UNITED STATES

DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

FLUME STUDIES WITH FINE AND COARSE SANDS

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By Carl F. Nordin, Jr.

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ABSTRACT

This report presents a summary of hydraulic and sediment-transport data for two series of laboratory studies in a recirculating flume. Sands with median diameters of 0.25 and 1.1 millimeters were used in the studies. Velocities and depths were controlled, and the slopes, bed configurations and sediment-transport rates adjusted to the imposed independent variables. Mean depths were varied from about 0.2 to 0.9 meter and mean velocities ranged from about 0.4 to 2.0 meters per second.

INTRODUCTION

During the period 1965-1973, the U.S. Geological Survey conducted a series of experiments on flow and sediment transport in laboratory channels with sand beds. The purposes of the studies were: (1) to extend the experimental hydraulic and sediment transport data through a greater range of depths, (2) to investigate the statistical properties of the bed configurations generated by the flow, (3) to study the segregation and sorting of heavy minerals associated with river sediments, and (4) to further develop stochastic models of bed configurations and sediment transport. Turbulence data were collected during some of the studies, and during some, Prof. H.W. Shen and his coworkers (using radioactive tracers) collected data on the motion of single particles.

The experiments were conducted at the Engineering Research Center of Colorado State University at Fort Collins, Colorado. Several interpretive reports have been published on the results of the studies. Some preliminary analyses of the bed forms are given by Nordin (1969, 1971a, 1971b) and Nordin and Richardson (1968), and a stochastic model of sediment transport based on sounding records of the bed is reported by Lee and Jobson (1975). Todorovic and Nordin (1975) summarize and extend the theory of stochastic models of single particle motion, and Brady and Jobson (1973) report the sorting and stratification of heavy minerals. The turbulence data and corresponding hydraulic data for a few of the runs are given by McQuivey (1973). Some of the unpublished data (runs 15-48 of the Bernardo sand, described below) were provided in 1971 to C. T. Yang in a personal communication from V. R. Schneider. Yang (1972) cited these data incorrectly as "Schneider, V. R., U.S. Geological Survey Professional Paper, 1972."

The purpose of this report is to make available in a single publication a summary of the hydraulic and sediment transport data. A more detailed interpretive report containing data on the bed configurations is in preparation for publication as a U.S. Geological Survey Professional Paper. In the following sections, the flume, the sediment, and the experimental procedures are described, and the basic data are summarized in tables and graphs.

ACKNOWLEDGEMENTS

Many people took part in these studies. Special acknowledgements are due R.E. Rathbun, who was involved in most of the studies and who supervised much of the work, and to H.E. Jobson, who was instrumental in developing an efficient system for data acquisition and reduction. Others who assisted at various times include J.P. Bennett, V.R. Schneider, T.N. Keefer, R.S. McQuivey, M.E. Moss, M.R. Karlinger, B.K. Lee, C.T. Yang, and G.V. Sabol. Thomas Maddock, Jr., was involved in the initial planning and design of the experiments.

EQUIPMENT AND PROCEDURES

The experiments were carried out in a recirculating flume 2.38 m wide, 1.22 m deep, and 61 m long. Figure 1 shows a schematic diagram of the system. The flume was supported at the upstream end on a pivot and downstream at third points along the flume on pairs of electrically powered synchronized screw jacks for slope adjustment. The bottom and walls were constructed of aluminum plate coated with epoxy to prevent deterioration and chemical reactions, and plexiglas panels were installed along 22 m of the left side for viewing and photographing the bed. A variable speed carriage for instruments was mounted parallel to the floor of the flume on rails attached to the side support frame. Depth of flow was controlled by an adjustable slotted tailgate.

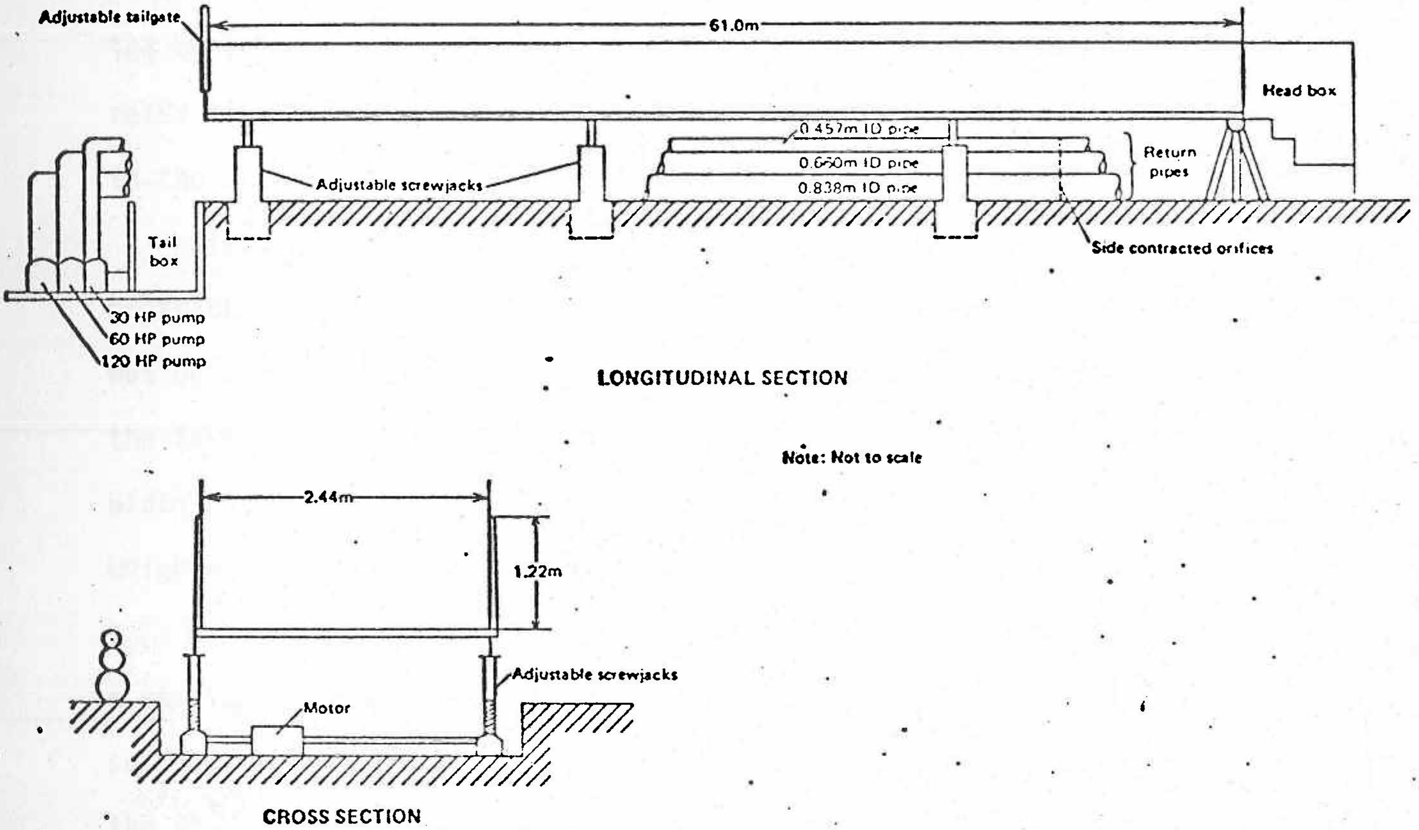

Figure 1.--Schematic diagram of the flume used in the experiments.

The tailbox for the flume was mounted in the floor of the laboratory and connected to a sump for water supply. The water and sediment dropped from the flume into the tail box and were recirculated through three return pipes with 30, 60, and 120 horsepower pumps that could be operated individually or in any combination. The smallest pump had variable speed; discharge of the two larger pumps was controlled by valves or bypassing part of the flow back to the tailbox. The rated capacity of the pumps was 2.83 m^3/s, but head losses with sediment in the system reduced the usable capacity to about 2.5 m^3/s.

Discharge was measured by water-air manometers connected to side-contracting orifice meters in the return pipes. Sediment discharge was determined from samples at the nappe of the flow downstream of the tailgate. The sampler was a vertical slot that traversed the width of the nappe to collect a width-depth integrated or discharge-weighted concentration.

Depth and water-surface slope were determined usually by fitting a straight line to sonic soundings of the bed and water surface; for some of the earlier runs, water surface and bed elevations relative to the flume carriage were measured with a point gage and a sounding rod with a base plate. Elevation of the flume carriage relative to a horizontal datum was established by precise leveling.

Water temperature was not preselected, but for each run it was controlled to within ± 1°C by adding cold water or steam to the system.

In the experiments, sand in the flume covered the bed to a depth of approximately 0.3 m. Water discharge and depth were controlled, and the bed slope, water-surface slope, and sediment discharge adjusted to the pre-selected depth and velocity. The system was assumed to be in equilibrium when the time-averaged water-surface slope, bed slope, and sediment discharge attained constant values. After equilibrium conditions were established, the flow was maintained for several days and a number of observations, usually 30 or more, were taken at hourly intervals, as follows: bed and water-surface profiles were obtained with a sonic sounder, water temperature was measured to the nearest 0.1°C, sediment discharge was sampled, and the water discharge was recorded.

SEDIMENT

Two different sands were used in the experiments. The finer sand with a median diameter d_{50} of 0.25 mm was a natural untreated river sand obtained from the Rio Grande conveyance channel near Bernardo, New Mexico. Its average size distribution shown in figure 2 was determined by analyses using the visual accumulation tube (Interagency Report No. 11, 1957), and is given in terms of fall diameters. Comparisons by Brady and Jobson (1973) for the same sandsize distributions by sieve analysis, visual accumulation tube analysis, and direct measurement of the intermediate axes of the particles converted to sieve size are shown in figure 3. Values of median diameter, d_{50}, and sorting coefficient, σ, are equivalent in the sieve-size and fall-diameter distributions.

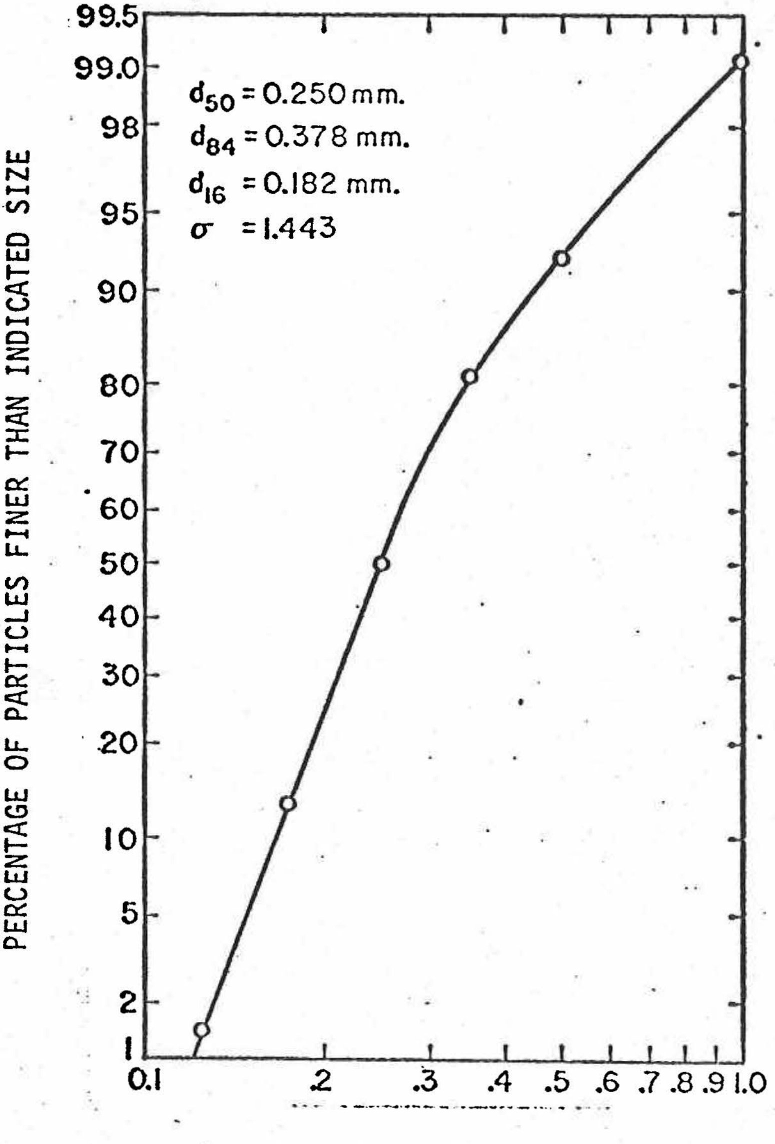

Figure 2.--Average size distribution of the Bernardo sand.

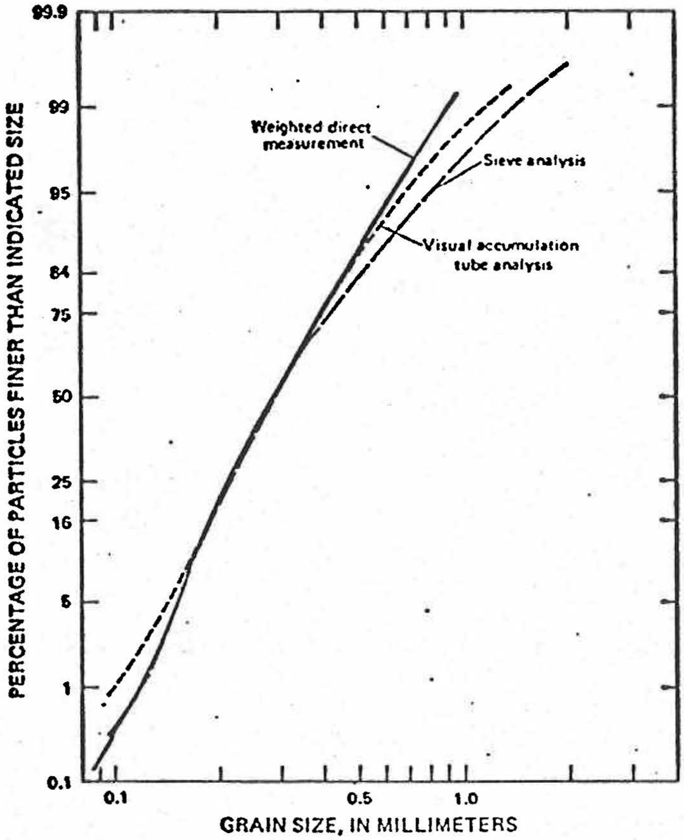

Figure 3.--Comparisons of size distributions of the Bernardo sand determined by visual-accumulation tube, sieve analysis, and weighted direct measurement (after Brady and Jobson, 1973).

The Bernardo sand was chosen because its size distribution is representative of many river sands and because the results of the flume studies would be comparable to the field data reported by Culbertson and others (1972). A more detailed description of the sand and its mineralogy is given by Brady and Jobson (1973).

The coarser sand with median sieve diameter d_{50} of 1.14 mm was from Cherry Creek near Denver, Colorado. The sand was mined commercially, washed, and sieved to remove material coarser than 4 mm. Its average size distribution determined by sieving is shown in figure 4. Values of d_{50} and σ of the sediment discharge reported below for the flume studies with this sand were from sieve analysis. Figure 5 shows the relation between fall diameter and sieve diameter for the Cherry Creek sand. Table 1 lists the particle-size distributions for the two sands.

PRESENTATION OF DATA

The hydraulic- and sediment-transport data for the Bernardo sand studies are presented in table 2 and for the Cherry Creek sand studies in table 3. In these tables, each "run" consisted of a period of time during which the flume was operated continuously and a series of observations at hourly intervals were obtained. The data in tables 2 and 3 are the averages of all observations for each run after equilibrium flow had been established.

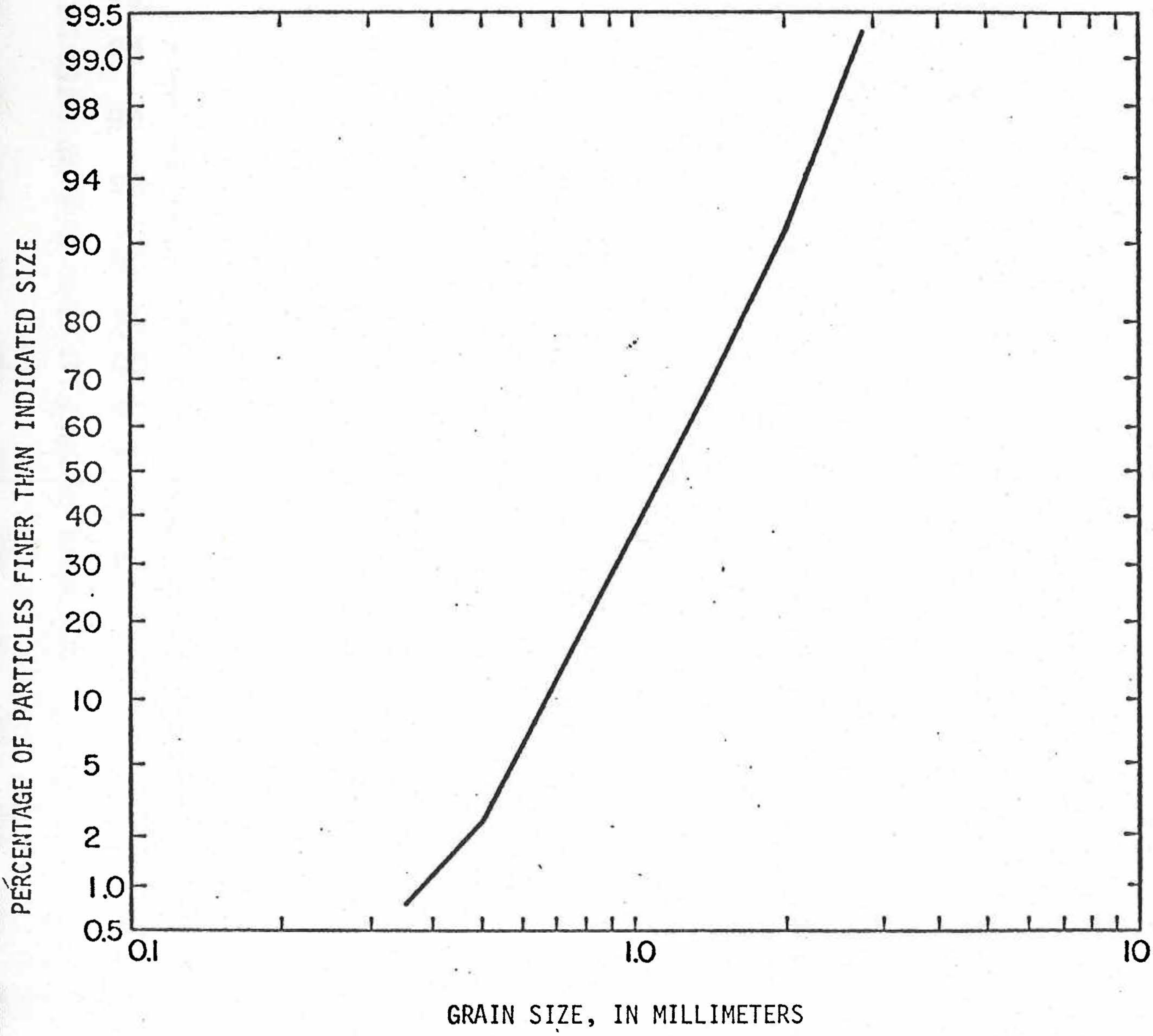

Figure 4.--Sieve-size distribution of the Cherry Creek sand.

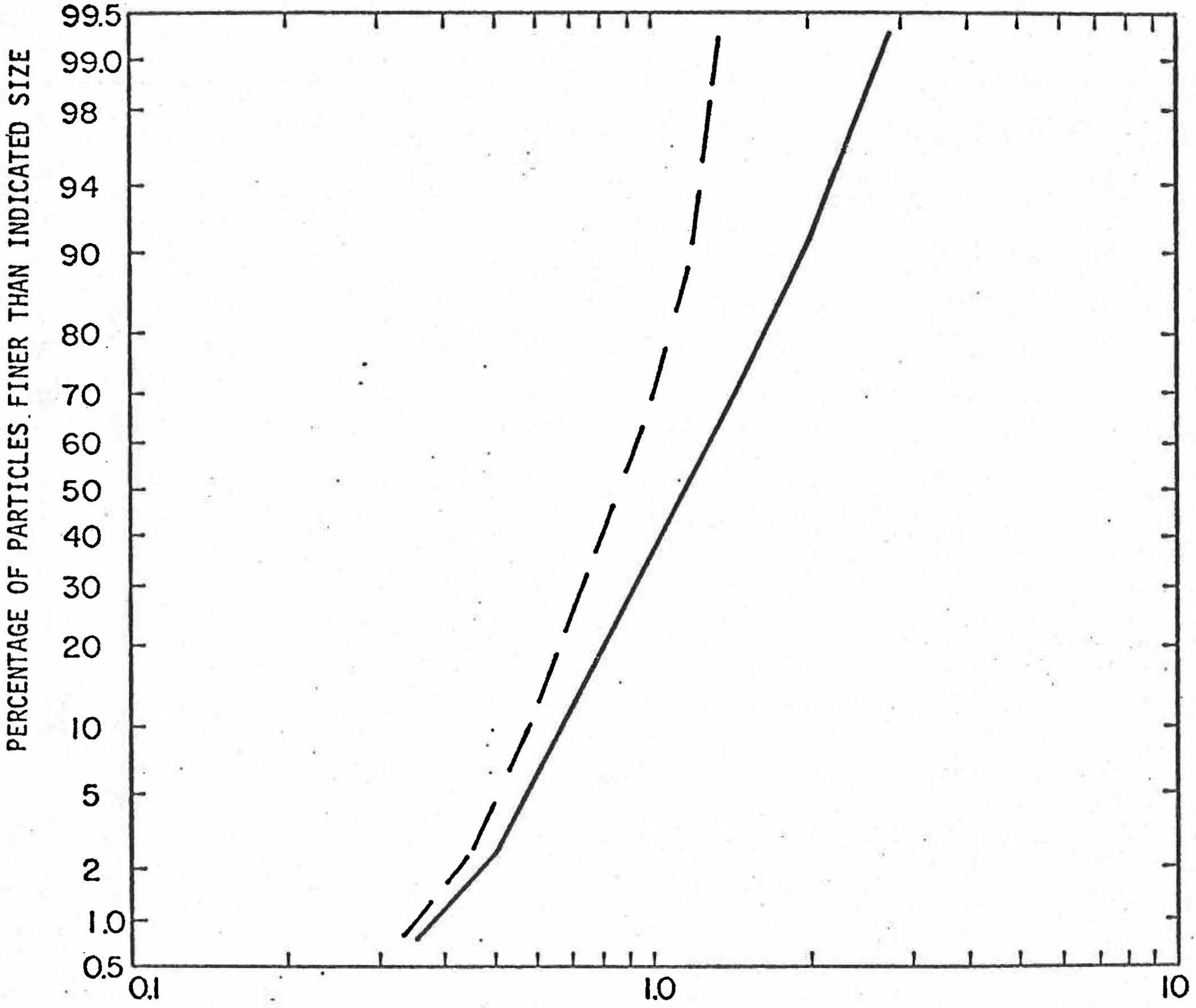

Figure 5.--Comparison of sieve-size distribution and fall diameter-size distribution for the Cherry Creek sand. The dashed curve is the fall diameter-size distribution.

The run numbers correspond to the numbers assigned to the observations in the original laboratory notes, and are in the sequence that the studies were performed. Run number 26 and 44 of the Bernardo sand and run number 2 of the Cherry Creek sand are omitted because these runs were conducted specifically to study unsteady flow conditions where equilibrium was not established. These data will be described in a later report.

Runs 1 through 14 of the Bernardo sand were preliminary runs to determine the operating characteristics of the flume, and during these runs, some minor modifications were made on the system to improve the entrance conditions and to prevent air entrainment in the tailbox. The runs were conducted to cover a range of depth and bed forms. Subsequent sets of runs were conducted holding depth approximately constant.

In the total load columns of table 2 and table 3, d_{50} is the median diameter, or the diameter for which 50 percent by weight is finer. The sorting coefficient, σ, is $1/2(d_{50}/d_{16} + d_{84}/d_{50})$ where d_{16} and d_{84} are the diameters for which 16 and 84 percent by weight are finer.

Finally, the last column of the tables indicates the configuration of the bed observed during the studies. The nomenclature follows generally the recommendations for definitions and descriptions of the ASCE and Task Force on Bed Forms and Alluvial Channels, Committee on Sedimentation (1966).

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Table 1.--Particle-size distributions.

Bernardo sand		Cherry Creek sand		
Fall diameter (mm)	Percent finer	Sieve diameter (mm)	Fall diameter (mm)	Percent finer
1.000	99.1	2.83	1.35	99.3
.500	92.4	2.00	1.21	91.6
.350	81.0	1.41	1.01	69.1
.250	50.0	1.00	.79	39.9
.177	13.2	.707	.60	12.8
.125	1.4	.500	.26	2.61
.088	0.0	.350	.34	.80
		.250	.24	.16
		.177	-	.04

Table 2.--Basic data, Bernardo sand.

Run No.	Water Discharge Q (m^3/s)	Mean Depth D (m)	Mean Velocity V (m/s)	Energy Slope S (m/m)	Temperature T (°C)	Total Load			Bed Configuration
						Conc C (mg/l)	d_{50} (mm)	σ	
1	1.322	0.853	0.634	0.00063	20.1	285	0.149	1.41	Ripples
2	1.351	.738	.750	.00078	19.4	808	.180	1.48	Dunes with ripples
3	.813	.546	.610	.00097	16.7	698	.196	1.45	Large dunes
4	1.988	.820	.994	.00079	21.7	1450	.191	1.54	Dunes and flat bed
5	2.002	.832	.988	.00071	10.2	698	.180	1.46	Dunes and flat bed
6	1.943	.759	1.049	.00157	22.3	1810	.169	1.41	Transition
7	1.999	.546	1.503	.00150	21.7	1400	.205	1.45	Flat bed
8	2.044	.479	1.753	.00165	20.2	2760	.217	1.37	Flat bed
9	1.960	.457	1.759	.00160	21.4	8870	.180	1.33	Breaking antidunes
10	1.379	.338	1.673	.00305	22.6	8520	.206	1.37	Antidunes
11	1.365	.311	1.801	.00449	23.2	15700	.196	1.36	Antidunes
12	1.371	.393	1.430	.00120	24.8	1640	.209	1.39	Flat bed
13	.844	.238	1.457	.00300	22.8	5560	.217	1.36	Antidunes
14	1.073	.719	.613	.00050	23.7	164	.169	1.48	Dunes with ripples
15	.281	.320	.361	.00032	22.7	.8	.121	2.25	Ripples
16	.427	.320	.547	.00047	21.7	73.0	.241	1.50	Ripples
17	.557	.308	.742	.00111	20.6	996	.179	1.50	Dunes
18	.700	.326	.880	.00089	21.3	873	.183	1.53	Transition
19	.814	.335	.995	.00093	21.7	1030	.193	1.49	Transition
20	1.019	.329	1.269	.00122	21.8	1720	.205	1.56	Flat bed
21	1.149	.317	1.497	.00189	21.2	3840	.192	1.46	Flat bed and antidunes
22	1.273	.311	1.679	.00266	21.8	6730	.192	1.42	Antidunes
23	1.565	.326	1.967	.00427	21.7	17200	.184	1.43	Antidunes
24	1.012	.329	1.261	.00123	20.9	2040	.213	1.43	Flat bed
25	.498	.329	.620	.00120	20.4	639	.195	1.46	Dunes
27	.844	.613	.565	.00029	21.3	54.5	.145	1.50	Ripples

Table 2.--Basic data, Bernardo sand--Continued.

Run No.	Water Discharge Q (m^3/s)	Mean Depth D (m)	Mean Velocity V (m/s)	Energy Slope S (m/m)	Temperature T (°C)	Total load Conc C (mg/l)	Total load d_{50} (mm)	Total load σ	Bed Configuration
28	1.023	.616	.682	.00068	21.2	435	.157	1.48	Dunes
29	1.193	.613	.798	.00093	21.3	765	.169	1.49	Dunes
30	1.344	.631	.631	.00083	20.9	872	.162	1.50	Dunes
31	1.533	.637	.987	.00089	21.3	1080	.167	1.46	Transition
32	1.711	.619	1.134	.00077	21.6	1100	.168	1.52	Transition
33	1.891	.637	1.218	.00070	22.0	1210	.160	1.53	Transition
34	2.056	.622	1.356	.00082	22.2	1750	.167	1.52	Transition
35	2.214	.597	1.520	.00086	22.4	1340	.198	1.56	Flat bed
36	1.516	.655	2.040	.00086	20.9	1080	.173	1.45	Dunes
37	1.030	.619	.683	.00051	21.6	258	.180	1.45	Dunes
38	1.025	.826	.509	.00014	21.1	17.8	.144	1.52	Ripples
39	1.293	.847	.626	.00020	21.2	56.6	.171	1.48	Ripples and dunes
40	1.534	.860	.732	.00052	21.1	356	.173	1.45	Dunes
41	1.807	.835	.888	.00063	21.4	736	.173	1.45	Dunes
42	2.090	.817	1.049	.00083	20.9	831	.177	1.47	Dunes
43	1.532	.853	.736	.00055	21.0	380	.185	1.42	Dunes
45	.482	.329	.601	.00102	20.8	351	.206	1.43	Dunes
46	2.076	.527	1.615	.00179	21.0	1800	.200	1.59	Flat bed
47	1.378	.585	.965	.00106	20.9	778	.183	1.47	Dunes
48	.731	.335	.896	.00122	20.7	827	.206	1.45	Transitions

Table 3.--Basic data, Cherry Creek sand.

Run No.	Water Discharge Q (m^3/s)	Mean Depth D (m)	Mean Velocity V (m/s)	Energy Slope S (m/m)	Tempera-ture T (°C)	Total load			Bed Configuration
						Conc C (mg/l)	d_{50} (mm)	σ	
1	0.346	0.256	0.555	0.00156	17.4	152	0.98	1.49	Dunes
3	.373	.299	.512	.00074	20.1	33	.94	1.44	Dunes
3A	.379	.287	.543	.00099	19.8	65.5	.98	1.51	Dunes
4	.462	.309	.613	.00173	20.3	165	1.08	1.51	Dunes
4A	.464	.311	.613	.00167	20.0	169	1.05	1.50	Dunes
5	.565	.314	.738	.00261	19.8	307	1.12	1.51	Dunes
5A	.566	.319	.728	.00252	18.3	325	-	-	Dunes
6	1.137	.359	1.298	.00577	19.9	2350	1.09	1.51	Dunes
7	.706	.315	.920	.00471	18.2	1090	1.14	1.50	Dunes
8	.833	.301	1.137	.00554	21.0	1480	1.08	1.50	Dunes
14	1.356	.309	1.804	.00520	21.5	2920	1.06	1.57	Transition
9	.744	.607	.503	.00039	22.3	2.9	1.01	1.46	Small Dunes
10	.920	.619	.610	.00068	21.6	26.9	1.08	1.48	Dunes
11	1.136	.612	.762	.00113	21.2	64.3	.98	1.62	Dunes
12	1.352	.615	.902	.00176	25.6	181	.95	1.77	Dunes
13	1.606	.630	1.045	.00254	24.0	412	.96	1.67	Dunes
15	1.023	.811	.518	.00010	21.2	1.1	.96	1.50	Dunes
16	1.236	.909	.558	.00029	22.8	8.9	.92	1.48	Dunes
17	1.533	.893	.704	.00047	22.0	29.7	.94	1.53	Dunes