A STUDY OF METHODS USED IN

MEASUREMENT AND ANALYSIS OF SEDIMENT LOADS IN STREAMS

REPORT NO. 2

EQUIPMENT USED FOR SAMPLING BED-LOAD AND BED MATERIAL

SEPTEMBER 1940

A Study of Methods Used in

MEASUREMENT AND ANALYSIS OF SEDIMENT LOADS IN STREAMS

Planned and conducted jointly by

Tennessee Valley Authority, Corps of Engineers

Department of Agriculture, Geological Survey

Bureau of Reclamation, Indian Service, and

Iowa Institute of Hydraulic Research

Report No. 2

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The cooperative study of methods used in

MEASUREMENT AND ANALYSIS OF SEDIMENT LOADS IN STREAMS

will cover phases indicated by the following titles of reports completed or in preparation.

Report No. 1

FIELD PRACTICE AND EQUIPMENT USED IN SAMPLING SUSPENDED SEDIMENT

Report No. 2

EQUIPMENT USED FOR SAMPLING BED-LOAD AND BED MATERIAL

Report No. 3

ANALYTICAL STUDY OF THE ACCURACY OF METHODS OF SAMPLING SUSPENDED SEDIMENT IN A VERTICAL SECTION*

Report No. 4

ANALYSIS OF SEDIMENT SAMPLES*

Report No. 5

LABORATORY STUDY OF SAMPLER INTAKES*

*Indicates reports are in preparation and the titles are tentative.

SYNOPSIS

The available literature concerning bed-load and bed material samplers has been reviewed and, in this report, the samplers are classified according to their type of construction and principle of operation. The samplers are described and illustrated by photographs and drawings. Bed-load samplers of the basket, pan, and pressure-difference types, and bed material samplers of the drag bucket, vertical and grab bucket types, are included. The results of calibrations of bed-load samplers performed by Shamov, Einstein, Ehrenberger, and the Swiss Federal Authority for Water Utilization are presented.

The various field conditions encountered in bed-load sampling are discussed, and the type of sampler suitable for each case is indicated.

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I. INTRODUCTION

1. Purpose of this report--"Methods used in the measurement and analysis of sediment loads in streams" is the subject of a survey instigated by a group of Federal agencies mutually interested in problems which involve transportation of sand, silt, gravel, and other insoluble materials in flowing water. This report, which is the second in a series on five different phases of the general project, is a review of equipment developed and used for sampling bed-load and bed materials in streams. This study completes the review of the technique and the various types of apparatus used in sediment sampling. The titles of other reports in the series are given on page 2.

Bed-load problems are not as numerous in the United States as those of suspended load, because most of the important rivers have beds composed of fine material and therefore carry much more sediment in suspension than along the bed. Therefore, the development of bed-load samplers in this country has not been as rapid as that of suspended sediment samplers. However, to sample the bed-load is more difficult than to sample suspended sediment. The samplers developed here and abroad have not been greatly diversified, for the most part falling into a few general classifications, each of which includes samplers of the same principle of operation and construction. Most of these types have been developed in Europe, and only in very recent years have American engineers contributed appreciably to the improvement of the equipment for sampling bed-load. The various types of bed-load samplers which are in use are described in this report. The results of calibrations and discussions of the applicability of each type to various field conditions are also given.

2. Authority and personnel--This report is a contribution from a study of methods used in measurement and analysis of sediment loads of streams, which study has been planned and conducted jointly by the following agencies of the United States Government: Corps of Engineers, War Department; Geological Survey, Bureau of Reclamation, and Indian Service, Department of Interior; Flood Control Coordinating Committee, Department of Agriculture; and the Tennessee Valley Authority. The Iowa Institute of Hydraulic Research, State University of Iowa, Iowa City, where the study is conducted under the direction of Prof. E. W. Lane, is cooperating in the project. The representatives of the collaborating agencies, engaged in the preparation of this report are Victor A. Koelzer, U. S. Geological Survey; Cleveland R. Horne, Jr., U. S. Engineer Department; Vernon J. Palmer, U. S. Soil Conservation Service; and Clarence A. Boyll, Tennessee Valley Authority.

3. Acknowledgments--Dr. H. A. Einstein of the Sedimentation Studies Branch, Soil Conservation Service, Department of Agriculture, who has made an extensive study of bed-load problems in Europe, has reviewed this report and has made many helpful suggestions. Section 5, "Functions of a bed-load sampler", and Section 21, "Selection of the proper type of bed-load sampler", were prepared largely by Dr. Einstein. Dr. Paul Nemenyi of the Iowa Institute of Hydraulic Research has assisted in the study of foreign literature on bed-load samplers.

The facilities of the U. S. Engineer Sub-Office at Iowa City and the Iowa City District Office of the U. S. Geological Survey, were used in handling administrative details and in the preparation of this report.

4. Definition of terms--Usage of the terms "bed-load" and "bed material" differs, and it seems advisable to define these terms as used in this report.

Bed-load is that part of the solids load of the stream which is moving in almost continuous contact with the stream bed, being rolled or pushed along the bottom by the force of the moving water. A bed-load sampler is, therefore, one which obtains a sample of the material moving in this manner.

Bed material is the material of which the bed is composed, and may be the result of either suspended or bed-load movement, or both, or, in some cases, may even be residual. Bed material samplers are instruments which sample this material, without regard to whether it is in motion or at rest. Equipment for taking samples from very great depths, such as core drilling apparatus, is not described in this report as this method of sampling is not within the scope of this project.

II. DESCRIPTIONS OF BED-LOAD SAMPLERS

5. Functions of a bed-load sampler--By definition a bed-load sampler must be capable of measuring the rate of transportation of bed-load material. The rate of transportation of such material as is rolled or pushed along the bottom cannot be conveniently or accurately derived by separate measurements of the flow velocity and the sediment concentration, such as are relied upon in suspended load sampling. This is due to the fact that bed-load material does not move at the same velocity as the water, and that furthermore, close to the stream bed, both concentration and velocity are changing rapidly with depth and time.

In this bottom layer the rate of transportation can be determined accurately only by means of an apparatus which will trap all solid particles moving through a certain part of the cross section during a measured period. Such is the principle of all true bed-load samplers. It may be pointed out that samplers for the determination of sediment concentration close to the stream bed are not considered bed-load samplers, in the sense of the definition used here. Description of such suspended load type samplers will be found in the earlier report: "Field Practice and Equipment Used in Sampling Suspended Sediment".

6. Classification of bed-load samplers--The bed-load samplers, as defined, may be grouped into several distinct classes, according to their type of construction and principle of operation. The rate of bed-load movement for all types is determined by placing the sampler on the stream bed and measuring the amount of material collected in a given time.

Probably the oldest and most common class is the box or basket type.

Fundamentally this type consists merely of a box or basket, generally made of meshed material, which is lowered to rest on the stream bed with the upstream end open to catch a sample of the moving material. The introduction into the stream of the sampler causes an increased resistance to flow and a resultant lowering of stream velocity. Hence, the entrance velocity is decreased from that of the undisturbed stream, causing some of the material to drop out before entering the basket. Thus, the efficiency, that is, the per cent of the material moving toward the sampler which is actually caught by it, is less than 100 per cent and must be determined to obtain reliable results with this type of equipment. Samplers of this class are described in Section 7.

The tray or pan type consists of a flat pan or a tray-shaped device with baffles or slots to check the moving material. Since this type also causes obstruction to the stream, and consequent reduction of entrance velocity and movement of material, it must be calibrated to determine its efficiency. Descriptions of samplers of this type are given in Section 8.

The pressure-difference type is designed to overcome the objection of decreased velocity and bed-load movement at the entrance to the sampler. A rational solution to the problem lies in the formation of a pressure drop at the exit of the apparatus just sufficient to overcome the energy losses, thus giving an entrance velocity the same as that in the undisturbed stream. This is accomplished by designing the instrument with a section diverging in a downstream direction which will cause a suction at the entrance. With such a diverging section, the velocity decreases toward the downstream end of the sampler and some of the material is deposited. Thus if the section is of sufficient length the necessity of a collecting screen at the exit may be eliminated. Some of the samplers of this type have collecting screens, while others have only baffles to check the movement of the material. Section 9 gives the descriptions of samplers of this type.

Another system which has been used in special cases is to construct slots in the stream bed and allow the moving material to drop into them. In one type the material is piped to the bank from the slots and the rate of bed-load movement determined, while in another type the slot is dug into the bed to collect a sample for size analysis only. These types are described in Section 10.

7. Box or basket type--As stated previously, the development of samplers has been more rapid in some countries than in others, due primarily to the different degrees of importance of the problem in the various countries. This is particularly true of the basket type of sampler. Some samplers in use today in countries in which the bed-load problem is relatively unimportant are not as advanced in design as those used ten years ago in countries where the bed-load has been studied extensively. For this reason the development of basket samplers cannot conveniently be discussed in chronological order.

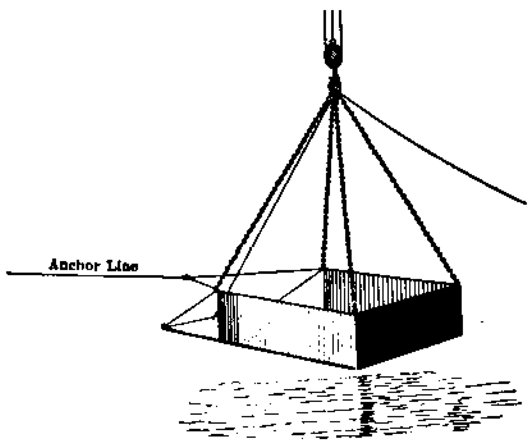

Fig. 1--Davis sampler.

Fig. 1 shows one of the earliest devices, which was used by A. P. Davis (1,10)* in the Nicaragua Canal in

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*Numbers refer to bibliography at the end of this report.

1898. This sampler consisted of a box, open at the top and at the upstream end. Davis found that considerable material washed over the downstream end of the box and because of this the sampler was unsatisfactory.

Kurtzman (8) used a basket sampler in the Tirol rivers in 1918 which probably overcame in part the objection of material washing over the back of the box. This sampler consisted of an iron box suspended at the end of a rod, with the upstream end open, and the side, top and downstream end made of screen.

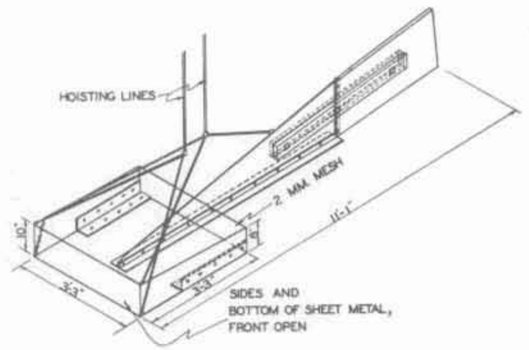


Fig. 2--Bogardi sampler.

A very similar type was developed and used by John Bogardi (10) for observations in the Danube conducted by the Royal Hungarian River Engineering Office at Györ, Hungary, in 1936. The bottom and sides of this sampler, Fig. 2, were made of sheet metal and the downstream end and top of 2-mm. mesh screen. The sampler was provided with a rudder and was suspended from two hoisting lines. In lowering, the upstream end was held lower than the downstream end and the force of the water pressed it down upon the bottom. In raising, the upstream end was held higher to prevent the entrapped material from running out.

Fig. 3--Punjab sampler.

Fig. 3 shows a basket type sampler which was used recently in the Punjab, India. This sampler consists of a wire cage, 24 by 12 by 9 in., with the sides and top made of three layers of 1/2-in. mesh overlapped to retain particles larger than 1/8 in. (3.2 mm.) in size, and the bottom made of 1/8-in. sheet metal. Although this sampler was not used to obtain the rate of bed-load transportation, it seems likely that it could be adapted to that purpose.

Fig. 4 shows a basket sampler of apparently a design similar to the earlier basket types which has been used recently in the Vistula River in

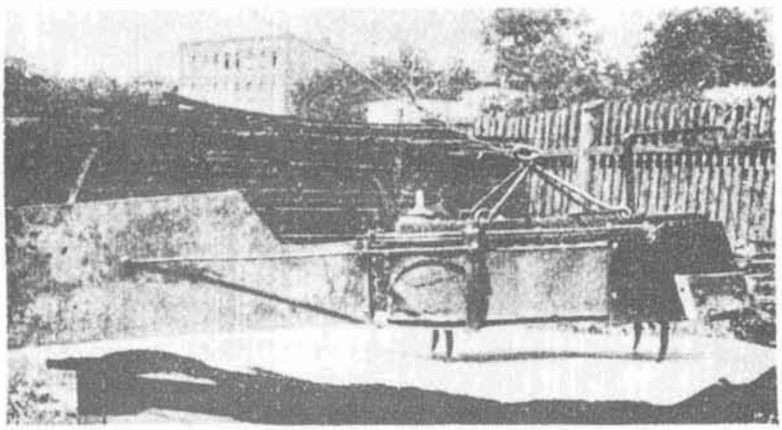


Fig. 4--Polish sampler.

Poland (2). A detailed description of the features of this sampler is not available.

Fig. 5 shows a sand trap designed in 1931 by Mr. K. Luders of

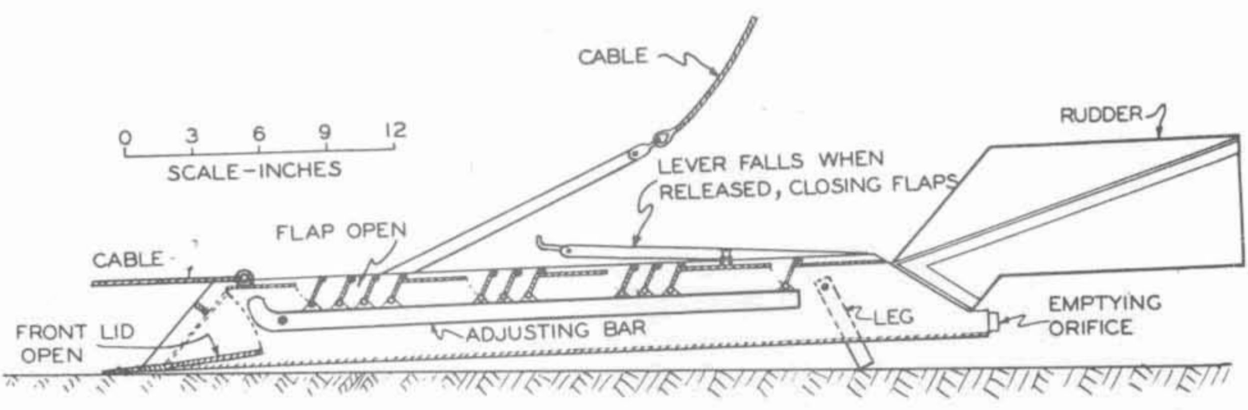
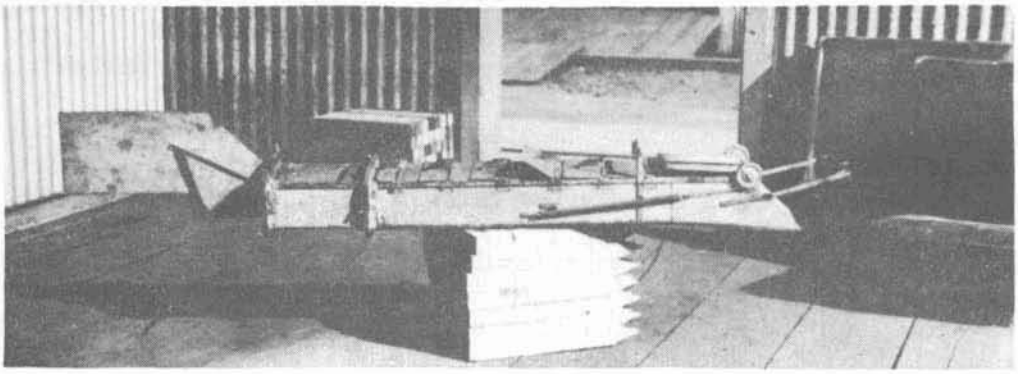
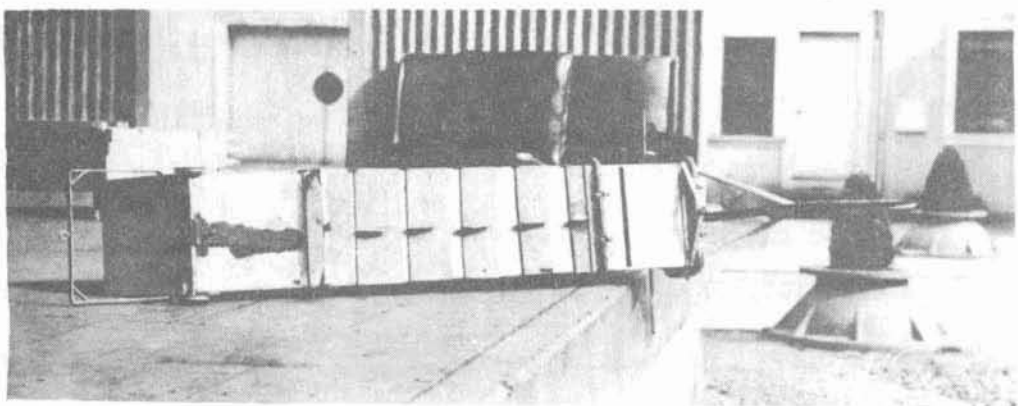


Fig. 5--Luders sampler.

Wilhelmshaven, Germany (20), which is an improvement of an earlier design by Moller (1923). This trap consisted essentially of a box with a hinged door at the front and flap valves at the top. The water entered at the front and escaped through the openings in the top, depositing the bed-load in the sampler. By releasing a lever which actuated an adjusting bar to which the flap valves were attached, all the openings in the top could be closed simultaneously. Five-minute sampling durations were used in these measurements.



a. Side view with door and one flap valve open.



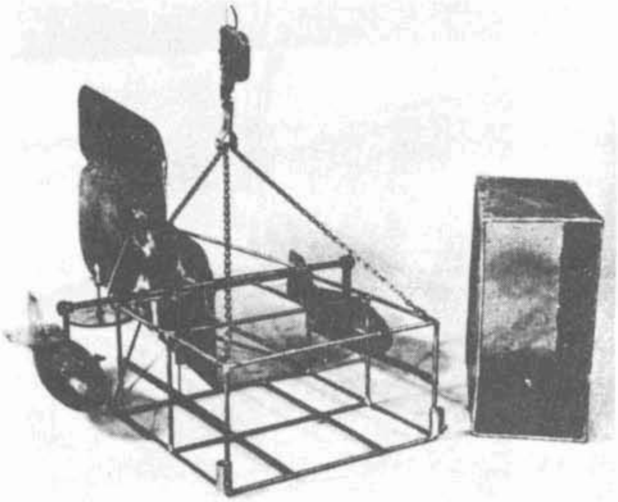
b. Top view with door and flap valves closed.

Fig. 6--Sampler of the Portland U. S. Engineer District.

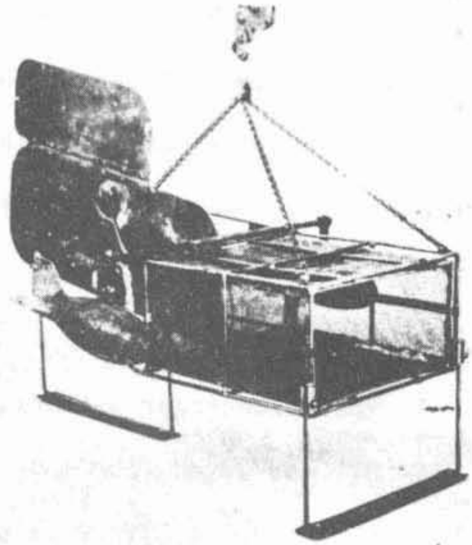
The Portland U. S. Engineer District used a similar type, which is shown in Fig. 6, for investigations in 1935-36 in the Columbia River estuary and in a log pond in the Columbia River. This consisted of a box 3 ft. long, 9 in. wide, and 5 in. deep. Water entered the sampler through an open door at the front and escaped through flap valves at the top, much the same as in the Luders sampler. The door could be closed when the sampling was completed by releasing a spring arrangement. This sampler was found to be unsatisfactory for use at points where appreciable velocities existed.

Fig. 7 shows a basket type sampler developed by the Rock Island U. S. Engineer District. This sampler consists of a light, brass frame into which a 12 by 12 by 6-in. basket of No. 20 mesh (0.86 mm. opening) is fitted, as shown in Fig. 7a. Samples may be taken with the basket resting on the stream bed or supported on standards at heights ranging from 3 to 24 in., as shown in Fig. 7b. Two hangers on either side of the basket are provided for the addition of streamlined weights. The entire apparatus may be suspended from the boom ordinarily used for water discharge measurements which is shown in Fig. 7c. This sampler is reported to be very satisfactory. It is being used in the present investigations of the Rock Island District.

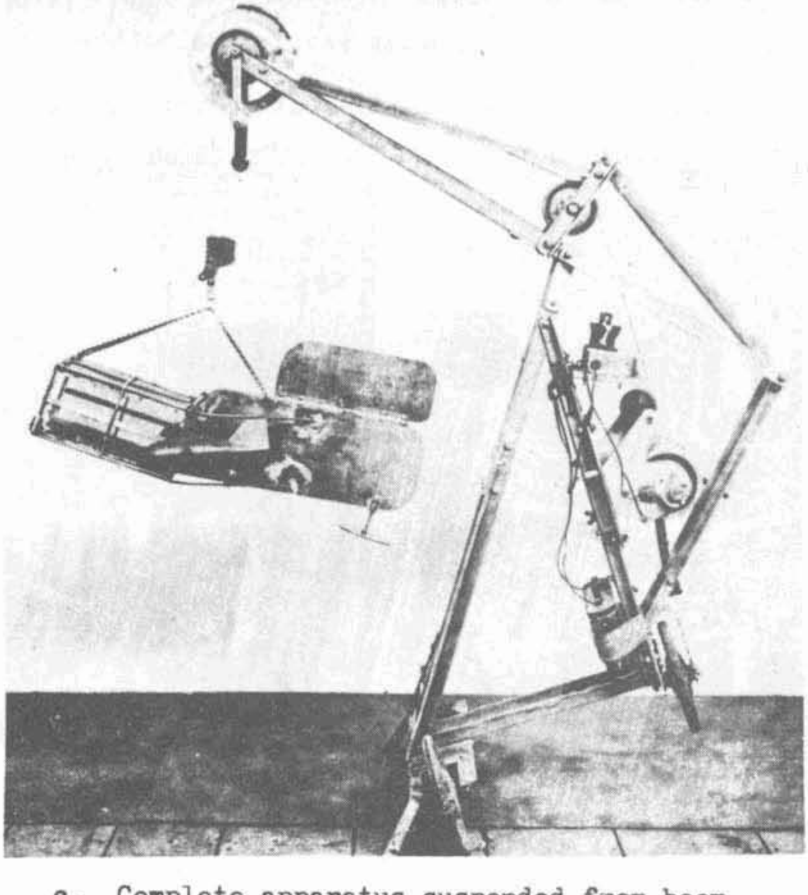
Probably the most intensive development of the basket type bed-load samplers has taken place in the last ten years in Germany and Switzerland. The different samplers used there are closely associated in development, each individual one representing merely a stage of improvement upon another sampler. One of the earlier German samplers of this series was the Mulhofer sampler (12), Fig. 8. This sampler was of the ordinary basket type, suspended from a cable and held in position by a stay wire. One distinguishing feature of the Mulhofer sampler was the metal plate above the entrance to the sampler which could be adjusted to form any angle with the longitudinal axis of the basket. The purpose of this plate, or



a. Sampling basket and frame unassembled.



b. Sampler assembled and resting on standards.



c. Complete apparatus suspended from boom.

Fig. 7--Sampler used by Rock Island U. S. Engineer District.

vane, was not definitely described, but it may have been intended to press the sampler to the bottom. The Mulhofer sampler was apparently intended for material ranging in size from 6 to 200 mm.

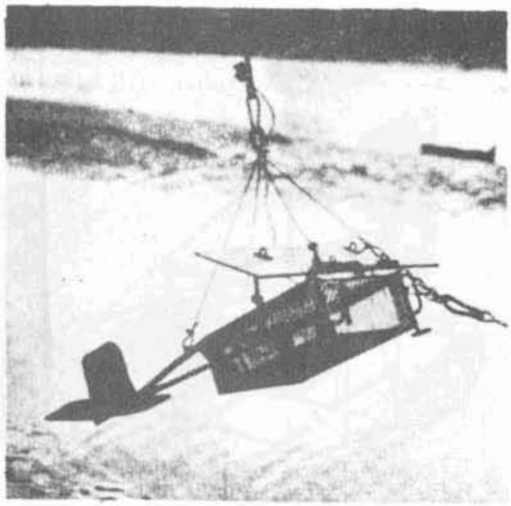
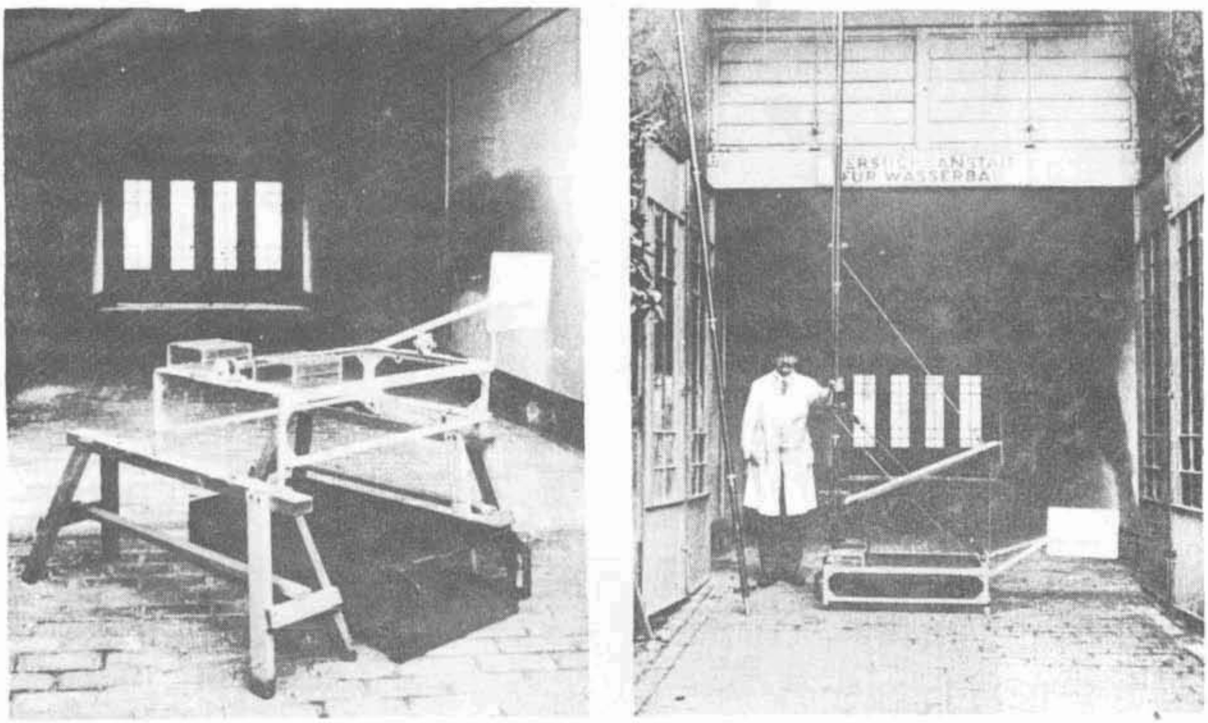


Fig. 8--Mulhofer sampler.

The Ehrenberger sampler, shown in Fig. 9, was used in the Danube at Vienna in 1931 (4,5). This sampler was somewhat similar to the types used by Mulhofer, being 1 m. long, 25 cm. high, and 50 cm. wide, with the sides, back and top of 4.5-mm. mesh. The principal improvement in this sampler was in the bottom, which was made of loosely interwoven iron rings to allow it to fit the stream bed. The



a. Frame and basket unassembled. b. Complete apparatus.

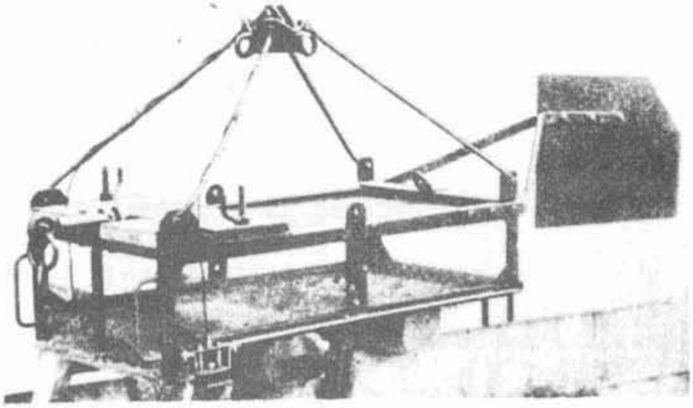
Fig. 9--Ehrenberger sampler.

lower front cross piece of the rigid frame to which the mesh was attached was 5 cm. lower than the remaining portion of the framework, thus insuring contact of the front edge with the stream bed. To determine whether bed-load movement occurred at a greater distance than 10 cm. above the stream bed, two small auxiliary traps were provided on the top of the frame. A metal vane held in an inclined position a short distance above the basket was provided to hold the sampler firmly on the stream bed. The sampler was suspended on a steel bar and operated from a boat.

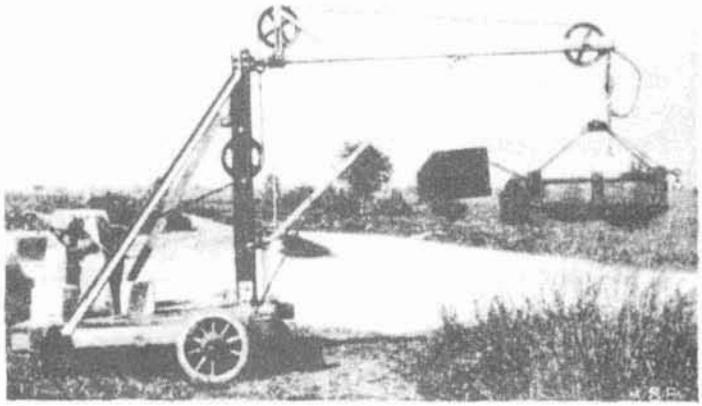
Ehrenberger found a definite periodicity in the wave-like movement of the bed-load, which corresponded temporally with the bottom velocity fluctuations. Because of this periodicity he considered it advisable to thoroughly sample a few verticals, rather than obtain meager data in a great number of verticals. Accordingly, samples were taken repeatedly at the same point for about 2 hr. Individual samples were taken with collecting times of 100 to 300 sec., depending upon the amount of bed-load movement.

The results of calibrations of the Ehrenberger sampler are given in Section 13. This sampler was apparently intended for material of 10 to 50 mm. diameter.

The Nesper sampler, shown in Fig. 10, which embodied most of the essential features of the Mulhofer and Ehrenberger samplers, was used for investigations of the Rhine River at Brugg, Germany (13). The sampling basket, shown in Fig. 10a, had an iron frame into which a sediment basket, 1 m. long, 50 cm. wide, and 25 cm. deep, was placed. The basket was covered with 4.5-mm. mesh. The front of the basket was weighted with iron plates to keep the sampler firmly on the stream bed and had a sharp cutting edge at the bottom. The bottom was similar to the Ehrenberger sampler, being constructed of loosely woven rings. Electric lamps which flashed the moment the basket touched the bed were used to obtain an accurate record of the filling time. The basket was suspended by a cable from a boom mounted on a truck, as shown in Fig. 10b, and was operated from a bridge. The sampler was braced by a line from a cable car located at a section 100 ft. upstream from the bridge. The weight of the sampling basket was 75 kg. (165 lbs.).



a. Sampling basket.



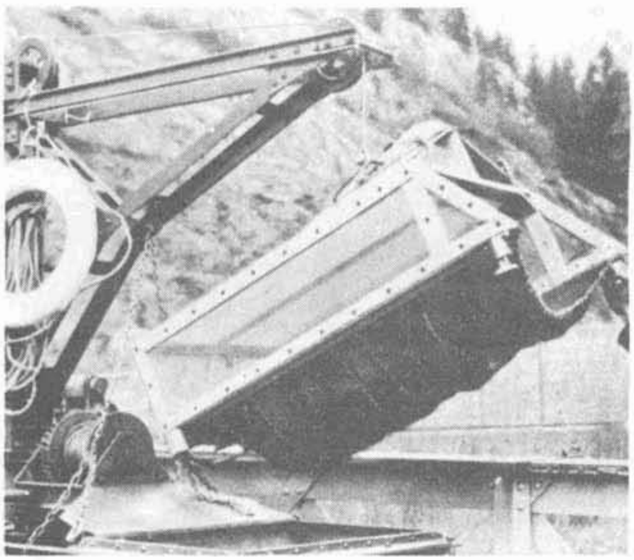
b. Sampler suspended from crane on movable truck.

Fig. 10--Nesper sampler.

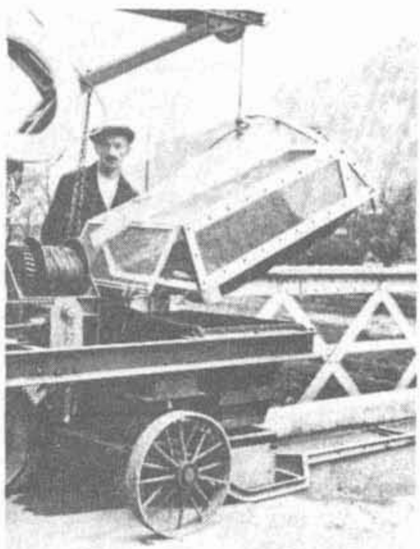
Calibrations of the Nesper sampler, which were performed for material ranging in size from 3.7 to 12 mm., are described in Section 12. The field technique with this sampler consisted of taking 15 to 30 samples at each sampling point in order to compensate for the wave-like movement of the bed-load. The samples were taken over periods of 1 to 2 min. duration.

The non-rigid suspension of the Nesper sampler was found to be the cause of considerable digging. Since the water velocity was less near the bottom, a decreasing downstream force was exerted on the box as it was lowered and if the suspension apparatus was elastic the box tended to move upstream. This forward movement caused bottom material to be loosened and scooped into the basket, thereby increasing the catch over that resulting from the bed-load movement only.

Fig. 11 shows a sampler used by the Swiss Federal Authority for Water Utilization (16) which contains modified features of the Mulhofer, Nesper, and Ehrenberger samplers. In this sampler the mesh basket was not removable, the trapped material being emptied through a hinged door at the rear. The bottom of the trap was constructed of loosely interwoven rings as in the Ehrenberger and Nesper samplers, but differed in that the front of the mesh bottom was not rigid, the intention being to avoid digging effects. This sampler omitted the metal vane attached above as in the Ehrenberger sampler. The apparatus was suspended from a cable, with stay wires holding it in position. The location of the stay wires was determined by trial and error to find the position best suited to avoid



a. Sampling basket.



b. Complete apparatus on truck.

Fig. 11--Sampler used by the Swiss Federal Authority for Water Utilization.

horizontal movement of the basket. The sampler was lowered with the tail touching bottom first in order to avoid digging. The front of the sampler had a free opening of 70 by 30 cm., was 130 cm. in length, and weighed 140 kg. (308 lbs.). The material for which the Swiss apparatus was used varied in size from 3.75 to 250 mm. The results of calibrations performed on this sampler are described in Section 14.

8. Tray or pan type--This type has been used most extensively in Russia where considerable study has been made and several designs are prevalent. However, its use has not been entirely limited to that country.

Fig. 12 shows a tray type sampler used in San Francisco Bay at Chipps Island by the San Francisco U. S. Engineer District in 1930 to determine the material moved by the tides. This sampler consisted merely of a flat pan divided into compartments by transverse vertical strips of sheet metal which were intended to trap the moving material. Since the flow reversed direction due to the tides, the pan was made symmetrical about a transverse center line.

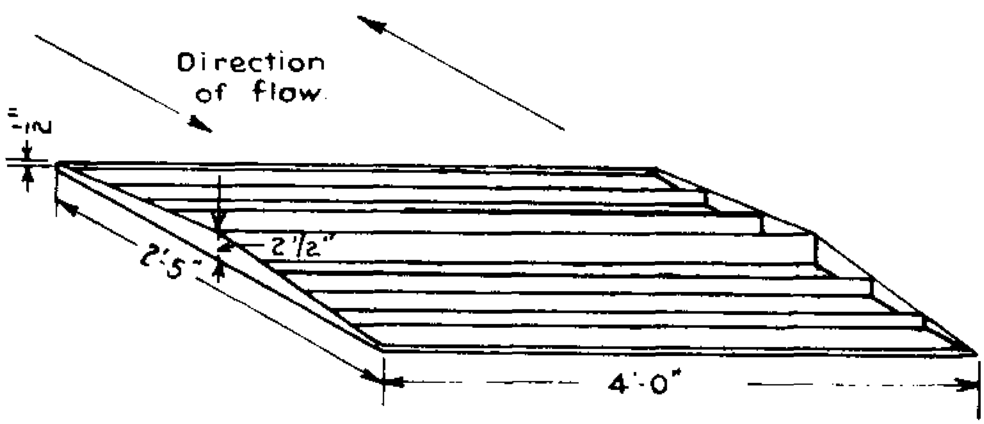


Fig. 12--Sampler of San Francisco U. S. Engineer District.

Fig. 13 shows the Losievsky sampler which has been used in Russia (15). This sampler consisted primarily of a flat wedge-shaped pan

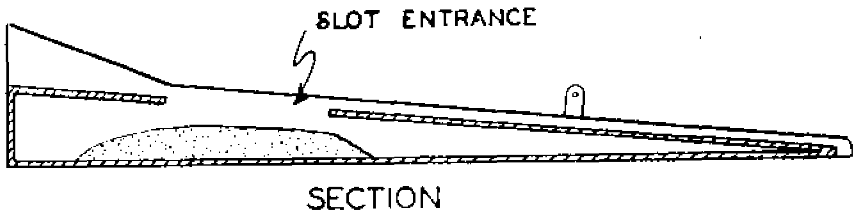


Fig. 13--Losievsky sampler.

container pointing upstream, thus forming an upward slope on the top of the container. The bed-load material moved up the slope and dropped into the container through a slot entrance in the top.

Fig. 14 shows another Russian sampler known as the Polyakov sampler (15). This sampler was also wedge shaped but the rear portion of the pan

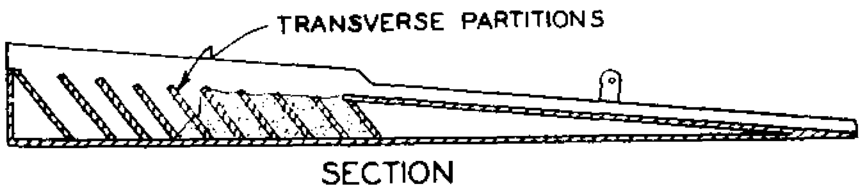


Fig. 14--Polyakov sampler.

was open at the top and divided by transverse strips of metal sloping at an angle of 45 degrees toward the rear. The material moved up the sloping front and was trapped by the partitions in the pan.

The sampler of the Scientific Research Institute of Hydrotechnics (Russia), Fig. 15, has many of the features of the pan type, but since the entrance conditions correspond to the pressure-difference type, it will be described with others of that group in Section 9. The results of calibrations of the Losievsky, Polyakov, and Scientific Research Institute of Hydrotechnics samplers are given in Section 11.

9. Pressure-difference type--The first sampler using the principle of pressure difference of which information is available was one made by Gontcharoff (8), and used on the Kuban River in 1925. This sampler consisted of a diverging iron box, 50 cm. in length, with the ratio of area at the exit to that at the entrance being about 2.5. The box had a 1:15 and 1:30 bottom slope upward from the entrance, with corresponding slopes downward from the middle to the exit. In this manner the entrance was at the bed at all times. The material was detained in the box either by baffles or screens. The large ratio of exit to entrance areas caused considerable decrease in velocity at the rear and hence much of the material was deposited without the use of the screen. The apparatus was rigidly suspended from a point near the entrance end.

Gontcharoff found that slight deviations of the axis of the box from the direction of stream flow caused considerable decrease in bed-load movement through the box. For deviations of 15 degrees it was observed that flow through the box ceased entirely. It was impossible in his investigations to estimate the direction of bottom flow as accurately as necessary to obtain good results. Therefore, a collapsible bag, suspended sediment sampler of the type developed by Gluschkov*, capable of measuring stream velocity, was set up at the center of the exit. By adjusting the direction of the box so that the velocity through it was a maximum, the true direction of flow could be reached. Generally, the second set-up would accomplish this reasonably well.

The field technique of Gontcharoff's investigations consisted of

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*Described in preceding report, "Field Practice and Equipment Used in Sampling Suspended Sediment."

10-min. sampling periods at each of 4 to 8 sampling points in a river 130 to 165 ft. in width.

Another Russian sampler embodying some of the principles of the pressure-difference type and some of the tray type was the sampler of the Scientific Research Institute of Hydrotechnics (15), which is shown in Fig. 15. This sampler was somewhat similar to the Polyakov sampler,

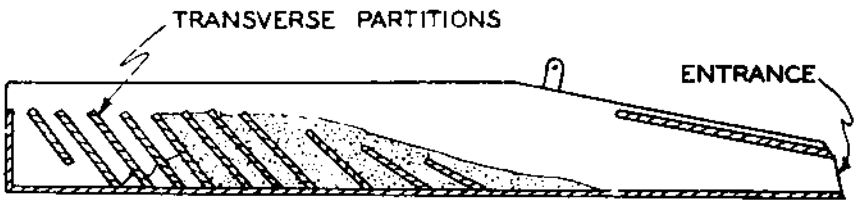


Fig. 15--Sampler of the Scientific Research Institute of Hydrotechnics.

shown in Fig. 14, in that it consisted of a flat pan with transverse partitions sloping toward the rear to trap the moving material. However, the entrance was at the front of the pan and the entrance section diverged toward the rear, creating a suction and consequently greater intake velocity, possibly approaching that of the undisturbed stream. This sampler was claimed to be quite satisfactory.

Fig. 16 shows a sampler developed by Jack M. Terry of the U. S. Geological Survey in 1935 and used a few times experimentally. The sampler consisted of a rectangular entrance flume and a round

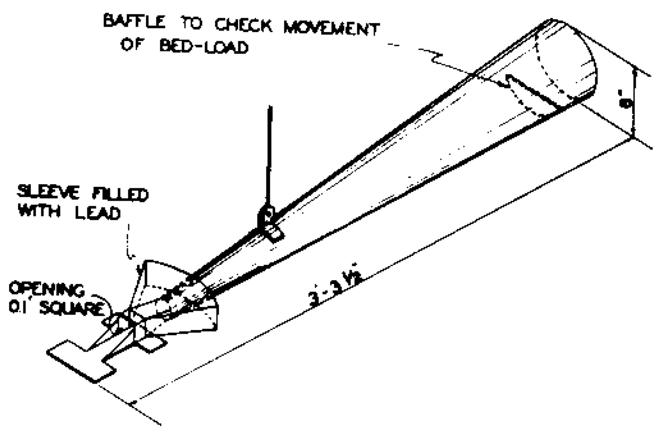
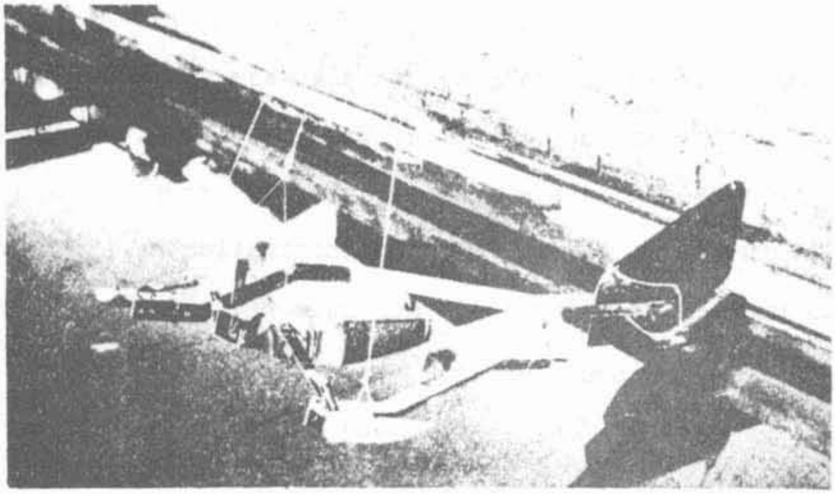


Fig. 16--Terry sampler.

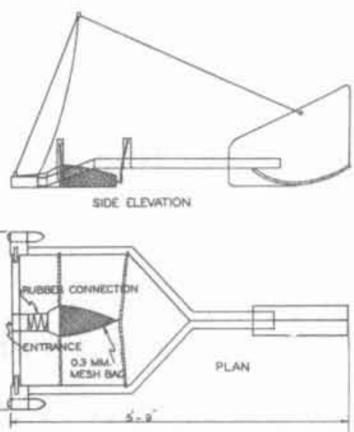
funnel diverging toward the rear. The decreased velocity toward the rear of the funnel caused the material to be deposited in front of a check baffle. The funnel was apparently satisfactory from the standpoint of the deposition of material but experiments were discontinued due to the difficulty of getting the entrance flume flush with the stream bed when the material was moving in riffles. Two sizes of entrance flume, 0.1 and 0.4 ft. square, were used. Although this sampler was used only experimentally, the principle of an entrance flume and diverging section was regarded as promising.

The Hydraulic Structures Bureau of the upper section of the Rhine River at Arnhem, Holland (14), designed a sampler using the pressure-drop principle which is claimed to have 100 per cent efficiency. This device, shown in Fig. 17, is known as the Arnhem or Dutch sampler. The apparatus was designed with a rigid entrance connected to a bag of 0.2 to 0.3-mm. mesh by a rubber section. The rubber section diverged from the entrance, creating a pressure drop, and a resultant increased entrance velocity with which to transport material into the mesh bag where it was collected. The design was adjusted so the pressure difference would be sufficient to overcome the energy loss through the apparatus; thus, the entrance velocity was intended to be the same as that of the undisturbed stream.

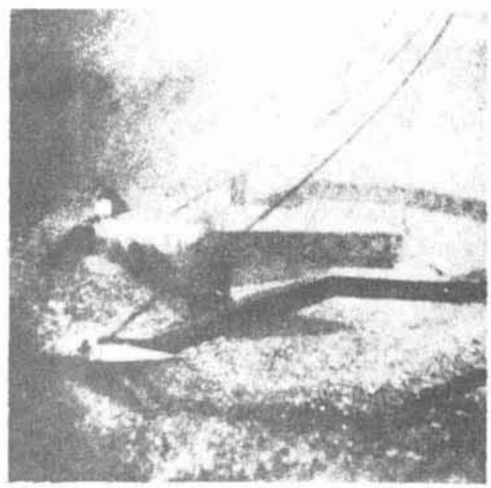
The collecting apparatus was fixed to a large framework by springs in such a manner that the entrance was pressed upon the bottom when the sampler was lowered to the bed. In lowering the apparatus the curved section of the rudder was brought into contact with the stream bed first and all the weight was placed on it, after which the front end was lowered. This method of support and of lowering was intended to reduce



a. View of complete sampler.



b. Sketch of sampler.



c. View of sampler in operation.

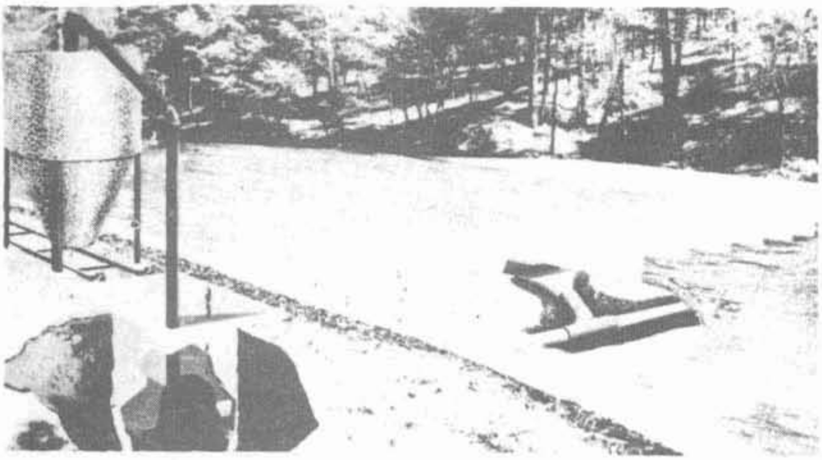
Fig. 17--Arnhem or Dutch sampler.

the possibility of digging or disturbing the material on the bed.

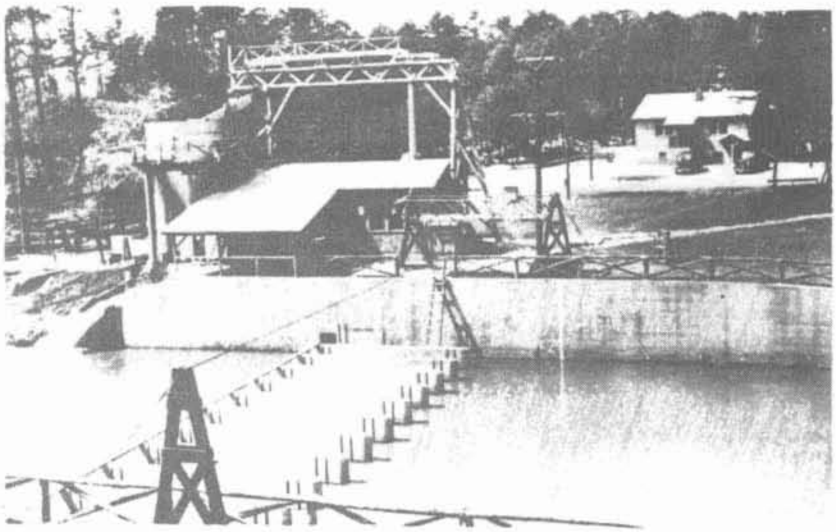
Several possible sources of error in the Dutch sampler were recognized by its users. If the bag was filled too full, the energy loss became larger due to clogging of the mesh and the efficiency of the sampler was decreased. When the apparatus was lowered to the bottom and the bag came to rest on the downstream side of a steep sand hill with the entrance at the top of the hill, the tail would be in an eddy and very little pressure difference might result. In such a case the efficiency would also be decreased.

The material in which the Dutch sampler was used was fine, being for the most part between the limits of 0.2 and 2.0 mm. in diameter. As a check on the bed-load determinations of this sampler, in places where local conditions were favorable, a determination of the total bed-load movement was made by dredging a cut across a river and measuring the rate of filling by repeated soundings.

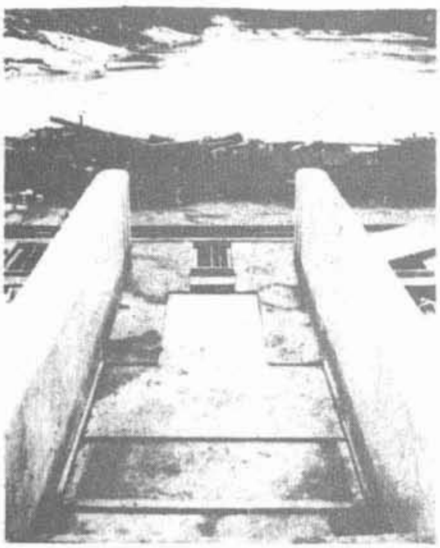
10. Slot type--The Soil Conservation Service Experiment Station (3) at Greenville, South Carolina, has constructed a very elaborate apparatus to measure the rate of bed-load transportation by the Enoree River as shown in Fig. 18. Fig. 18a, an artist's conception of the working arrangement, and Fig. 18b, an actual photograph, show the character and extensiveness of the installation. The entire width of the river bed for a length of about 100 ft. is paved with concrete. Near the lower end of this pavement the river is divided by vane walls into 14 sub-channels, 5 ft. wide. In the bottom of each sub-channel is a slot with a sliding door, as shown in Fig. 18c, which can be opened or closed as desired. Bed-load material drops into the slot when open and is pumped through a pipe beneath the floor to a hopper on the bank. This hopper has an overflow spillway over which the water wastes, while the heavier material which has been transported as bed-load falls to the bottom of the hopper. The rate of bed-load movement is determined by measuring the amount of material collected in a given time. This apparatus is being used not only to determine the bed-load movement in the river, but also to determine the efficiencies of various types of bed-load samplers.



a. Artist's conception of apparatus.



b. View of actual apparatus.



c. Door to slot in closed position.

Fig. 18--Bed-load collecting apparatus used by the Soil Conservation Service Experiment Station, Enoree River, Greenville, South Carolina.

Mulhofer (12) described a bed-load sampling device used for the River Inn, Germany. Six slots, each 1 m. deep, and approximately 1 m. long and 20 cm. wide, were constructed, as shown in Fig. 19, in a gravel bar which became inundated only during high stages. When the river rose to a stage high enough to overflow the bar, the slots were filled with the material being transported as bed-load. This apparatus was not capable of measuring the rate of bed-load movement, giving only a sample of the material moving in that manner during high stages.

Fig. 19--Mulhofer slot traps.

III. CALIBRATIONS OF BED-LOAD SAMPLERS

11. Shamov calibrations--G. I. Shamov (15) conducted laboratory tests on the Losievsky, Polyakov, and Scientific Research Institute of Hydrotechnics samplers to determine their efficiencies. Models of the samplers were placed in a flume in which the true rate of bed-load movement was determined volumetrically by a trap at the end of the flume. The sampler of the Scientific Research Institute of Hydrotechnics was found to be the better, having an average efficiency of 75 per cent as compared with 46 per cent for the Polyakov sampler and 38 per cent for the Losievsky sampler.

Shamov concluded that the low catch in the Losievsky and Polyakov samplers was due mainly to the inclined surface leading to the entrance. Mounds of material formed on the inclined surface and although some of the material rolled over the mounds into the sampler, other grains rolled in a transverse direction away from the sampler, thus reducing the catch. The transverse inclined baffles in the Polyakov sampler were found to be more effective in catching and holding the material than the slot opening of the Losievsky sampler, which caused whirlpools to form above the opening.

The Scientific Research Institute of Hydrotechnics sampler was more satisfactory because the mounds did not form with the entrance at the front of the sampler. In addition, the efficiency was probably aided by the diverging entrance which caused a suction, thereby increasing the entrance velocity to a value more nearly that of the undisturbed stream.

In the tests it was found that the efficiency increased with increases of stream velocity from 1.3 to 1.75 ft. per sec. With increases of velocity beyond 2.1 ft. per sec. the efficiency decreased markedly. This was judged to be due partially to the increase in size of the whirlpools, causing some of the particles to be thrown away from the sampler, and also to the fact that the mode of transport of some of the sand changed from bed-load to suspended movement.

12. Einstein calibrations--Dr. H. A. Einstein (6) performed tests on the Nesper sampler at the Zurich Hydraulic Experiment Station to determine its efficiency. Models built to scales of 1:10, 1:5, and 1:2.5, Fig. 20, were tested in a laboratory flume where the actual bed-load movement was determined by a trap at the end of the flume.

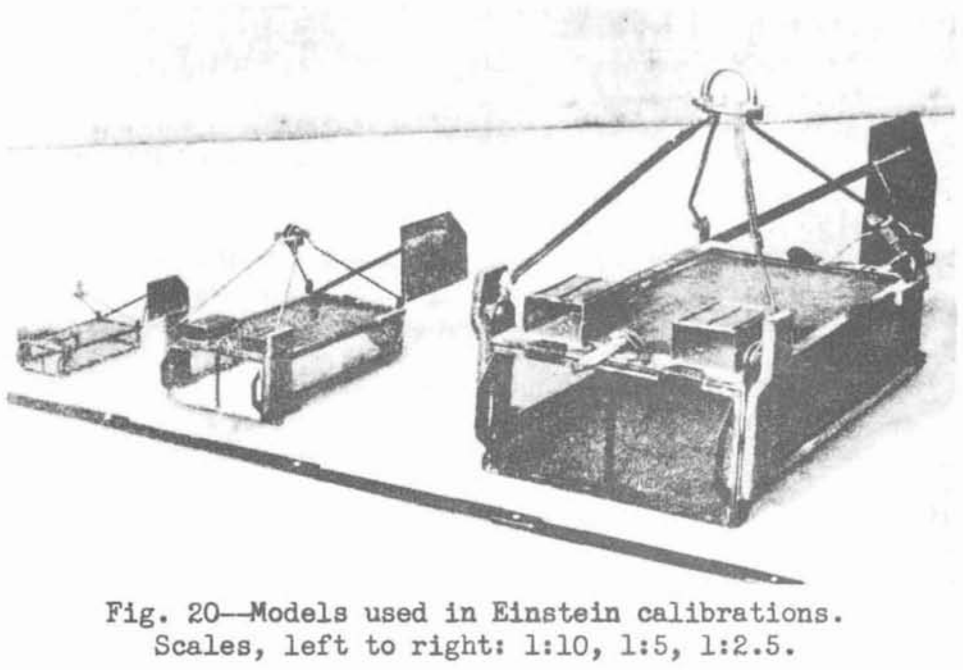


Fig. 20--Models used in Einstein calibrations.
Scales, left to right: 1:10, 1:5, 1:2.5.

Dr. Einstein determined the efficiency of the models, which were rigidly suspended to avoid movement, varying the total bed-load movement, particle size, and depth of water. Definite conclusions could not be drawn from the resulting data regarding the correlation of these factors. However, it was found that, in general, the tendency prevailed for the model to catch more of the large particles with low rates of bed-load movement and more of the fine particles with high rates of bed-load movement. In other words, for high rates of bed-load movement the efficiency decreased with increasing particle size, while for low rates of bed-load movement the efficiency increased with increasing particle size. As a result of all the laboratory calibrations, a mean efficiency of 45 per cent was determined for the Nesper sampler. This efficiency varied considerably for short individual determinations, but it was indicated that over a sufficiently long sampling period it would give values which were reasonably satisfactory. The tests also indicated that the basket should not be filled to more than one-third of its capacity, as a greater loss of material was experienced when filled beyond this amount.

Laboratory tests were also run on the model while it was suspended non-rigidly in the same manner as in the field measurements at Brugg. As explained previously, the basket would tend to swing back upstream upon reaching the stream bed if there was elasticity in the suspension apparatus. This forward movement caused a digging action and an apparent increased efficiency. The laboratory experiments showed a forward movement equivalent to a distance of 7 to 10 cm. in nature, which resulted in absurd "efficiencies" of as much as 200 per cent. It was impossible, however, to accurately calibrate the trap while it was subject to digging tendencies. Because of such inconsistencies in the efficiency of the non-rigidly suspended sampler, the rigidly suspended apparatus was recommended as likely to give much more reliable results.

The wave-like movement of the bed-load, which is a source of inaccuracy in measurements made with a short filling time, was indicated by observing the material trapped at the end of the flume at different intervals. Fig. 21 shows the variation in rate of movement during a 1-hr. period. Fig. 22 shows the size analysis and rate of movement of the mean samples obtained in each 2-hr. period over a total testing time of 80 hr. This figure indicates that a long period of fluctuation in rate of movement may occur in addition to short fluctuations. In these experiments a complete cycle, or period of fluctuation, occurred about once every 16 hr.

13. Ehrenberger calibrations--Ehrenberger (5) performed laboratory tests on his sampler to determine its efficiency. Complete details are not available regarding these experiments but it is believed that his calibrations were not as thorough as those on the Nesper sampler by Dr. Einstein.

Figs. 23 and 24 show the results of the Ehrenberger calibrations in graphical form. Fig. 23 shows the variation of efficiency as a function of bottom velocity and the per cent of total capacity to which the basket was filled, while Fig. 24 shows the variation of the efficiency as a function of the bottom velocity and particle size. The efficiency found in these experiments seems quite high when compared to the efficiencies of other samplers of very similar design, which is probably due to the fact that the tests were carried out on a metal floor as contrasted with sand beds used in other tests.

14. Swiss calibrations--The Swiss Federal Authority for Water Utilization (16) made a thorough study and calibration of their sampler, consisting of laboratory investigations with a 1:2.5 scale model supplemented by field measurements with the actual sampler.

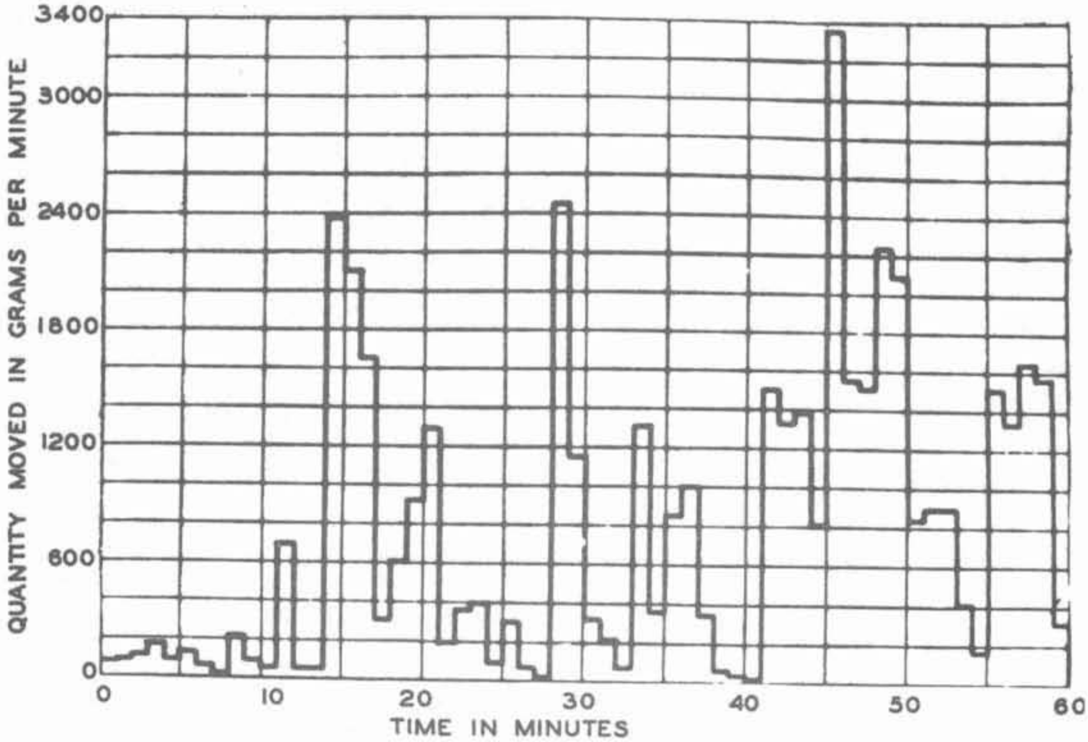


Fig. 21--Variation in rate of bed-load movement over period of 1 hr.

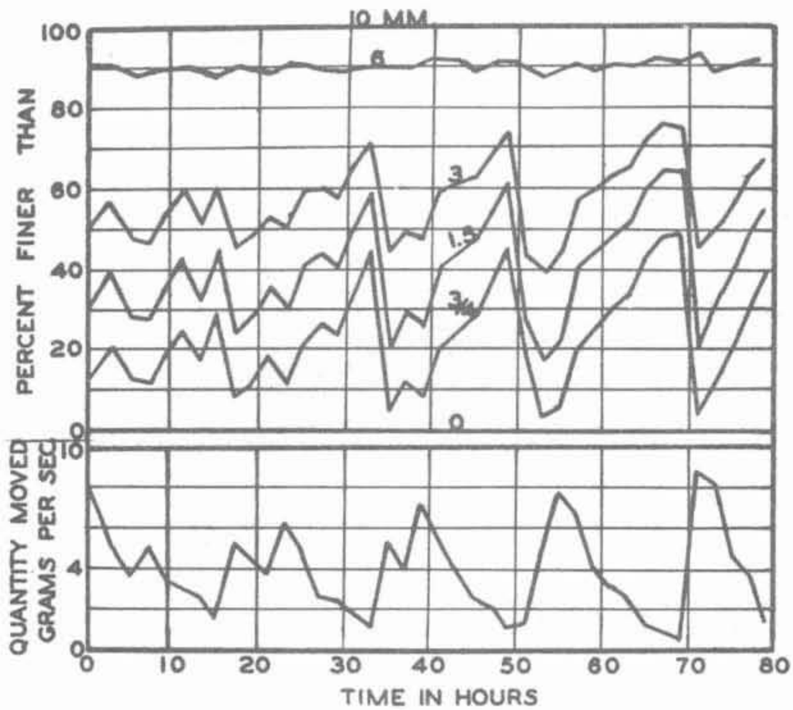


Fig. 22--Rate of movement and size analysis of mean of 2-hr. sampling periods, over a total period of 80 hr.

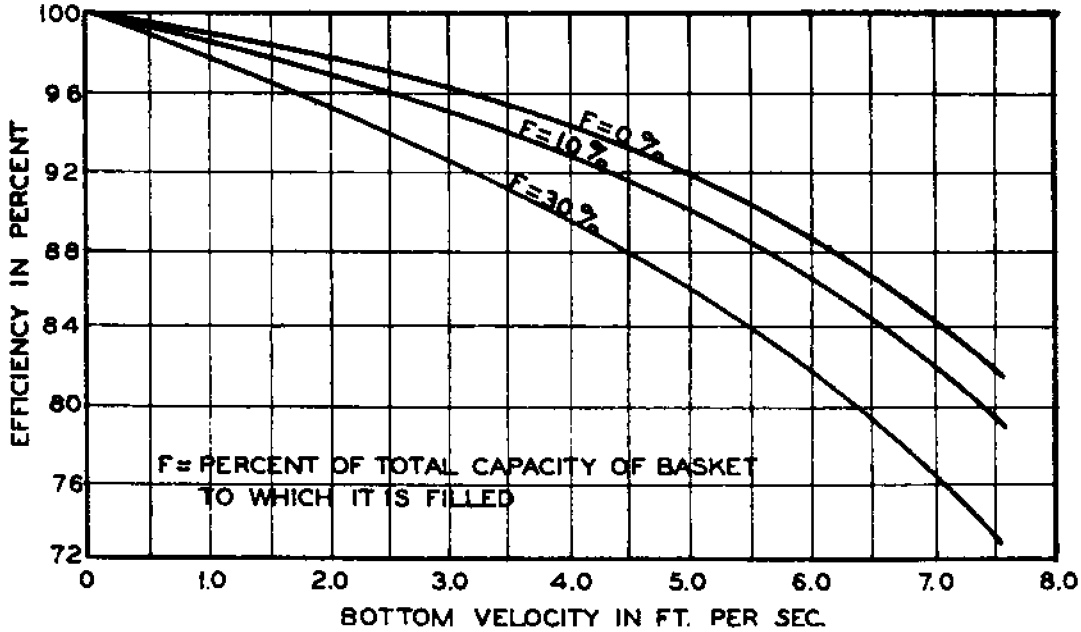


Fig. 23--Efficiency of Ehrenberger sampler as a function of bottom velocity and degree of filling.

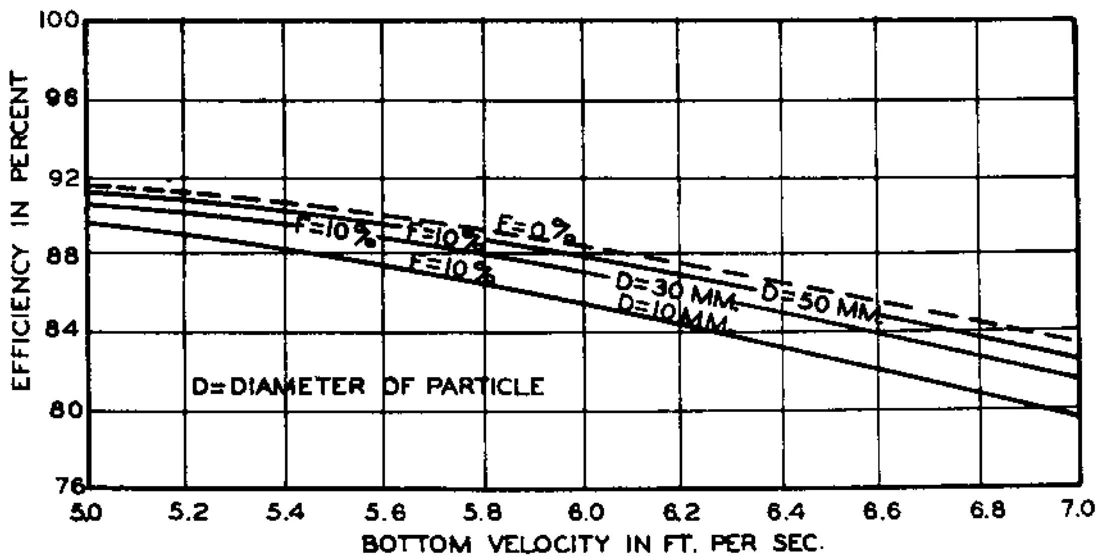


Fig. 24--Efficiency of Enrenberger sampler as a function of bottom velocity and particle size.

The laboratory calibrations consisted of determinations of the efficiency of the sampler with varying sampling durations and rates of bed-load movement. A calibration curve for field conditions was then computed, translating the laboratory sampling period into the sampling duration in the field on the basis of the Froude law. Fig. 25 shows the efficiency of the sampler as a function of sampling duration and rate of bed-load movement. As seen in the figure the efficiency was found to increase with increasing sampling duration. This may have been due to a point of stabilization in movement of material in the vicinity of the sampler being

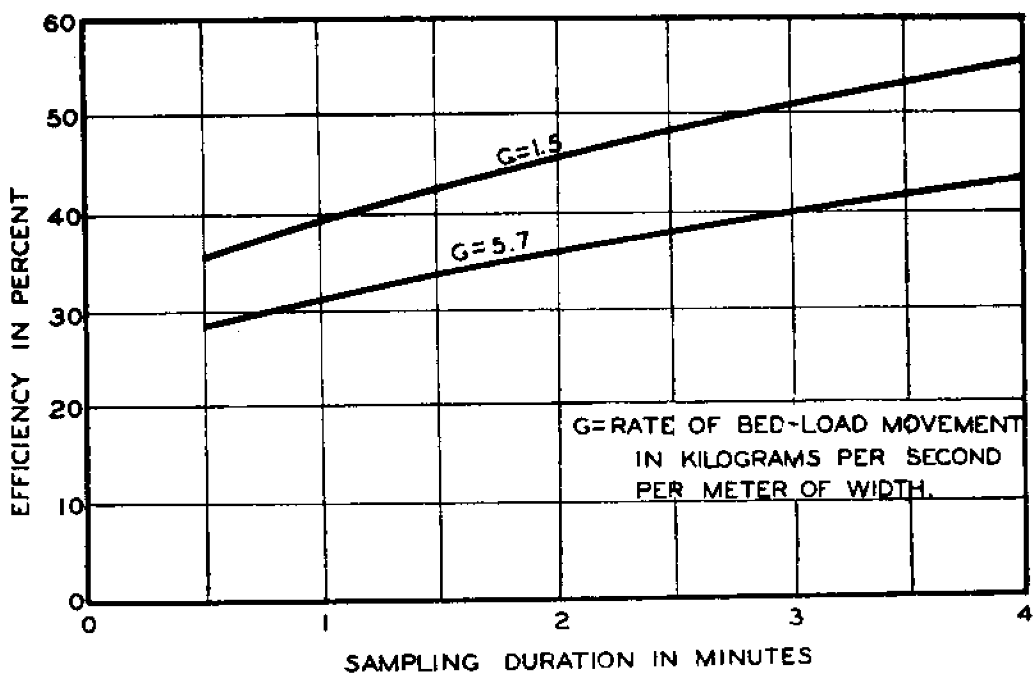


Fig. 25—Efficiency of Swiss sampler as a function of sampling duration and rate of bed-load movement.

approached after it had been in place for some time. This possibility is evident from the following considerations. When a sampler is first placed in the sampling position considerable disturbance of flow is caused which may become less as the material fills in around the entrance to the sampler.

In addition, if the sampler entrance does not entirely fit the shape of the stream bed, some of the material transported during the first stages of sampling will fill up the cavities at the entrance, thus decreasing the catch during that period. These factors would tend to produce the effect shown by the curve. The efficiency was also found to decrease with increasing rates of bed-load movement.

To determine the reliability of the laboratory calibrations, a comparison was made of the hydraulic resistance offered by the model in the laboratory to that determined for the actual sampler by field measurements. The coefficient in the formula for hydraulic resistance was found to be 1.2 in the field as compared with 1.1 in the laboratory. Because of this relatively close agreement the tests were reported to be quite reliable.

A study was also made to compare the results obtained in the field with and without bracing cables. It was found that in this particular case the use of bracing cables did not materially change the results. This was probably due to the type of material encountered, which resisted digging, but the absence of a rigid front or cutting edge on the bottom of the sampler may also have been the cause of this desirable effect.

IV. BED MATERIAL SAMPLERS

15. Classification of bed material samplers--Bed material samplers, that is, those collecting a sample of the material present on the stream bed, can be grouped in several general classifications, based on similarity of construction and operation.

The most common class is the drag bucket type. Samplers of this class consist essentially of some type of weighted bucket with a cutting edge. The bucket is lowered to the stream bed and dragged along it by means of a tow line operated from a boat, cutting a sample from the stream bed. Generally these samplers are intended to collect a layer of only 1/2 to 2 in. thickness from the stream bed. Samplers of this class are discussed in Section 16.

Another group which has been used considerably is the vertical type. Samplers of this class consist of a pipe, tube or inverted cone which is thrust or forced by its own weight vertically into the stream bed to cut a sample of its material. The sample may be held in the container upon raising by different means, such as a partial vacuum or a valve which closes automatically. This class might also be extended to include core drilling apparatus, but considering the scope of this project, the discussion of this group, given in Section 17, is limited to those which penetrate the stream bed only a few inches.

The grab bucket types, described in Section 18, have been used somewhat less extensively. These samplers are somewhat similar to the clamshell bucket which has been widely used in earthwork operations, but are much smaller. The cupped jaws which upon reaching the bottom, close together to collect bed material may be closed either by a pull on an auxiliary line or by an automatic spring arrangement.

16. Drag bucket type--Fig. 26 shows the first known sampler of this common type, which was used by the Mississippi River Commission in its investigations in 1879. This consisted of a bucket, perforated to allow water to escape while being dragged along the bottom. The tow line was connected to a weighted sphere, which in turn was connected to the bucket, tending to cause the dragging force to be exerted in a direction parallel to the stream bed.

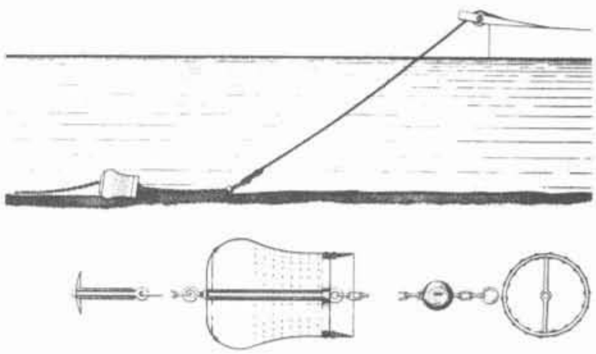


Fig. 26--Mississippi River Commission dredge bucket.

The Mann sampler (9), shown in Fig. 27, consists of an iron tube about 4 in. in diameter and 6 to 8 in. long, closed at one end, with a tow line attached at the other. A modified form of this sampler has been used with a tough rubber sack closing the after end.

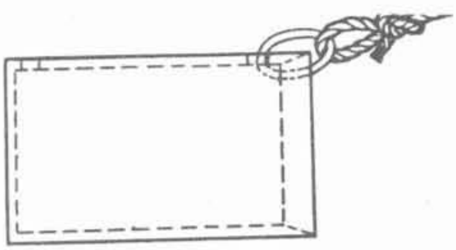


Fig. 27--Mann sampler

Fig. 28 shows a sampler used by the U. S. Waterways Experiment Station, Vicksburg, Mississippi (18). It consisted of a steel pipe 4 in. in diameter and 4 ft. long, capped on the after end, and flaring at the forward end to a diameter of about 8 in. This device

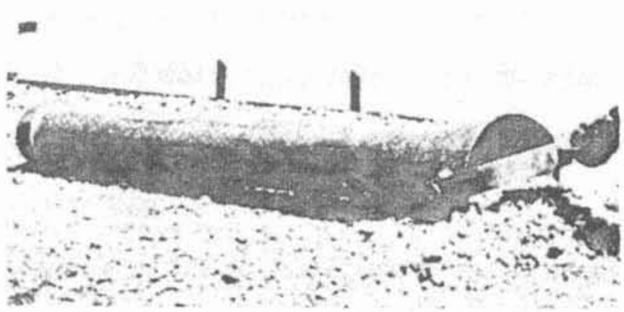


Fig. 28--U. S. Waterways Experiment Station sampler.

was attached by means of a bail to a tow line. In using the sampler, it was found that it operated best when dragged in a downstream direction since when dragged upstream, the force of the current on the line tended to pull the mouth of the sampler off the bottom.

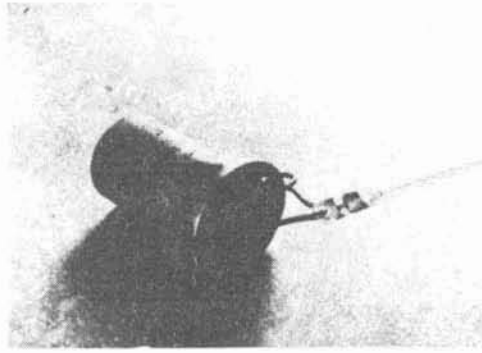


Fig. 29--St. Paul sampler.

The St. Paul sampler, shown in Fig. 29, used for investigations in the Upper Mississippi River in 1937, was similar to the U. S. Waterways Experiment Station sampler, though much shorter. The mouth of the sampler was flared in order to have the cutting edge on the river bed at all times.

Fig. 30 shows a sampler used by Professor Russell in the shallow water of the Mississippi River delta. He found it to be very satisfactory under the conditions in which it was operated. This sampler was similar in design to the U. S. Waterways Experiment Station sampler, except that it did not have the flared edge at the mouth. The bail was connected toward the center of the pipe so that the weight of the front of the pipe tended to keep the mouth on the bottom.

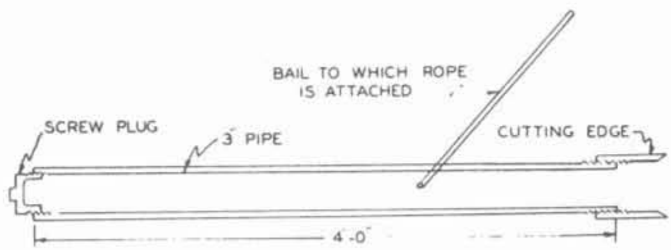
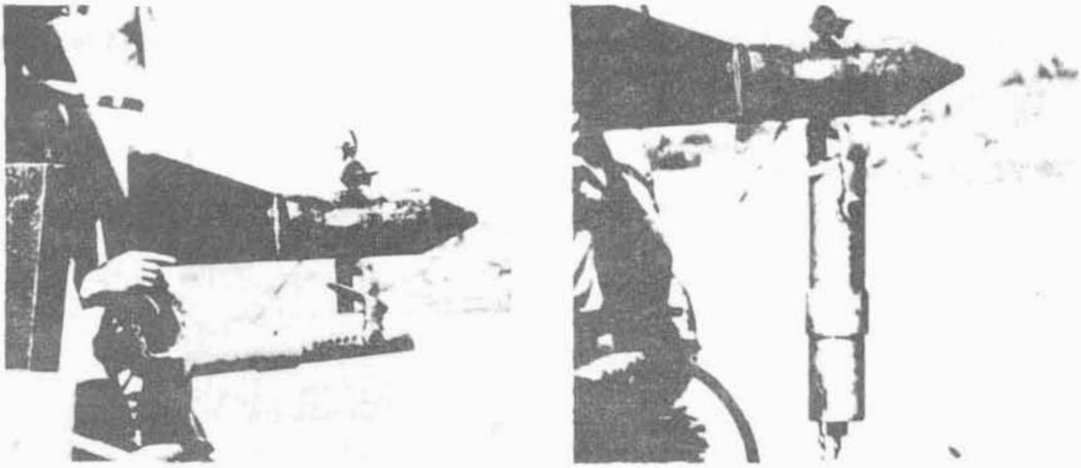


Fig. 30--Russell sampler.

The Vicksburg U. S. Engineer District sampler, shown in Fig. 31, consists essentially of a pipe with a cutting edge, suspended below a weight or the suspended sediment sampler known as the Vicksburg horizontal toggle trap*. The sampling pipe is attached to the suspended sediment sampler or weight by a bail near its front end, so that when it is brought



a. Sampling position. b. Position after sampling.

Fig. 31--Sampler used by Vicksburg U. S. Engineer District.

to the surface after sampling, the pipe rotates to have its cutting end at the top. The rotation closes a lid over the cutting end, thus keeping the sample from falling out.

The Lugn sampler, shown in Fig. 32, used for investigations in the upper Mississippi River in 1925 (11), was the first of a series of drag buckets designed to scoop the bottom to a constant depth. This sampler consisted of two weights rigidly attached to a central stem, and a loose fitting cylinder with cutting edge, which seated on a shoulder on the lower weight. In dragging along the bottom, the forward weight tended to keep the front end from being lifted off the

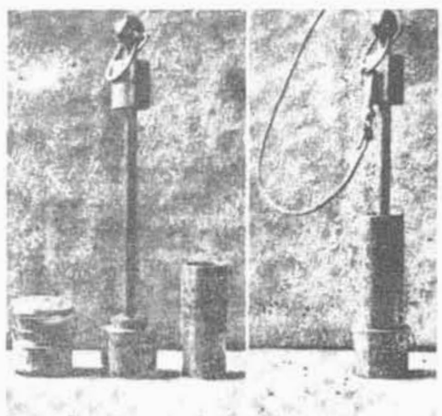


Fig. 32--Lugn sampler.

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*Described in preceding report, "Field Practice and Equipment Used in Sampling Suspended Sediment."

bottom. Thus the central stem was kept at a more or less constant distance off the bottom, and as a result the cutting cylinder scooped a layer of fairly constant depth.

Many samplers of designs similar to the Lugn sampler have been used. The Straub Missouri River sampler (17), shown in Fig. 33, was almost identical in design to the Lugn, though much larger. In the Ft. Peck sampler, shown in Fig. 34, the forward weight is omitted and the cutting cylinder slides down over guide rods to seat upon a base plate. In the Rock Island sampler, shown in Fig. 35, the lower weight and cylinder are held together by a clamp which may be loosened to allow the weight to slip down into a jar, thus giving a convenient method of emptying the cylinder. In the simplified Rock Island sampler, Fig. 36, the cutting cylinder and the base form a complete unit, hinging upon the central stem.

17. Vertical type--Fig. 37 shows a pipe sampler used in the Imperial Valley Canals prior to 1928 (7). It consisted of a short section of pipe threaded into a cone section which prevented the sampler from being thrust too far into the bed. A 1/2-in. pipe extending above the cone and capped at the end, was used as a handle. After the lower pipe was driven into the bed, the handle pipe was filled with water and capped, forming, as it was withdrawn from the bottom, a partial vacuum which held the material in the sampler.

Fig. 38 shows a sampler used by the Missouri River U. S. Engineer Division (17) in 1929-30. This sampler consisted of a square sheet iron tube containing a pair of check valves at the bottom. An extension handle at the upper end could be adjusted to the length desired for different depths of water. The sampler was thrust into the stream bed and, upon

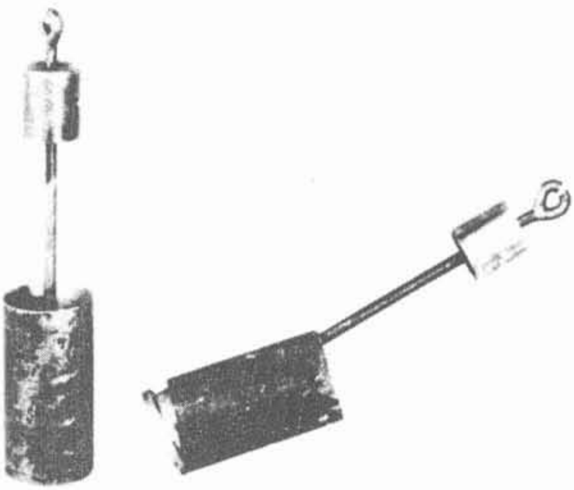
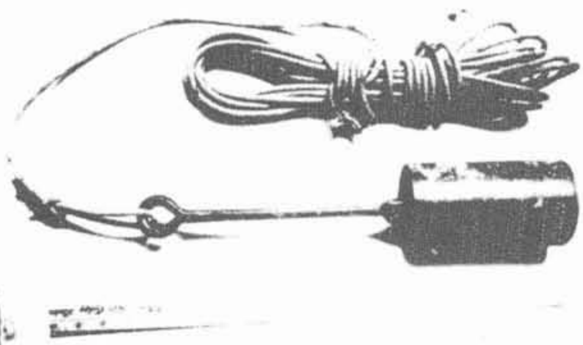
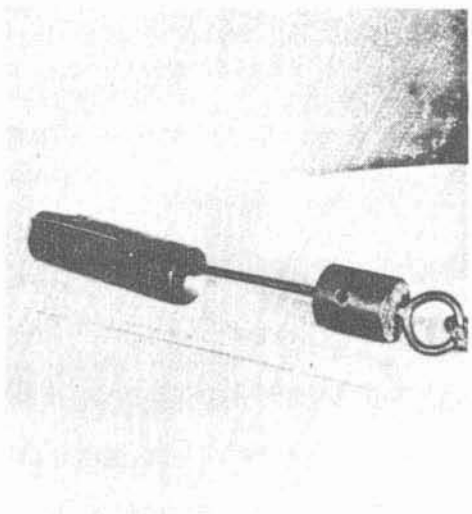


Fig. 33--Straub Missouri River drag bucket sampler.

Fig. 34--Ft. Peck sampler.





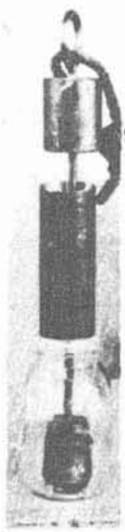
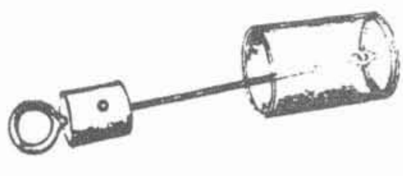


Fig. 35--Rock Island sampler.

Fig. 36--Simplified Rock Island sampler.



raising, the material was held in the tube by the check valves. This device, developed by Dr. Straub, was used primarily for determining the unit weight of natural deposits, and its use was limited largely to fine, freshly deposited material.

The valve lead (9), shown in Fig. 39, consists of a long, slender weight having at its base a cylinder that collects a sample of the bed. The lower end of the cylinder is fitted with a butterfly valve, which admits sediment and retains it in the tube. The sampler is thrust into the stream bed by its own weight, and the cylinder is perforated at its upper end to allow water to escape as the sampler penetrates the bottom. The cylinder is detachable so that it can be easily emptied.

The cup lead, or Stellwagen cup (9), shown in Fig. 40, consists of a lead weight, with an inverted hollow cone about 2 to 3 in. below the base of the weight and connected to it by an iron spike. A stiff leather washer is mounted loosely on the spike between the cone and the base of the weight. The sampler is dropped through the water and due to its own weight is thrust into the stream bed, the force of the water holding the washer up so the cone will be open to fill with bottom material. In raising the sampler, the force of the water holds the washer down on the cone and keeps the material from being washed out.

18. Grab bucket type--Samplers of this type are very similar in operation, consisting of cupped jaws which are closed at the stream bed to trap a sample of the bed material. A disadvantage common to this type is the possibility of large particles becoming caught between the closed jaws, allowing some of the fine material to escape.

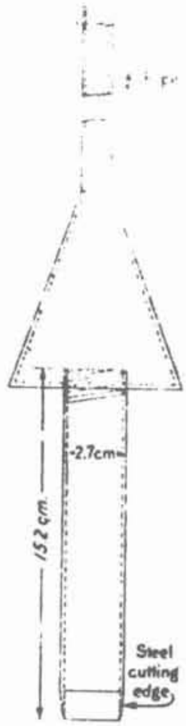


Fig. 37--Pipe sampler used in Imperial Valley Canals.

Fig. 38--Pipe sampler used by Straub on Missouri River.

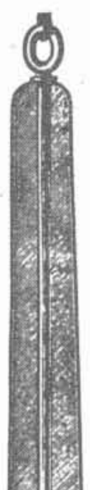


Fig. 39--Valve lead sampler.

Fig. 40--Cup lead, or Stellwagen cup.

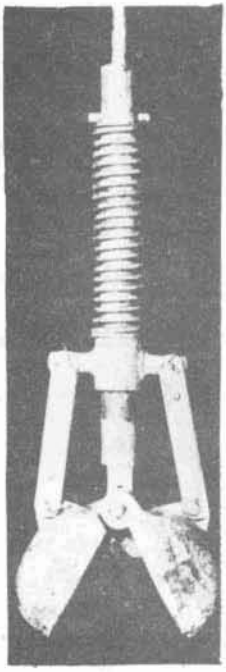


Fig. 41--Ross clamshell, or telegraph snapper.

Fig. 41 shows the Ross clamshell, or telegraph snapper (9). The sampler consists of two spherical cupped jaws which are normally held closed by a spring arrangement. The jaws may be pulled apart and blocked in the open position by means of a catch. The sampler is dropped to the bottom in the open position, and the impact causes the catch to be released and the jaws to close, trapping a sample of the bottom material. This sampler sometimes fails to operate in streams with a soft bed because the impact on the closing mechanism may not be sufficient to cause it to act.

Fig. 42 shows the Lugn telegraph snapper used for a short time in the Mississippi River in 1925 (11). This sampler is similar in operation to the Ross sampler. Its use was discontinued when it was found that considerable fine material was lost due to the jaws being held apart by large particles.

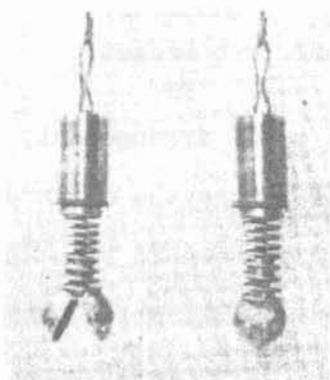


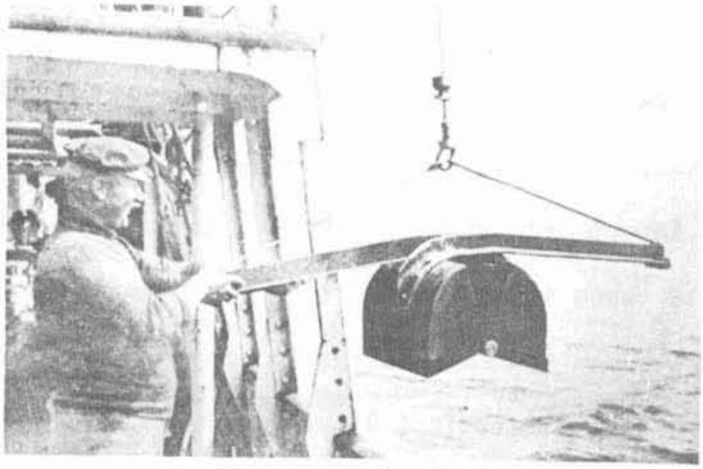
Fig. 42--Lugn telegraph snapper sampler.

The dwarf orange peel bucket (9), shown in Fig. 43, is a miniature form of a well-known type of excavator, having a frame carrying four jaws that form a hemisphere when closed. In the original design the jaws were closed by an auxiliary line but later designs have been adapted to be used with a

Fig. 43--Dwarf orange peel bucket.

single cable. Straub used this sampler for some time in the Missouri River investigations of 1929-30 (17), but later replaced it with the drag bucket type because it was too cumbersome and required too large a field party for its operation.

Fig. 44 shows a grab bucket used by the Dutch Department of Stream Management for obtaining bed material from the English Channel (21). The



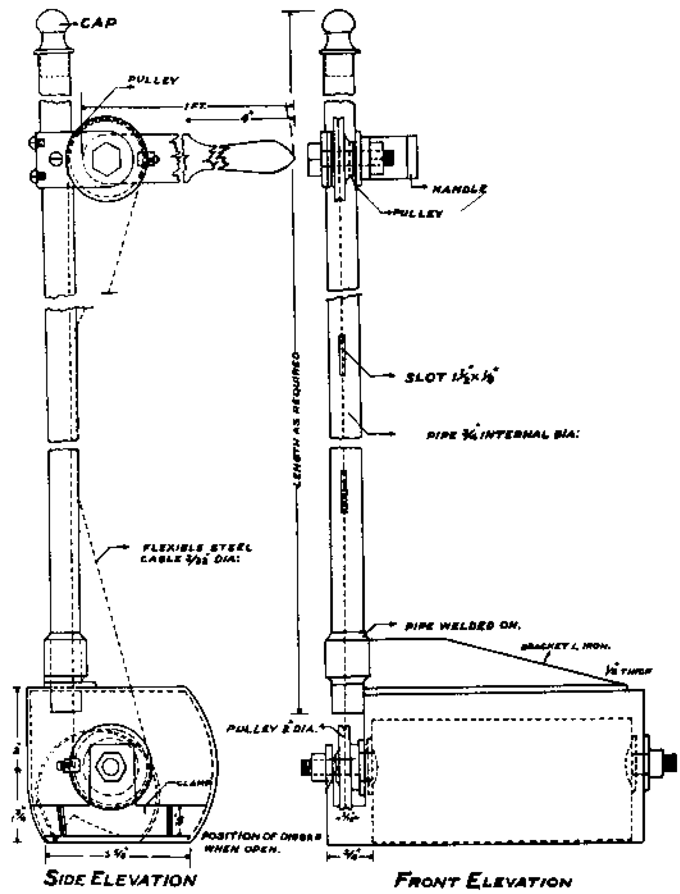
a. Open position before sampling.

b. Closed position after sampling.

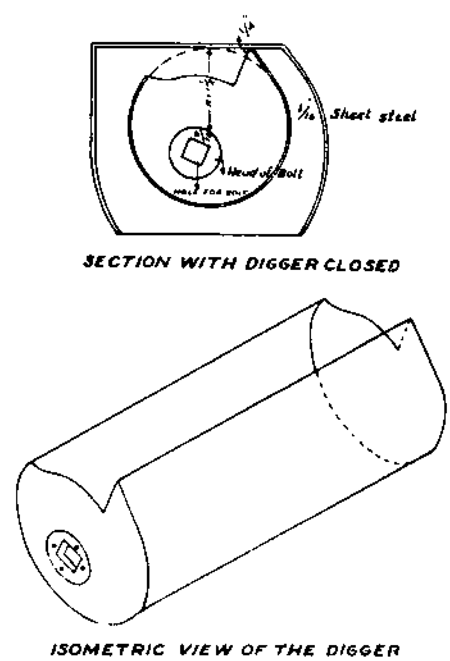
Fig. 44--Dutch Department of Stream Management grab bucket.

sampler consisted of two cupped jaws held apart by a catch arrangement, as shown in Fig. 44a. When the sampler was on the channel bottom the catch was released and the sampler hoisted up, closing the jaws as shown in Fig. 44b.

Fig. 45 shows a sampler used in the Punjab, India (19), which, while considerably different in many respects from the grab bucket types, is classified with them because it obtains a sample by digging. This consisted essentially of an eccentrically mounted scoop which digs into the bed when revolved, and a cowl which prevents the sample from being washed away while the apparatus is being brought to the surface. To take a sample, the apparatus is lowered to the bed and the handle at the top rotated, which in turn rotates the scoop by means of a wire belt.



a. Complete apparatus.



b. Digger.

Fig. 45—Punjab digging sampler.

V. SUMMARY

19. Investigation of bed-load samplers--In the available literature concerning bed-load samplers descriptions were found of twenty-one different samplers which have been developed since 1898. These varied from simple basket or pan types to types designed to give an entrance velocity the same as that of the undisturbed stream. The samplers are classified according to their principle of operation and are divided into three groups: the basket types, the pan types, and the pressure-difference types. Some merits and disadvantages of these samplers, as advanced by their users, are given in this report. Presented also is a brief description of an elaborate apparatus of the Soil Conservation Service on the Enoree River, South Carolina, where an intensive study is being made of bed-load movement.

A summary is given of the results of calibration of several of the samplers. These calibrations consisted of determinations of the efficiency, referring to the percentage of material in movement actually caught by the sampler, for varying conditions of particle size, sampling duration, water velocity and stream depth. The mean efficiencies ranged from 40 to 50 per cent for ordinary basket or pan types and approached 100 per cent for the best designed pressure-difference type. Included in the calibration data are two curves showing variation in rate of bed-load movement over periods of 1 hr. and 80 hr. The inaccuracy of measurements with short filling time due to these variations was pointed out.

20. Investigation of bed material samplers--Photographs and descriptions of twenty bed material samplers are given. These are classified

according to their principle of operation, being divided into three groups: the drag bucket type, the vertical type, and the grab bucket type. The presentation in this report is limited to samplers securing material of the immediate stream bed and consequently leaves out many types of apparatus designed to secure deeper samples.

21. Selection of the proper type of bed-load sampler--To briefly review what has been said concerning bed-load sampling, it is emphasized that the ideal sampler must be capable of doing two things; first, it must "cut out" or sample, a certain definite portion of the moving stream of water and solids; and second, it must collect all the solids from this sampled portion. Such performance can only be assured by careful consideration of the design of the entrance and of the separating mechanism. The proper design of these two features will vary with the conditions in the stream in which they are to be used.

In the ideal sampler the entrance does not influence the flow upstream in any way and offers no obstruction against the entrance of particles. Furthermore, it must rest securely in contact with the bed when in operation. Generally, the dimensions of the entrance will be governed by the particle size of the bed. Its smallest dimension should be at least twice the maximum grain size, while its width should not exceed more than 100 to 200 times the average grain size of the bed. The separating mechanism should, whenever possible, make use of screens. However, when the stream carries such great quantities of organic matter that a screen tends to plug up within the time of one sampling period, separation must be based on the principle of local velocity reduction.

All the different samplers described in this report try to approach as close as possible towards this ideal, while at the same time, taking in account the ease of operation and the special conditions in the streams where they are intended to be used.

The box or basket type sampler is the only one applicable for mountainous streams with coarse gravel as bed material. It is the smallest type for given entrance dimensions, therefore, the least cumbersome, but it has the disadvantage of creating a considerable back pressure. This back pressure causes the water of the slow moving bottom layers to be deflected around the samplers, but merely tends to retard the quick flowing upper layers. Therefore, the fine material creeping along the bottom (low rate of transportation) is very intensively deflected, while material of the same grain size, when moving by saltation (high rate of transportation) is more readily trapped. This explains the variation in efficiency with grain size and rate of movement as mentioned in Section 12.

For sandy beds the pressure-difference type of sampler seems to be the most satisfactory, especially when the entrance section is small and the frame flexible enough to guarantee a snug fit against the irregularities of the bed. (Arnhem type.)

The pan type samplers seem to be best suited for bases with low rates of movement on a comparatively smooth sand bed, when the whole of the transportation is concentrated in the bottom layer.

These are but a few general suggestions concerning the choice of sampler type under certain working conditions. The final selection of the type most applicable to the particular conditions in a given stream can only be based on a thorough calibration test duplicating all conditions of the river as closely as possible. This calibration is necessary, as the efficiency of a given sampler may change considerably with the grain size, rate of transportation, etc. For instance, when the Nesper type sampler was calibrated under the conditions for which the Swiss sampler was designed, it showed a considerable increase in efficiency. Furthermore, the apparent discrepancy between the Ehrenberger and the Einstein calibration of almost identical samplers can readily be ascribed to the fact that the Ehrenberger calibrations were carried out on a metal floor as contrasted with the sand bed used in the Einstein tests.

It must therefore be emphasized that the calibration of the trap is almost as important as the measurements themselves, regardless of the type of sampler used. Only very carefully performed bed-load measurements can be expected to furnish reliable results.

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