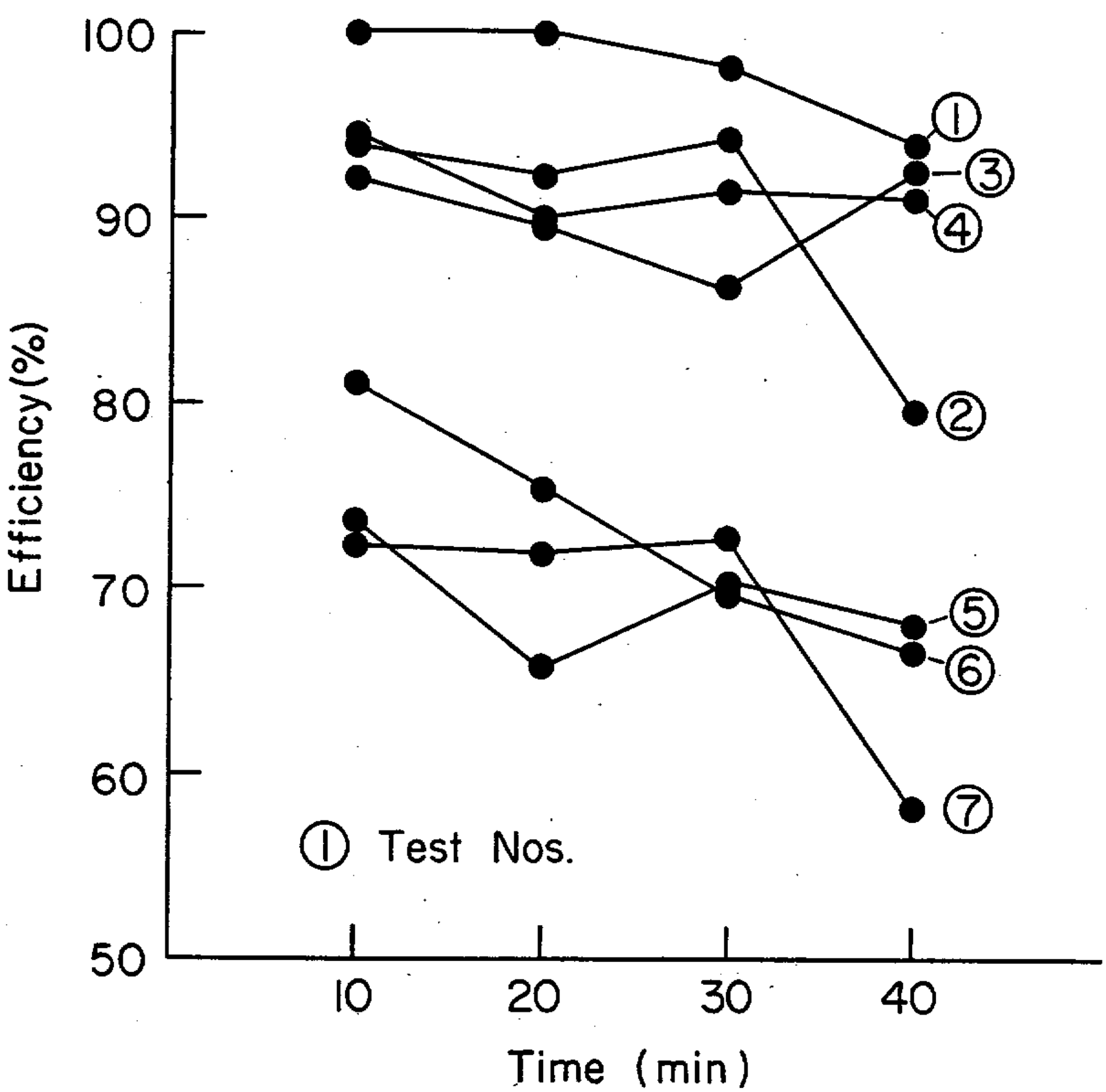

Fig. 6 Sediment filtration efficiency for stiff, dense vegetation with uniform particle size

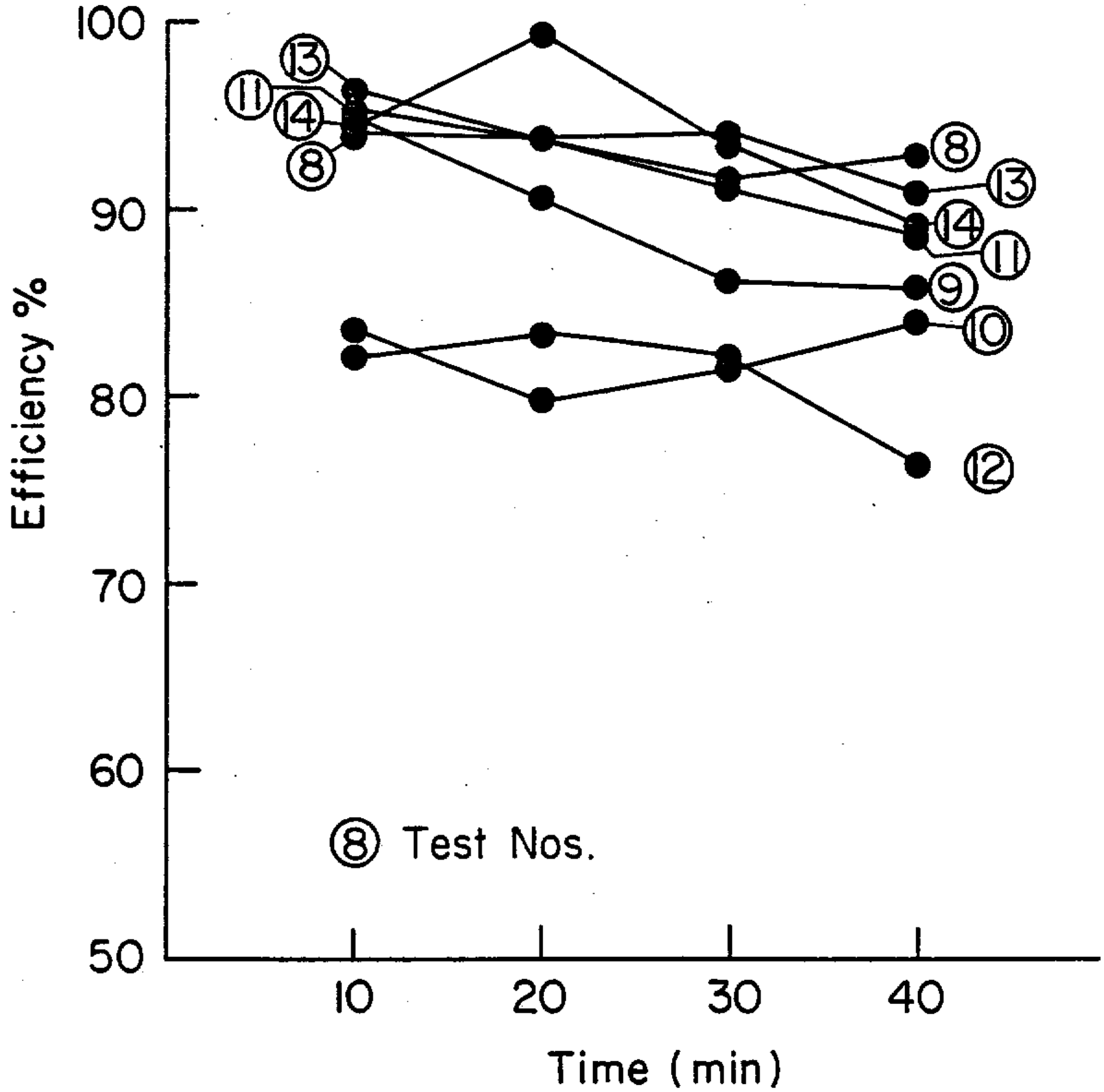

Fig. 7 Sediment filtration efficiency for stiff, less dense vegetation with mixed particles

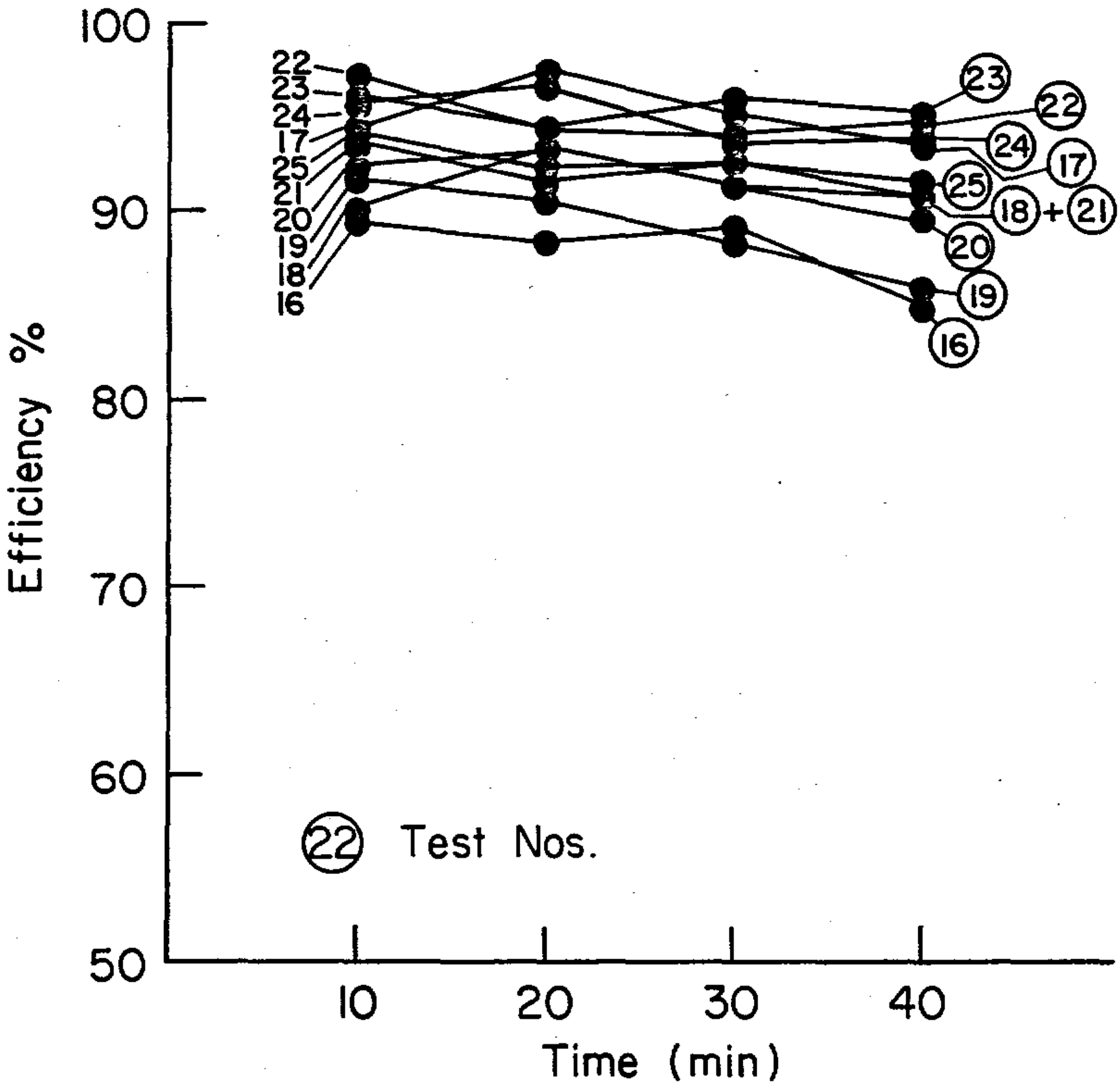

Fig. 8 Sediment filtration efficiency for stiff, dense vegetation with mixed particle size

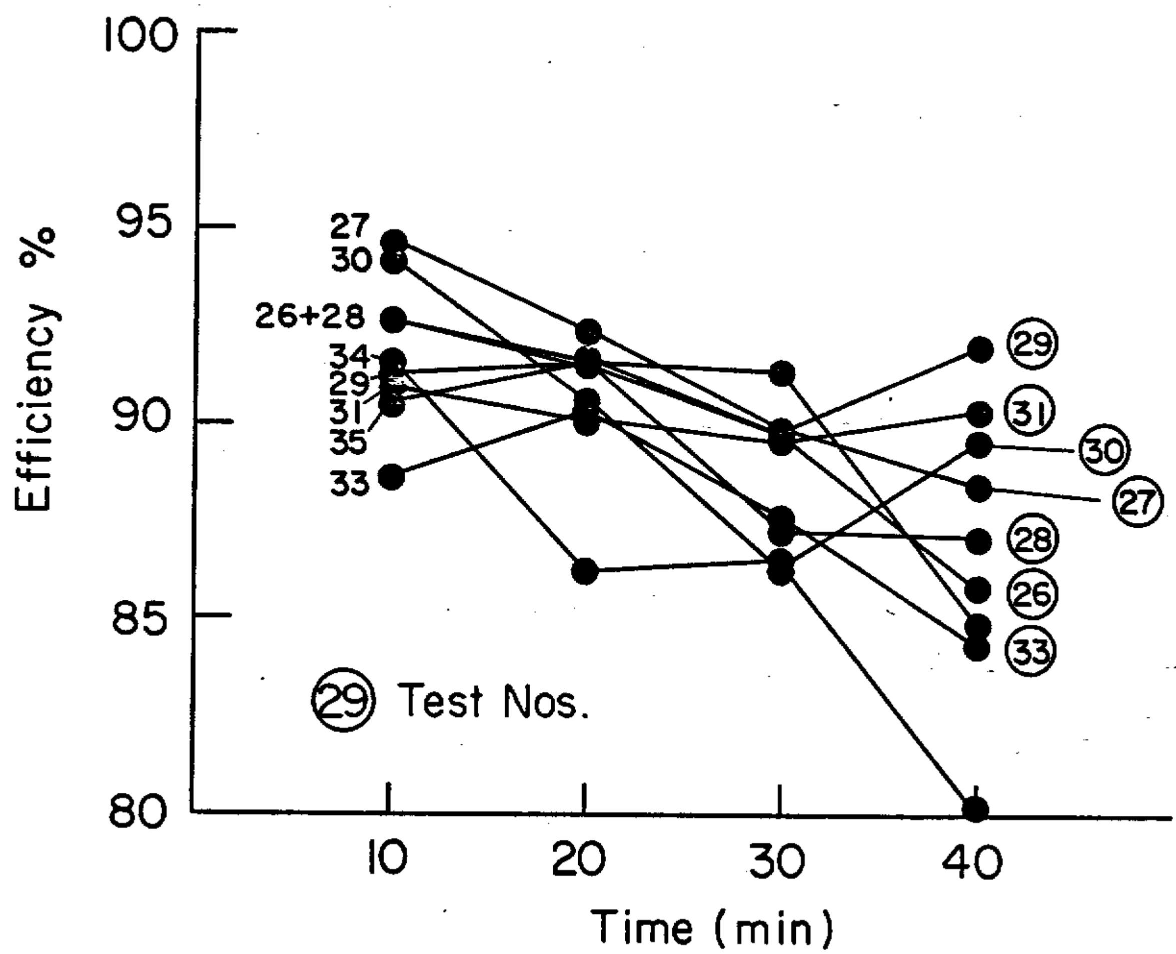

Fig. 9 Sediment filtration efficiency for less stiff vegetation with mixed particle size

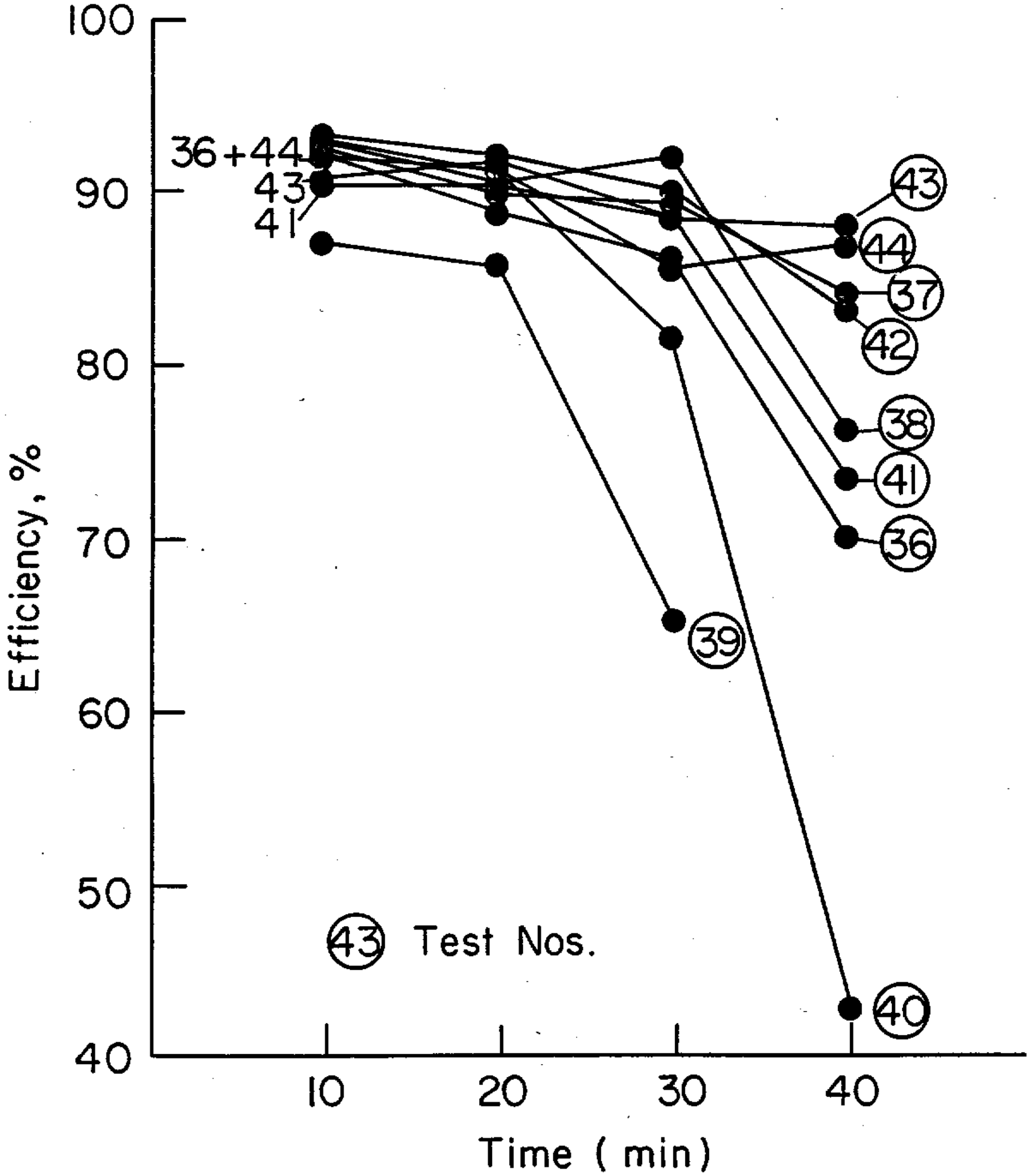

Fig. 10 Sediment filtration efficiency for least stiff vegetation with mixed particle size

The trapping efficiencies of the filter are also showed to decrease with increasing flow rate and channel slope. This is directly attributed to the increase in water depth and flow velocity. Both factors will cause the sediment to travel farther in the channel before it can be settled out. A probabilistic model intended for describing this phenomenon will be presented in Volume III of this project completion report along with the suspended solid motion in a channel with discrete filters.

It is also noted that the stiffness of the simulated vegetation has little effect on the suspended sediment trapping efficiency. The effect of stiffness manifests itself in the resulting bending due to flowing water. This in turn reduces the effective resistance of the vegetation to slow down the flow velocity and the capacity of storing the trapped sediment in the form of bedload.

Sediment Size Distribution

As described in a previous section on experimental procedures, sediment samples were taken at locations along the channel covered with simulated grass at 0.3 m, 1.5 m, 2.7 m and the end of the section. These samples were dried and analyzed for size distribution using a microscope photograph technique. Pictures were taken of several random groups of each dry sample spread on a slide glass under 50 or 100 power magnification.

The sediment particle sizes recorded on the photograph were classified into seven different size ranges as shown in Table III. Based on this particle size breakdown, numbers of different size particles were accounted for and the results were reduced for percent particle size composition by volume in each sample. The results of this analysis are presented in Table IV.

Observation of the results indicated that:

1. Large particles settle out first;
2. Increasing flowrate causes increased percent of large particles to move downstream;
3. More large particles move downstream as the channle slope increases; and

TABLE IV PERCENTAGE OF SEDIMENT TYPE PRESENT ALONG FLUME

Test	Sample Location (Ft. in Grass)	Discharge (cfs)	Slope (%)	Flex.	Density No. of blade/ft^2	Particle Size Breakdown (% by Volume) 0	1	2	3	4	5	6
8	1	.065	4.0	Stiff	1224	21.3	66.4	5.6	6.7			
8	5	.065	4.0	Stiff	1224			19.3	12.0	36.5	30.6	1.6
8	9	.065	4.0	Stiff	1224					38.4	54.7	6.9
8	End	.065	4.0	Stiff	1224					32.2	54.5	13.3
9	1	.107	4.0	Stiff	1224	38.1	39.6	15.2	7.1			
9	5	.107	4.0	Stiff	1224			37.2	23.1	22.5	13.9	3.3
9	9	.107	4.0	Stiff	1224							
9	End	.107	4.0	Stiff	1224					45.3	51.0	3.7
10	1	.131	4.0	Stiff	1224	29.9	48.3	13.2	8.6			
10	5	.131	4.0	Stiff	1224		22.0	42.0	23.5	9.5	2.7	.3
10	9	.131	4.0	Stiff	1224			7.2	0	35.9	50.7	6.2
10	End	.131	4.0	Stiff	1224					32.1	59.4	8.5
11	1	.065	3.0	Stiff	1224		68.3	14.5	16.3	.7	.2	
11	5	.065	3.0	Stiff	1224			39.1	22.2	30.4	7.7	.6
11	9	.065	3.0	Stiff	1224					39.1	50.6	10.3
11	End	.065	3.0	Stiff	1224					27.5	66.9	5.6
12	1	.131	3.0	Stiff	1224		71.3	7.8	20.0	.9		
12	5	.131	3.0	Stiff	1224			26.9	19.7	21.7	29.1	2.6
12	9	.131	3.0	Stiff	1224					41.4	51.2	7.4
12	End	.131	3.0	Stiff	1224					45.4	48.2	6.4
13	1	.107	3.0	Stiff	1224							
13	5	.107	3.0	Stiff	1224			19.7	6.1	44.6	25.2	4.4
13	9	.107	3.0	Stiff	1224					16.9	67.5	15.6
13	End	.107	3.0	Stiff	1224					32.5	59.7	7.8
14	1	.065	2.0	Stiff	1224	27.4	19.0	29.0	20.3	3.9	.4	
14	5	.065	2.0	Stiff	1224				3.8	27.7	50.4	18.1
14	9	.065	2.0	Stiff	1224					23.5	57.9	18.6
14	End	.065	2.0	Stiff	1224					18.0	74.8	7.2

TABLE IV (continued)

Test	Sample Location (Ft. in Grass)	Discharge (cfs)	Slope (%)	Flex.	Density No. of blade/ft^2	Particle Size Breakdown (% by Volume) 0	1	2	3	4	5	6
15	1	.107	2.0	Stiff	1224	21.2	22.0	39.2	15.7	1.9		
15	5	.107	2.0	Stiff	1224			14.4	21.9	31.1	28.5	4.1
15	9	.107	2.0	Stiff	1224					41.8	51.3	6.9
15	End	.107	2.0	Stiff	1224					10.5	80.3	9.2
16	1	.131	2.0	Stiff	1224	18.5	38.4	14.7	13.7	8.9	5.2	.6
16	5	.131	2.0	Stiff	1224			21.4	20.0	27.5	28.1	3.0
16	9	.131	2.0	Stiff	1224			4.0	7.5	32.8	52.7	3.0
16	End	.131	2.0	Stiff	1224					45.6	44.6	9.8
17	1	.074	4.0	Stiff	2232	17.3	36.0	27.5	17.1	2.1		
17	5	.074	4.0	Stiff	2232			6.1	5.7	40.3	43.8	4.1
17	9	.074	4.0	Stiff	2232					22.3	73.5	4.2
17	End	.074	4.0	Stiff	2232					8.1	88.8	3.1
18	1	.095	4.0	Stiff	2232	19.6	67.9	5.2	7.3			
18	5	.095	4.0	Stiff	2232			20.2	12.6	9.2	55.3	2.7
18	9	.095	4.0	Stiff	2232					34.9	59.8	5.3
18	End	.095	4.0	Stiff	2232					15.7	81.1	3.2
19	1	.124	4.0	Stiff	2232	46.7	43.1	8.2	2.0			
19	5	.124	4.0	Stiff	2232			18.4	4.3	41.6	34.3	1.4
19	9	.124	4.0	Stiff	2232				4.4	30.2	61.9	3.5
19	End	.124	4.0	Stiff	2232					29.4	63.7	6.9
20	1	.124	3.0	Stiff	2232	21.4	59.3	11.3	8.0			
20	5	.124	3.0	Stiff	2232			17.1	19.9	27.1	31.9	4.0
20	9	.124	3.0	Stiff	2232					30.0	65.5	4.5
20	End	.124	3.0	Stiff	2232					27.2	68.0	4.8
21	1	.095	3.0	Stiff	2232		70.1	6.7	9.4	9.1	4.3	.4
21	5	.095	3.0	Stiff	2232				8.4	58.7	27.6	5.3
21	9	.095	3.0	Stiff	2232					33.1	63.2	3.7
21	End	.095	3.0	Stiff	2232					34.4	60.8	4.8

TABLE IV (continued)

Test	Sample Location (Ft. in Grass)	Discharge (cfs)	Slope (%)	Flex.	Density No. of blade/ft^2	Particle Size Breakdown (% by Volume) 0	1	2	3	4	5	6
22	1	.074	3.0	Stiff	2232	25.0	52.0	19.9	3.1			
22	5	.074	3.0	Stiff	2232					42.3	50.7	7.0
22	9	.074	3.0	Stiff	2232					43.1	49.8	7.1
22	End	.074	3.0	Stiff	2232					27.0	64.5	8.5
23	1	.074	2.0	Stiff	2232	21.2	73.5		5.3			
23	5	.074	2.0	Stiff	2232				4.4	23.8	64.1	7.7
23	9	.074	2.0	Stiff	2232					42.9	48.5	8.6
23	End	.074	2.0	Stiff	2232					17.7	76.9	5.4
24	1	.095	2.0	Stiff	2232	39.9	55.2		4.9			
24	5	.095	2.0	Stiff	2232							
24	9	.095	2.0	Stiff	2232							
24	End	.095	2.0	Stiff	2232					34.5	60.4	5.1
25	1	.125	2.0	Stiff	2232							
25	5	.125	2.0	Stiff	2232				18.8	32.0	41.9	7.3
25	9	.125	2.0	Stiff	2232					38.0	51.6	10.4
25	End	.125	2.0	Stiff	2232					21.9	61.1	7.0
26	1	.078	4.0	Med.	1224		33.4	31.9	23.8	3.9	7.5	.5
26	5	.078	4.0	Med.	1224		33.8	19.4	27.2	7.3	9.7	2.6
26	9	.078	4.0	Med.	1224			37.9	8.8	17.2	31.3	4.8
26	End	.078	4.0	Med.	1224					30.0	59.6	10.4
27	1	.078	3.0	Med.	1224	23.0	15.9	30.4	11.4	8.3	9.1	1.9
27	5	.078	3.0	Med.	1224				37.7	20.1	37.0	5.2
27	9	.078	3.0	Med.	1224				5.5	35.9	50.3	8.3
27	End	.078	3.0	Med.	1224					23.1	67.6	9.3
28	1	.078	2.0	Med.	1224		40.4	30.9	21.6	7.1		
28	5	.078	2.0	Med.	1224			8.7	12.1	35.3	35.1	8.8
28	9	.078	2.0	Med.	1224					36.5	50.4	13.1
28	End	.078	2.0	Med.	1224					37.5	59.6	2.9

TABLE IV (continued)

Test	Sample Location (Ft. in Grass)	Discharge (cfs)	Slope (%)	Flex.	Density No. of blade/ft^2	Particle Size Breakdown (% by Volume) 0	1	2	3	4	5	6
29	1	.100	4.0	Med.	1224	34.5	47.8	9.1	8.6			
29	5	.100	4.0	Med.	1224			22.4	27.9	20.3	26.3	3.1
29	9	.100	4.0	Med.	1224			15.4	36.0	19.2	26.3	3.1
29	End	.100	4.0	Med.	1224					38.5	57.0	4.5
30	1	.100	3.0	Med.	1224	50.2	34.8	8.9	6.1			
30	5	.100	3.0	Med.	1224			21.4	23.3	35.5	17.5	2.3
30	9	.100	3.0	Med.	1224				7.8	35.9	50.7	5.6
30	End	.100	3.0	Med.	1224					16.3	77.9	5.8
31	1	.100	2.0	Med.	1224	18.2	63.1	9.7	9.0			
31	5	.100	2.0	Med.	1224			17.0	31.7	28.9	20.8	1.6
31	9	.100	2.0	Med.	1224				5.0	24.4	62.0	8.6
31	End	.100	2.0	Med.	1224					21.5	74.7	3.8
33	1	.127	4.0	Med.	1224		62.6	18.0	14.0	5.4		
33	5	.127	4.0	Med.	1224		20.3	31.1	10.9	14.1	18.2	5.4
33	9	.127	4.0	Med.	1224			16.2	3.8	23.9	50.1	6.0
33	End	.127	4.0	Med.	1224					29.7	58.7	11.6
34	1	.127	3.0	Med.	1224		43.3	38.7	18.0			
34	5	.127	3.0	Med.	1224			20.0	52.8	15.1	10.7	1.4
34	9	.127	3.0	Med.	1224				24.6	31.9	39.3	4.2
34	End	.127	3.0	Med.	1224					19.0	72.7	8.3
35	1	.127	2.0	Med.	1224		58.2	29.7	10.4	1.7		
35	5	.127	2.0	Med.	1224				18.7	21.8	55.5	4.0
35	9	.127	2.0	Med.	1224				12.5	28.4	53.5	5.6
35	End	.127	2.0	Med.	1224					22.3	74.2	3.5
36	1	.070	4.0	Least	1224	21.2	29.3	28.0	13.1	3.8	4.2	.4
36	5	.070	4.0	Least	1224			53.3	10.0	9.7	22.8	4.2
36	9	.070	4.0	Least	1224				17.3	27.3	47.5	7.9
36	End	.070	4.0	Least	1224					33.8	56.4	9.8

TABLE IV (continued)

Test	Sample Location (Ft. in Grass)	Discharge (cfs)	Slope (%)	Flex.	Density No. of blade/ft^2	Particle Size Breakdown (% by Volume) 0	1	2	3	4	5	6
37	1	.070	3.0	Least	1224		51.2	26.1	18.3	4.4		
37	5	.070	3.0	Least	1224					34.7	56.6	8.7
37	9	.070	3.0	Least	1224					33.1	58.8	8.1
37	End	.070	3.0	Least	1224					35.7	55.6	8.7
38	1	.070	2.0	Least	1224		36.9	21.3	19.8	12.8	8.3	.9
38	5	.070	2.0	Least	1224		18.3	28.6	16.7	16.2	18.3	1.9
38	9	.070	2.0	Least	1224					26.0	65.0	9.0
38	End	.070	2.0	Least	1224					44.2	45.6	10.2
39	1	.090	4.0	Least	1224		44.4	34.0	15.9	3.9	1.8	
39	5	.090	4.0	Least	1224			23.4	21.9	19.5	30.8	4.4
39	9	.090	4.0	Least	1224			29.7	27.7	21.9	17.4	3.3
39	End	.090	4.0	Least	1224					20.1	64.8	15.1
40	1	.090	3.0	Least	1224		33.9	38.9	24.2	3.0		
40	5	.090	3.0	Least	1224			7.4	6.9	48.4	30.6	6.7
40	9	.090	3.0	Least	1224					37.6	49.1	13.3
40	End	.090	3.0	Least	1224							
41	1	.090	2.0	Least	1224		62.0	29.7	8.3			
41	5	.090	2.0	Least	1224				11.3	44.0	38.0	6.7
41	9	.090	2.0	Least	1224					20.1	73.9	6.0
41	End	.090	2.0	Least	1224					41.5	52.0	6.5
42	1	.1105	4.0	Least	1224	22.7	47.1	12.0	16.8	1.4		
42	5	.1105	4.0	Least	1224			34.0	31.7	13.5	18.1	2.7
42	9	.1105	4.0	Least	1224				15.6	30.3	44.0	10.1
42	End	.1105	4.0	Least	1224					42.7	49.8	7.5
43	1	.1105	3.0	Least	1224		74.8	17.2	8.0			
43	5	.1105	3.0	Least	1224			13.6	26.2	27.7	29.7	2.8
43	9	.1105	3.0	Least	1224				23.9	17.4	50.5	8.2
43	End	.1105	3.0	Least	1224					42.2	51.1	6.7

TABLE IV (continued)

Test	Sample Location (Ft. in Grass)	Discharge (cfs)	Slope (%)	Flex.	Density No. of blade/ft^2	Particle Size Breakdown (% by Volume) 0	1	2	3	4	5	6
44	1	.1105	2.0	Least	1224		62.6	24.0	13.4			
44	5	.1105	2.0	Least	1224				19.8	46.6	27.2	6.4
44	9	.1105	2.0	Least	1224							
44	End	.1105	2.0	Least	1224					28.7	65.4	5.9

4. increased stem density and stiffness of the simulated vegetation acts to decrease the distance a given particle size travels before settling out.

Bed Load Profile

As mentioned in the previous section the larger particles settle out first. These larger particles then form the bed load which moves along at a more or less constant rate over the smaller particles. Figures 11 through 16 show some typical profile plots of trapped sediment for the three classes of sand tested. As the bed load progresses down the flume the smaller particles keep settling out and become mixed with the bed load.

Table V gives the distance of bed load movement in ten minute time increments and the average maximum height the bed load moves for the parameters used. Examination of this table shows the following:

1. For each test the bed load progressed at a more or less constant rate.
2. Maximum height of bed load movement decreases as stiffness decreases.
3. Rate of bed load movement greatly increased as stiffness decreased. As mentioned previously, the stiffness of grass does not affect removal efficiency very much. However, due to the bent height of grasses the amount of sediment that can be trapped in a given length of grass greatly decreases with decreasing stiffness.
4. Rate of bed load movement is marginally affected by slope of bed, flowrate and density.

From profile plots, such as those in Figures 11 through 16, Table VI is constructed to show the leading edge slope of bed load in 10 minute time increments. This Table shows also the sediment bed slope at the end of each test after water has receded. From these results the following general conclusions are made:

1. The sediment bed slope increases with increasing particle size.

2. The sediment bed slope decreases as the channel slope increases.
3. The sediment bed slope slightly decreases with increasing flowrate.
4. An increase in density of vegetative cover and to a lesser extent increasing stiffness causes an increase in sediment bed slope.
5. There is a great decrease in sediment bed slope after water recedes. Figure 17 shows the sediment bed formed by the trapped solids in the stiff and flexible simulated grass filters after the flow has receded.

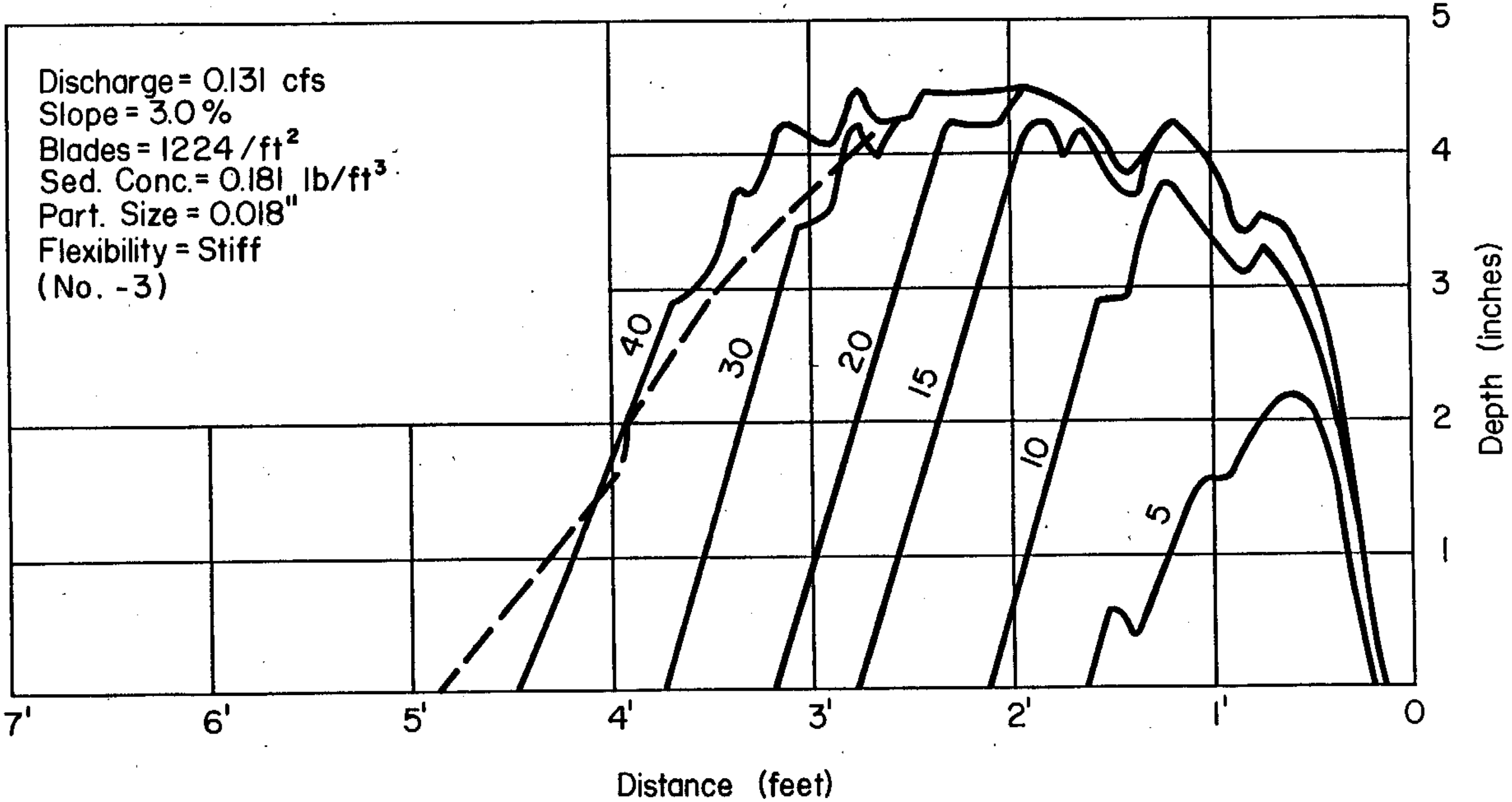

Fig. 11 Typical sediment bed profile and its forward progress patern

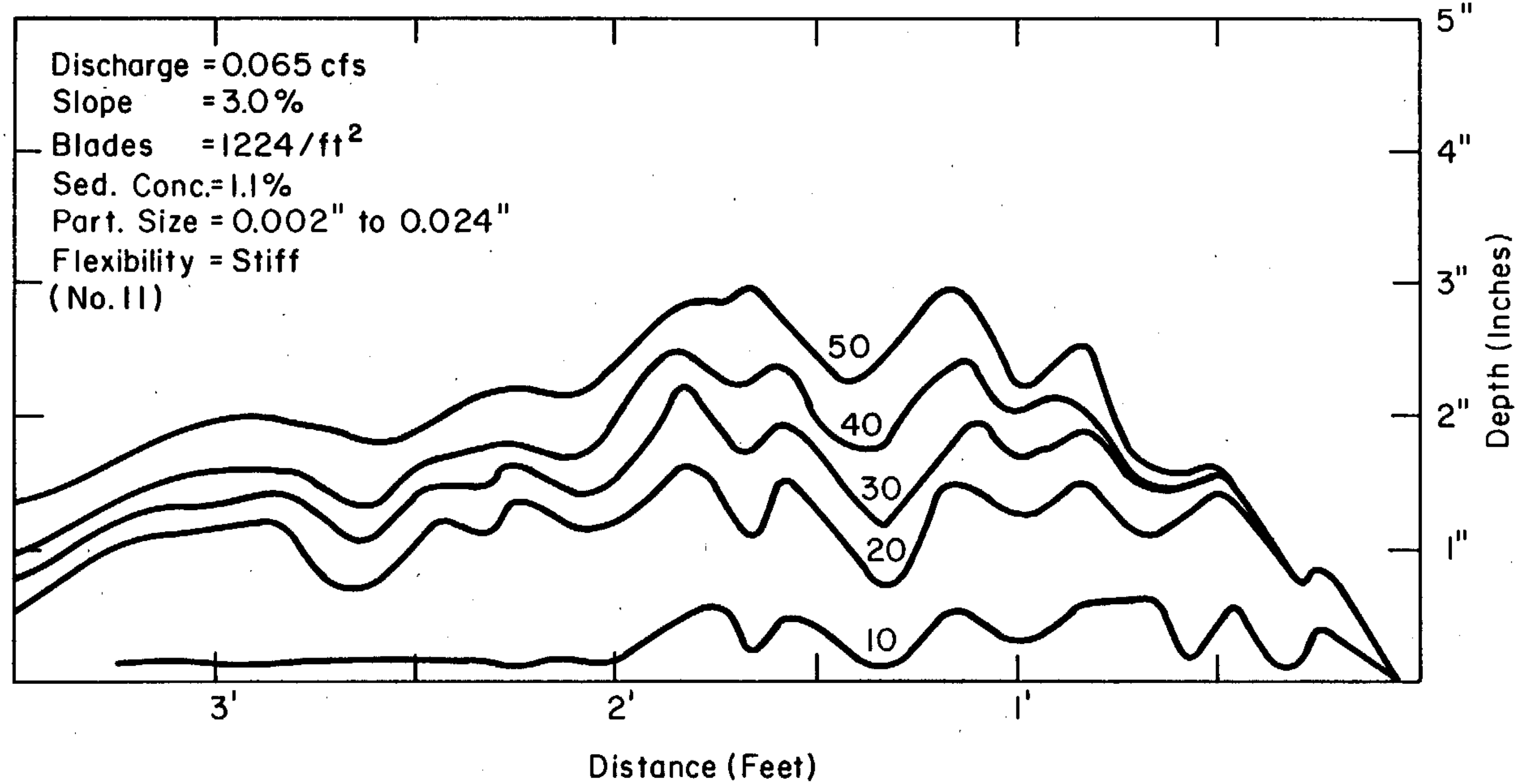

Fig. 12 Typical sediment bed profile and its forward progress patern

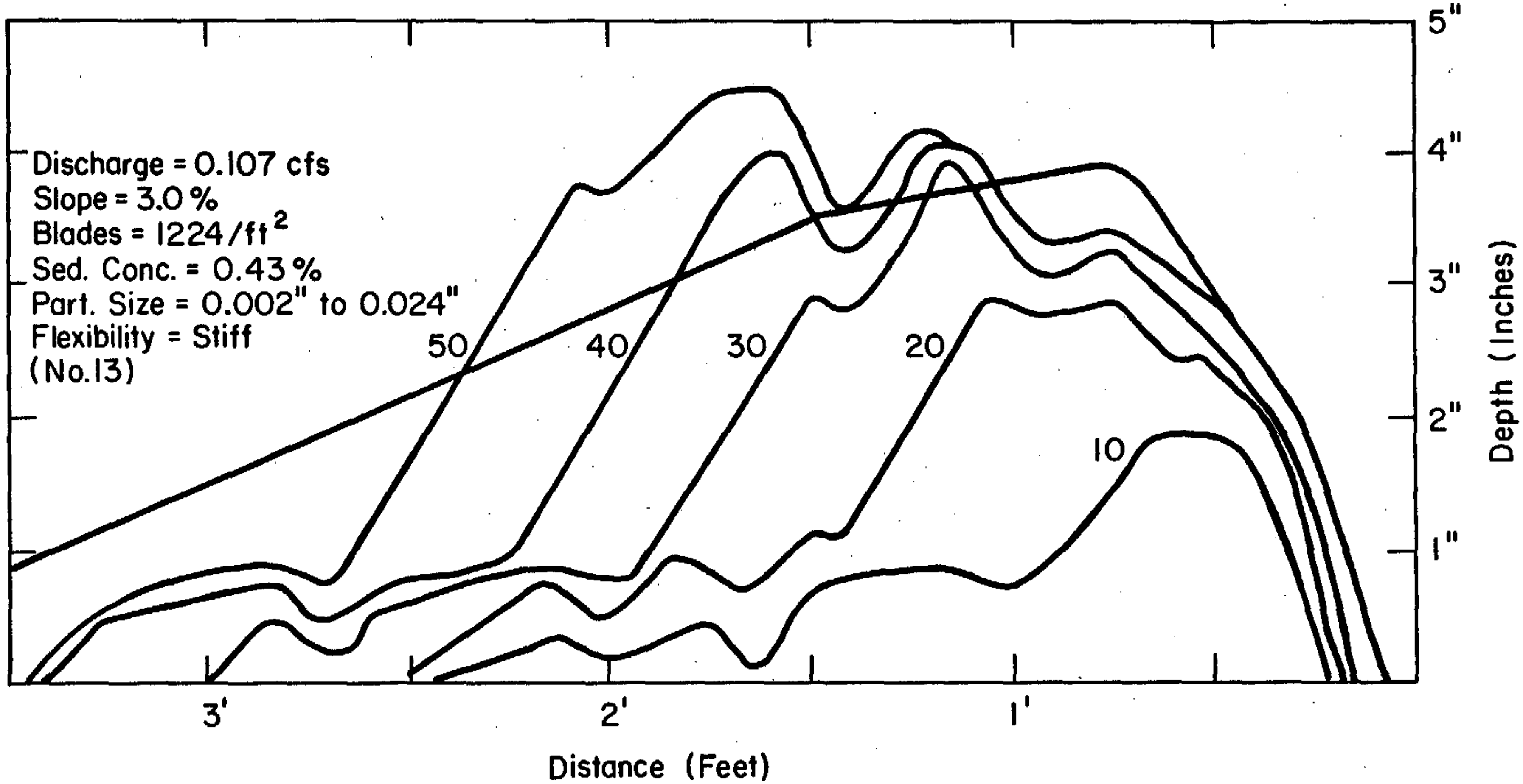

Fig. 13 Typical sediment bed profile and its forward progress patern

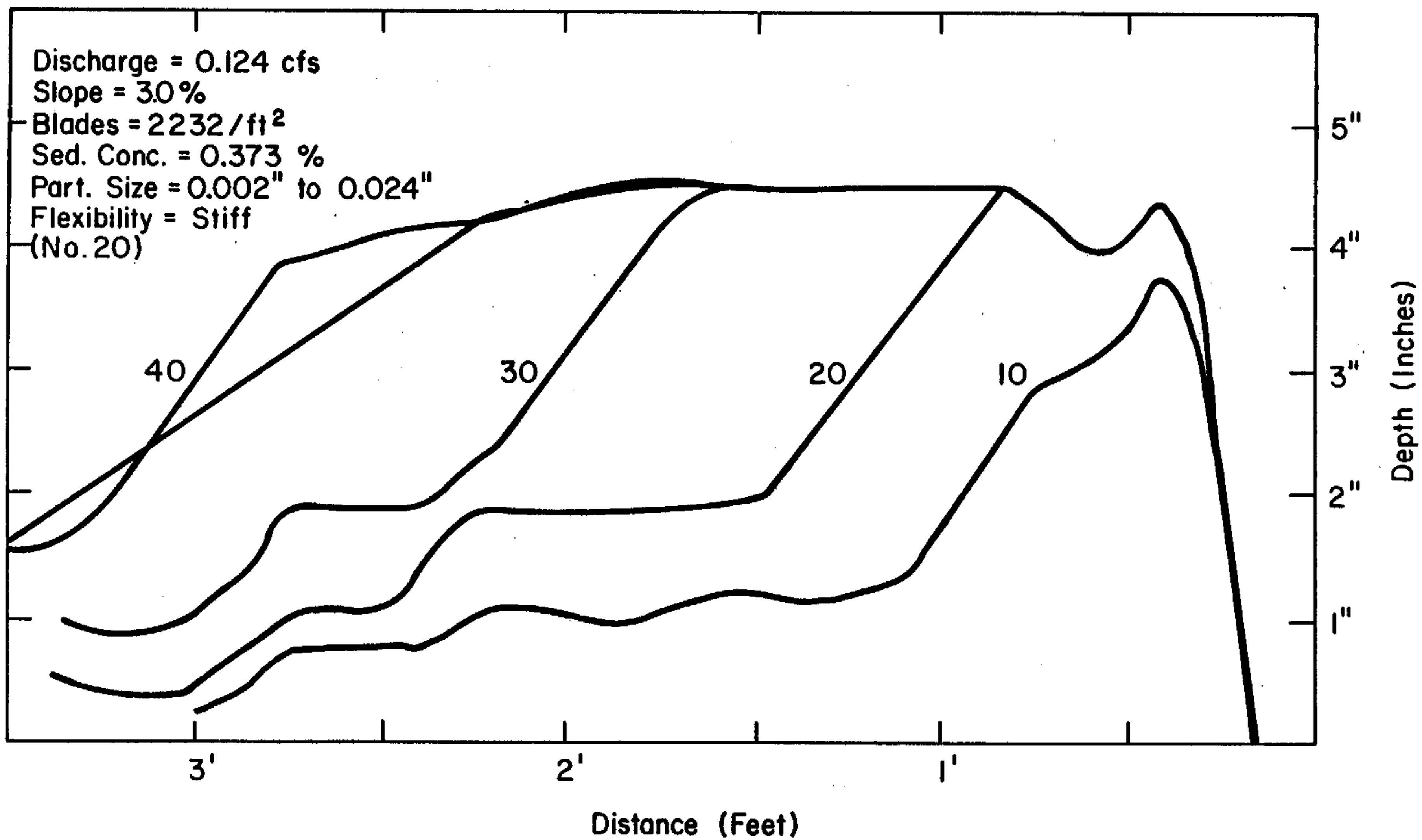

Fig. 14 Typical sediment bed profile and its forward progress pattern

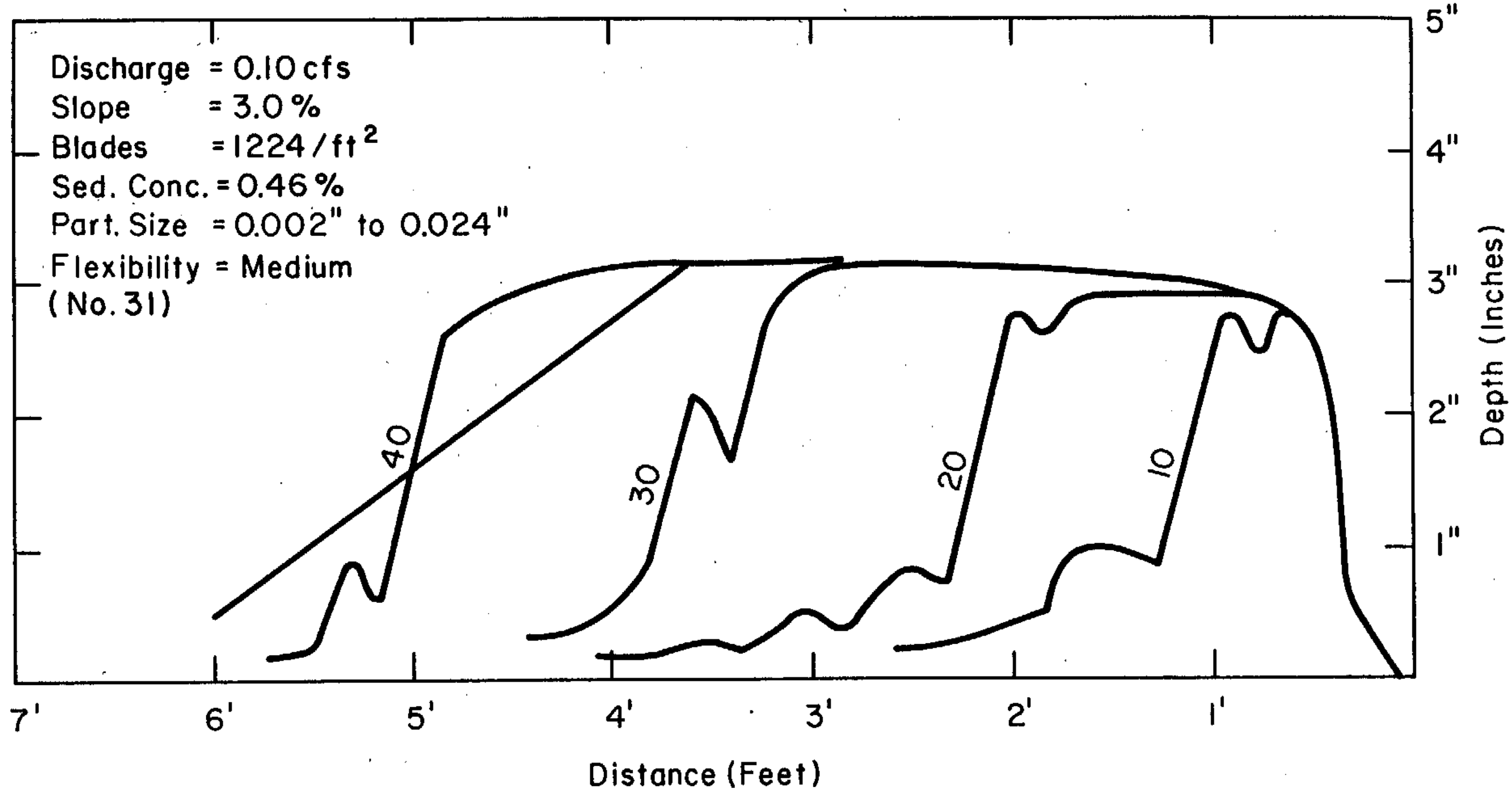

Fig. 15 Typical sediment bed profile and its forward progress pattern

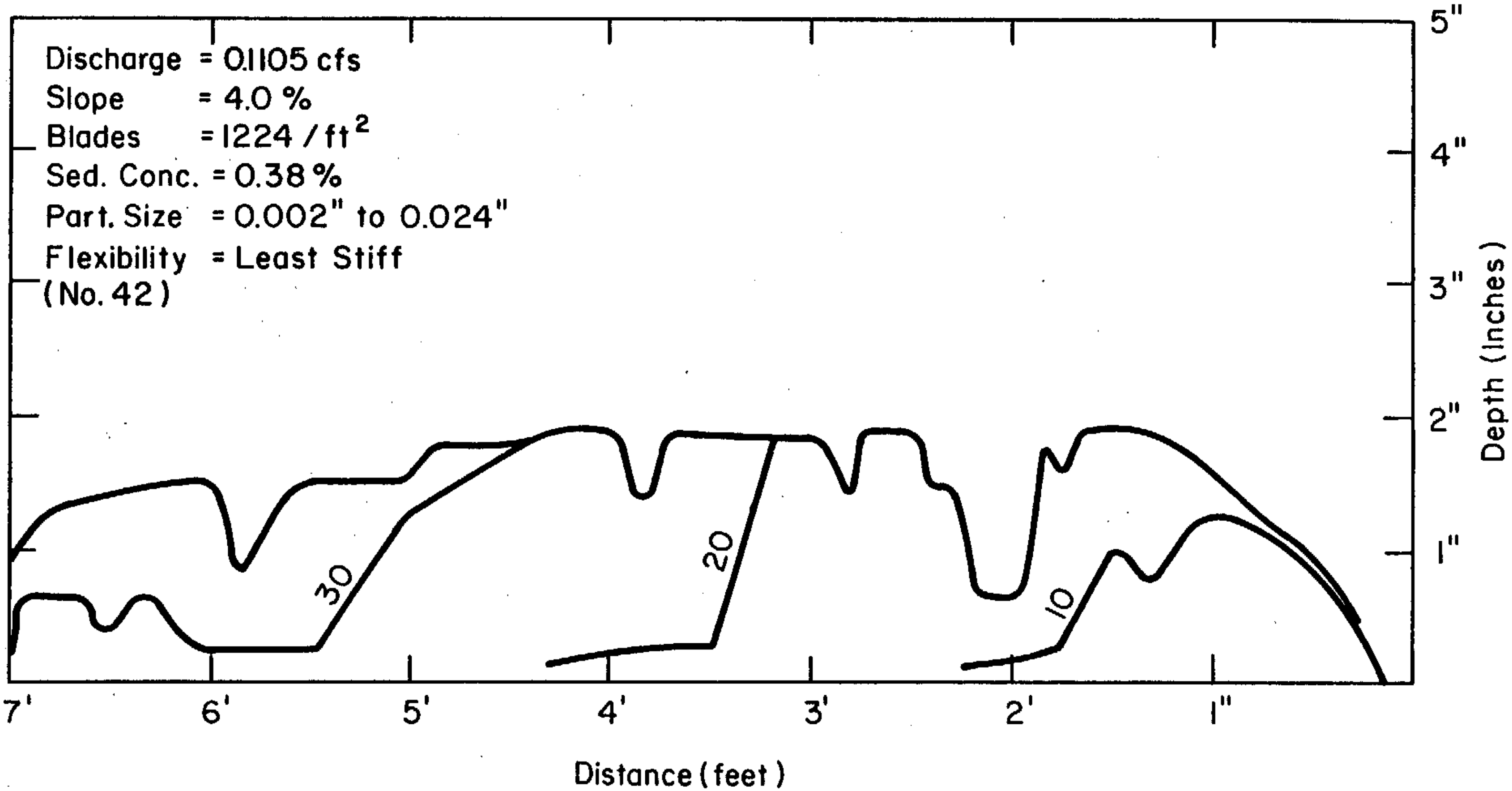

Fig. 16 Typical sediment bed profile and its forward progress pattern

TABLE V BED LOAD PROGRESSION WITH TIME AND MAXIMUM HEIGHT OF PROGRESSION

Test	Sediment Class	Discharge (cfs)	Slope (%)	Flex.	Density No. of blade/ft^2	Average bed load progress 10	20	30	40	Max. Height (in)
-1	70	.107	3.0	Stiff	1224	1' 5.0"	6.0"	6.0"	6.0"	4-3/8
-2	70	.065	3.0	Stiff	1224	1' 1.0"	8.0"	6.5"	6.0"	4-5/8
-3	70	.131	3.0	Stiff	1224	1' 4.0"	8.0"	8.5"	5.0"	4-1/2
-4	70	.065	4.0	Stiff	1224	11.5"	1' 0.5"	7.0"		4-5/8
-5	70	.131	4.0	Stiff	1224	1' 4.5"	5.5"	5.0"	6.0"	4-1/2
-6	70	.131	4.0	Stiff	1224	10.0"	8.5"	6.5"	5.0"	4-3/8
-7	70	.107	4.0	Stiff	1224	1' 1.5"	10.0"	3.0"	3.0"	4-1/4
-8	70	.027	4.0	Stiff	1224					
-9	70	.107	2.0	Stiff	1224	9.0"	7.5"	6.5"	6.5"	4-1/2
-10	70	.131	2.0	Stiff	1224	1'	7.0"	7.5"	7.0"	4-1/2
-11	70	.065	2.0	Stiff	1224	9.0"	4.5"	6.0"	5.0"	4-1/2
1	130	.065	2.0	Stiff	1224					4-1/2
2	130	.107	2.0	Stiff	1224					3-1/4
3	130	.131	2.0	Stiff	1224					1-1/8
4	130	.065	3.0	Stiff	1224					3
5	130	.107	3.0	Stiff	1224					1-3/4
6	130	.065	4.0	Stiff	1224					3-3/4
7	130	.107	4.0	Stiff	1224					1-7/8
8	Mix	.065	4.0	Stiff	1224	1' 1.0"	8.0"	7.5"	5.0"	4-1/2
9	Mix	.107	4.0	Stiff	1224	1' 2.0"	5.0"	4.5"	6.0"	4-1/4
10	Mix	.131	4.0	Stiff	1224	6.0"	3.5"	5.0"	6.0"	4-1/4
11	Mix	.065	3.0	Stiff	1224	1' 1.0"	9.0"	9.0"	10.5"	4-5/8
12	Mix	.131	3.0	Stiff	1224	1'10.5"	10.5"	8.0"	1' 0.5"	4-3/8
13	Mix	.107	3.0	Stiff	1224	1'	6.5"	5.5"	4.0"	4-1/4
14	Mix	.065	2.0	Stiff	1224	10.0"	11.0"	10.5"	10.0"	4-5/8
15	Mix	.107	2.0	Stiff	1224	9.0"	7.5"	10.0"	12.0"	4-5/8
16	Mix	.131	2.0	Stiff	1224	8.0"	7.0"	7.0"	6.5"	4-1/2

TABLE V (continued)

Test	Sediment Class	Discharge (cfs)	Slope (%)	Flex.	Density No. of blade/ft^2	Average bed load progress 10	20	30	40	Max. Height (in)
17	Mix	.074	4.0	Stiff	2232	10.0"	11.0"	10.0"	11.0"	3-1/2
18	Mix	.095	4.0	Stiff	2232	8.5"	7.0"	10.0"	11.5"	4-1/2
19	Mix	.124	4.0	Stiff	2232	11.0"	9.5"	1' 0.5"	1'	4-1/2
20	Mix	.124	3.0	Stiff	2232	9.5"	6.5"	10.0"	10.5"	4-1/2
21	Mix	.095	3.0	Stiff	2232	1'	8.5"	11.0"	11.5"	4-1/2
22	Mix	.074	3.0	Stiff	2232	10.0"	8.5"	6.5"	11.0"	4-3/4
23	Mix	.074	2.0	Stiff	2232	9.0"	9.0"	1'	9.0"	4-3/4
24	Mix	.095	2.0	Stiff	2232	9.0"	8.0"	1' 2.0"	1' 4.0"	4-1/2
25	Mix	.125	2.0	Stiff	2232	10.0"	9.0"	10.5"	9.5"	4-5/8
26	Mix	.078	4.0	Med.	1224	1' 4.0"	1' 7.0"	2' 1.0"	1' 4.0"	2-7/8
27	Mix	.078	3.0	Med.	1224	1'10.0"	1' 8.0"	1' 5.0"	2' 3.0"	2-7/8
28	Mix	.078	2.0	Med.	1224	1' 9.0"	1' 4.0"	1' 8.0"	1' 6.0"	3-3/8
29	Mix	.100	4.0	Med.	1224	1'10.0"	1' 2.0"	11.0"	1' 3.0"	3
30	Mix	.100	3.0	Med.	1224	1' 3.0"	1'	1' 6.0"	1' 3.0"	3-1/8
31	Mix	.100	2.0	Med.	1224	1' 3.0"	1' 4.0"	1' 4.0"	1' 5.0"	3-1/2
33	Mix	.127	4.0	Med.	1224	2' 4.0"	1' 2.0"	1' 1.0"	2' 2.0"	2-1/2
34	Mix	.127	3.0	Med.	1224	2' 2.0"	1' 2.0"	1' 8.0"	1' 7.0"	2-3/4
35	Mix	.127	2.0	Med.	1224	1' 2.0"	1' 2.0"	1' 6.0"	1' 3.0"	2-7/8
36	Mix	.070	4.0	Least	1224	1'10.0"	2'	1' 1.0"	1' 2.0"	2
37	Mix	.070	3.0	Least	1224	2' 2.0"	1' 9.0"	2'	2' 4.0"	2-1/4
38	Mix	.070	2.0	Least	1224	1' 6.0"	2'	2' 4.0"	2' 8.0"	2-1/8
39	Mix	.090	4.0	Least	1224	3' 2.0"	3' 9.0"	1'11.0"		2
40	Mix	.090	3.0	Least	1224	2' 9.0"	2'	3' 1.0"		1-7/8
41	Mix	.090	2.0	Least	1224	2' 5.0"	2' 3.0"	2' 7.0"	2' 9.0"	2-1/4
42	Mix	.1105	4.0	Least	1224	1' 9.0"	1' 9.0"	2'	2' 2.0"	1-7/8
43	Mix	.1105	3.0	Least	1224	2' 5.0"	1' 9.0"	2'11.0"	2' 4.0"	2
44	Mix	.1105	2.0	Least	1224	2' 1.0"	1' 8.0"	1'10.0"	3' 1.0"	2-1/8

TABLE VI LEADING EDGE SLOPE OF SAND FOR TEN MINUTE TIME INTERVAL

Test	Sediment Class	Discharge (cfs)	Slope (%)	Flex.	Density No. of blade/ft^2	Time (Minutes) 10	20	30	40	End
-1	70	.107	3.0	Stiff	1224	15.4	19.9	21.5	22.2	7.7
-2	70	.065	3.0	Stiff	1224	21.4	15.5	20.9	22.2	8.2
-3	70	.131	3.0	Stiff	1224	17.8	24.3	21.5	22.0	7.8
-4	70	.065	4.0	Stiff	1224	17.0	18.0	18.8	19.3	6.0
-5	70	.131	4.0	Stiff	1224	14.0	15.7	18.4	14.0	5.9
-6	70	.131	4.0	Stiff	1224	19.7	19.0	20.3	19.9	7.4
-7	70	.107	4.0	Stiff	1224	20.6	19.9	18.4	18.2	5.4
-8	70	.027	4.0	Stiff	1224					
-9	70	.107	2.0	Stiff	1224	26.6	27.3	26.6	26.9	8.7
-10	70	.131	2.0	Stiff	1224	17.7	27.5	27.9	25.3	8.0
-11	70	.065	2.0	Stiff	1224	29.9	23.0	24.1	23.6	9.8
1	130	.065	2.0	Stiff	1224	22.1	22.6	31.0	26.6	
2	130	.107	2.0	Stiff	1224	17.4	18.4	19.0	19.7	4.5
3	130	.131	2.0	Stiff	1224	11.3	14.0	10.6	14.0	
4	130	.065	3.0	Stiff	1224	10.6	20.6	16.7	14.0	
5	130	.107	3.0	Stiff	1224	10.6	14.0	14.6	14.0	
6	130	.065	4.0	Stiff	1224	14.0	14.0	17.8	17.4	4.3
7	130	.107	4.0	Stiff	1224	10.6	14.0	11.3	17.4	
8	Mix	.065	4.0	Stiff	1224	20.6	22.6	22.6	23.6	
9	Mix	.107	4.0	Stiff	1224	23.0	26.6	23.6	22.3	9.5
10	Mix	.131	4.0	Stiff	1224	24.9	19.3	22.8	21.0	6.8
11	Mix	.065	3.0	Stiff	1224	23.6	25.1	28.8	28.1	7.9
12	Mix	.131	3.0	Stiff	1224	20.6	22.0	24.8	23.6	7.9
13	Mix	.107	3.0	Stiff	1224	23.6	21.1	23.4	23.2	6.3
14	Mix	.065	2.0	Stiff	1224	26.6	26.6	32.9	29.4	9.2
15	Mix	.107	2.0	Stiff	1224	30.3	29.4	32.0	26.6	8.5
16	Mix	.131	2.0	Stiff	1224	18.4	22.6	22.3	31.1	6.5

TABLE VI (continued)

Test	Sediment Class	Discharge (cfs)	Slope (%)	Flex.	Density No. of blade/ft^2	Time (Minutes) 10	20	30	40	End
17	Mix	.074	4.0	Stiff	2232	28.8	22.6	25.1	26.6	8.6
18	Mix	.095	4.0	Stiff	2232	29.1	23.7	26.6	25.6	7.4
19	Mix	.124	4.0	Stiff	2232	21.8	22.6	22.3	25.6	5.9
20	Mix	.124	3.0	Stiff	2232	22.3	19.7	19.3	20.6	9.9
21	Mix	.095	3.0	Stiff	2232	24.6	24.2	25.1	22.6	8.0
22	Mix	.074	3.0	Stiff	2232	27.1	28.0	24.6	24.6	8.0
23	Mix	.074	2.0	Stiff	2232	31.3	30.3	30.7	30.4	6.0
24	Mix	.095	2.0	Stiff	2232	33.3	23.6	27.1	20.6	11.8
25	Mix	.125	2.0	Stiff	2232	29.4	32.9	27.6	32.7	8.0
26	Mix	.078	4.0	Med.	1224	14.0	11.3	23.0	13.7	6.7
27	Mix	.078	3.0	Med.	1224	32.0	20.6	30.3	13.1	7.4
28	Mix	.078	2.0	Med.	1224	35.3	33.7	30.7	29.4	10.6
29	Mix	.100	4.0	Med.	1224	22.1	19.7	20.6	22.6	8.3
30	Mix	.100	3.0	Med.	1224	25.1	26.6	22.6	26.6	5.4
31	Mix	.100	2.0	Med.	1224	19.5	23.0	23.6	25.6	7.4
33	Mix	.127	4.0	Med.	1224	34.5	18.0	20.6	18.0	4.0
34	Mix	.127	3.0	Med.	1224	11.0	32.0	26.5	17.8	7.1
35	Mix	.127	2.0	Med.	1224	20.6	32.0	34.5	18.8	12.4
36	Mix	.070	4.0	Least	1224	20.6	9.5	14.0	12.7	1.0
37	Mix	.070	3.0	Least	1224	16.7	24.6	26.6	8.5	3.6
38	Mix	.070	2.0	Least	1224	15.2	15.7	20.6	29.4	5.6
39	Mix	.090	4.0	Least	1224	22.6	8.5	18.4		2.1
40	Mix	.090	3.0	Least	1224	24.6	16.7	17.4		2.9
41	Mix	.090	2.0	Least	1224	23.6	29.4	14.0	16.3	3.6
42	Mix	.1105	4.0	Least	1224	14.0	21.3	11.3	17.4	2.9
43	Mix	.1105	3.0	Least	1224	22.1	19.0	20.6	17.4	2.4
44	Mix	.1105	2.0	Least	1224	26.6	15.4	26.6	16.3	1.4

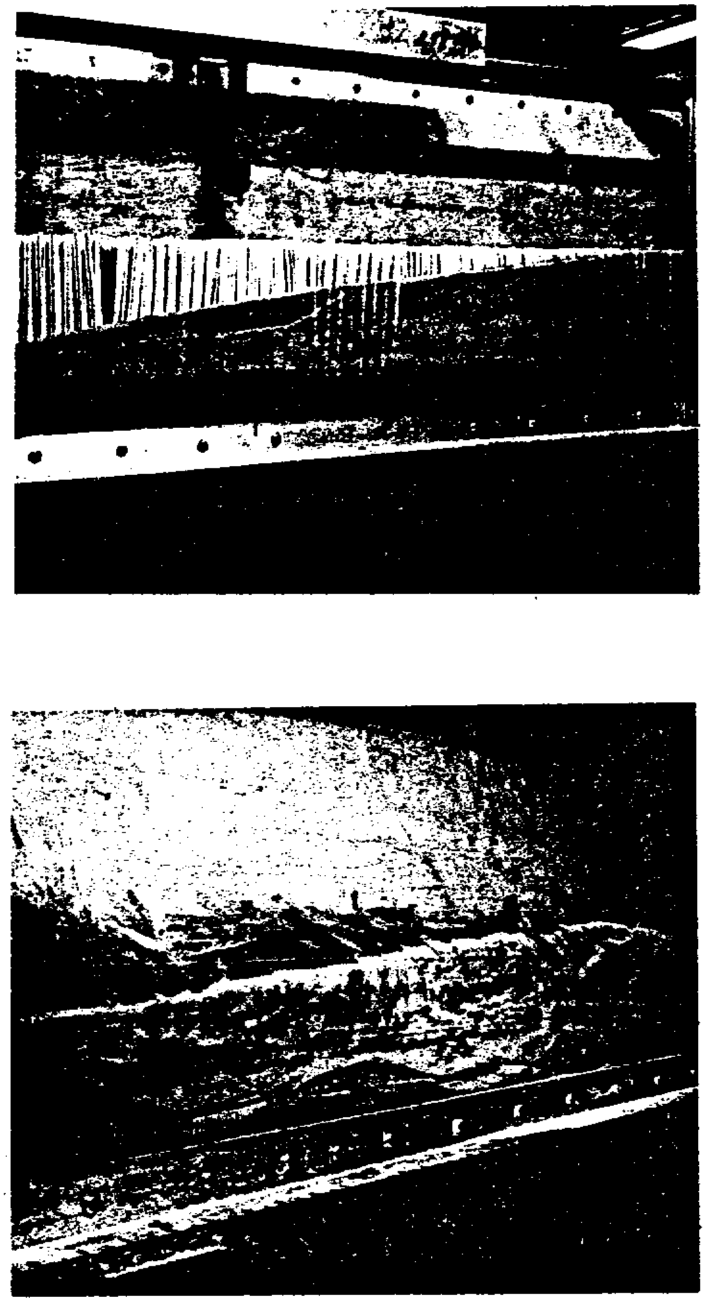

Fig. 17 Sediment bed formed by trapped sediments in stiff and flexible simulted grass

CHAPTER III

CONCLUSIONS

The experimental results confirm the high potential of using a vegetative filter as a sediment trapping system. The trapping efficiency of the system was found to be very high considering the fact that only approximately 4 meters (13 feet) of vegetation - covered section were used in the test flume for these series of experimental tests. In the actual engineering application, the length of the vegetative filter should be varied in accordance with the inflow and outflow conditions as specified in the design requirement.

The phase-I test results lead to the following summarized conclusions:

1. The high sediment trapping efficiency of a vegetative filter results from the reduction of flow turbulent fluctuation intensity and the increase in path length a sediment particle must travel around the vegetation stems in the general direction of the flow.
2. The depth and velocity of the flow have a direct effect on the efficiency of sediment trapping. It is noted that the efficiency is inversely proportional to both these parameters as anticipated.
3. The sediment trapping efficiency generally decreases with time for any given filter section. This can be attributed to two possible reasons: (a) the reduction of water depth resulted from sediment bed formation causes an ultimate flow velocity increase in the section; and (b) the transport of sediment downstream in the form of bedload.
4. The effect of the vegetation stem stiffness manifests itself in the resulting bending by the flowing water. This in turn reduces the effective resistance to flow and the storage capacity of bedload among the vegetation stems.
5. As expected, the larger particles settle out first. However, through the bedload transport, more and more larger particles

were found in the downstream section as the time of the test carries on.

6. Some effect was noted of the vegetation stem density per unit area of channel bed. The increase of vegetation density generally causes the shortening of travel distance of a given size sediment particle before it settles onto the channel bed.
7. The maximum height of the sediment bed formed by the trapped solid can reach no higher than height of the vegetation. As the sediment bed progress forward in the downstream direction, a slope forms along the leading edge of bed. This slope corresponds closely to the angle of repose measured from the horizontal line.
8. The rate of sediment bed progression was found to increase with increasing flow rate, sediment concentration and channel slope, while decreasing with the increasing vegetation stiffness and the decreasing particle size.

During the experimental work, artificial vegetations were used. The formation of the sediment bed did not cause any concern as to what effect it may have on the vegetation itself. However, should real grasses be used, the bedload, as it established its height all the way to the top of grass, will certainly cause the killing of the plants, and in turn the permanent loss of the filter.

Besides, even if only the artificial vegetations are used, the formation of bedload will result in temporary loss of function of the filter until it is cleaned as part of the needed maintainence. To clean the sediment bed which is established around the vegetation stem may prove to be a difficult task. As a result, the temporary loss of function could become permanent.

Based upon these considerations and the recognition of the actual mechanical advantages, a new filter system concept was conceived and constructed in which the vegetative filters were arranged in discrete fashion separation by blank spaces between every two consecutive filter strips. The results of the anlaytical and experiment analyses of the discrete filter system will be presented in volume II and volume III of this completion report concerning bedload and suspended load trapping efficiencies, respectively.

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