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A STUDY OF METHODS USED IN  
MEASUREMENT AND ANALYSIS OF SEDIMENT  
LOADS IN STREAMS



REPORT NO. 13

THE SINGLE-STAGE SAMPLER FOR  
SUSPENDED SEDIMENT

1961

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A Study of Methods Used in  
MEASUREMENT AND ANALYSIS OF SEDIMENT LOADS IN STREAMS

Cooperative Project

Sponsored by the

Subcommittee on Sedimentation  
Inter-Agency Committee on Water Resources  
(Formerly Federal Inter-Agency River Basin Committee)

Corps of Engineers	**	Geological Survey
Soil Conservation Service	**	Bureau of Reclamation
Agricultural Research Service	**	Coast and Geodetic Survey
Tennessee Valley Authority	**	Federal Power Commission
Bureau of Public Roads	**	Public Health Service
Bureau of Mines	**	Forest Service

REPORT NO. 13

THE SINGLE-STAGE SAMPLER FOR SUSPENDED SEDIMENT

Prepared for Publication by Project Offices of Cooperating Agencies  
at St. Anthony Falls Hydraulic Laboratory  
Minneapolis, Minnesota

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UNITED STATES GOVERNMENT PRINTING OFFICE : 1961

*First printing 1961*  
*Second printing 1968*

The cooperative study of methods used in  
MEASUREMENT AND ANALYSIS OF SEDIMENT LOADS IN STREAMS  
covers phases indicated by the following report titles

REPORTS -- NUMBERED SERIES\*

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 METHODS OF SAMPLING SUSPENDED SEDIMENT

Report No. 4

METHODS OF ANALYZING SEDIMENT SAMPLES

Report No. 5

LABORATORY INVESTIGATIONS OF SUSPENDED-SEDIMENT SAMPLERS

Report No. 6

THE DESIGN OF IMPROVED TYPES OF SUSPENDED-SEDIMENT SAMPLERS

Report No. 7

A STUDY OF NEW METHODS FOR SIZE ANALYSIS OF SUSPENDED-  
SEDIMENT SAMPLES

Report No. 8

MEASUREMENT OF THE SEDIMENT DISCHARGE OF STREAMS

Report No. 9

DENSITY OF SEDIMENTS DEPOSITED IN RESERVOIRS

Report No. 10

ACCURACY OF SEDIMENT SIZE ANALYSES MADE BY THE BOTTOM-  
WITHDRAWAL-TUBE METHOD

Report No. 11

THE DEVELOPMENT AND CALIBRATION OF THE VISUAL-ACCUMULATION TUBE

Report No. 12

SOME FUNDAMENTALS OF PARTICLE-SIZE ANALYSIS

Report No. 13

THE SINGLE-STAGE SAMPLER FOR SUSPENDED SEDIMENT

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\* For brief annotations on Reports 1 - 12 see pages 104-105.

## REPORTS -- LETTERED SERIES

- Report AA -- FEDERAL INTER-AGENCY SEDIMENTATION INSTRUMENTS  
AND REPORTS MAY 1959
- Report A -- PRELIMINARY FIELD TESTS OF THE U. S. SEDIMENT-  
\*\* SAMPLING EQUIPMENT IN THE COLORADO RIVER  
BASIN APRIL 1944
- Report B -- FIELD CONFERENCES ON SUSPENDED-SEDIMENT SAMPLING  
\*\* SEPTEMBER 1944
- Report C -- COMPARATIVE FIELD TESTS ON SUSPENDED-SEDIMENT  
\*\* SAMPLERS PROGRESS REPORT DECEMBER 1944
- Report D -- COMPARATIVE FIELD TESTS ON SUSPENDED-SEDIMENT  
\*\* SAMPLERS PROGRESS REPORT -- AS OF JANUARY 1946
- Report E -- STUDY OF METHODS USED IN MEASUREMENT AND ANALYSIS  
\*\* OF SEDIMENT LOADS IN STREAMS JULY 1946  
(Paper presented at ASCE convention, Spokane, Washington)
- Report F -- FIELD TESTS ON SUSPENDED-SEDIMENT SAMPLERS,  
COLORADO RIVER AT BRIGHT ANGEL CREEK NEAR GRAND  
CANYON, ARIZONA AUGUST 1951
- Report G -- PRELIMINARY REPORT ON U. S. DH-48 (HAND) SUSPENDED-  
\*\* SEDIMENT SAMPLER (Superseded by material in Report No. 6)
- Report H -- INVESTIGATION OF INTAKE CHARACTERISTICS OF DEPTH-  
\*\* INTEGRATING SUSPENDED-SEDIMENT SAMPLERS AT THE  
DAVID TAYLOR MODEL BASIN NOVEMBER 1954
- Report I -- OPERATION AND MAINTENANCE OF U. S. P-46 SUSPENDED-  
SEDIMENT SAMPLER REVISION 1958
- Report J -- OPERATING INSTRUCTIONS, SUSPENDED-SEDIMENT HAND  
SAMPLER, U. S. DH-48 NOVEMBER 1958
- Report K -- OPERATOR'S MANUAL, THE VISUAL-ACCUMULATION-TUBE  
METHOD FOR SEDIMENTATION ANALYSIS OF SANDS  
REVISION OCTOBER 1958
- Report L -- VISUAL-ACCUMULATION TUBE FOR SIZE ANALYSIS OF  
SANDS SEPTEMBER 1954  
(Paper presented at ASCE convention, Austin, Texas)
- Report M -- OPERATION AND MAINTENANCE OF U. S. BM-54 BED-  
MATERIAL SAMPLER NOVEMBER 1958
- Report N -- INTERMITTENT PUMPING-TYPE SAMPLER  
PROGRESS REPORT FEBRUARY 1960
- Report O -- INSTRUCTIONS FOR SAMPLING WITH U. S. D-49 SUSPENDED-  
SEDIMENT SAMPLERS MARCH 1960

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\*\* Out of print

### SYNOPSIS

A single-stage sampler is a simple container equipped with intake and exhaust tubes; the sampler is used to obtain suspended-sediment samples automatically (without immediate attention) when a water surface first rises to a selected stage.

Because single-stage sampling imposes special restrictions on intake and exhaust components, the intake velocity of the single-stage sampler does not adjust to stream velocity. Therefore, several types of single-stage samplers are required to cover a range of hydraulic conditions. Four types of single-stage samplers have been approved but may require modification for some sampling conditions.

Suggestions are given on the field operation of the samplers and on the use of data from the samples. Laboratory studies of the single-stage samplers and of the sampler components provide data that indicate probable sampling accuracy of the instruments for a wide range of sampling conditions. Consistently successful use of the single-stage samplers requires more knowledge and engineering judgment than are needed for use of other sediment samplers.

Accurate sampling of suspended sediment in a stream requires a sampler having a sharp nozzle that points directly into the approaching flow and having the same velocity in the nozzle as that in the stream. Inter-Agency Report No. 6 discusses the requirements for accurate sampling and describes a series of point- and depth-integrating samplers that meet these requirements.

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## THE SINGLE-STAGE SAMPLER FOR SUSPENDED SEDIMENT

### I. INTRODUCTION

1. Role of single-stage sediment samplers--Investigation and development to promote the effective use of single-stage suspended-sediment samplers were begun in 1956 by personnel of the Federal Inter-Agency Sedimentation Project.

Single-stage samplers normally are installed at points in the stream cross section at which samples of suspended sediment are desired. A sample is collected when a rising stage first submerges a sampler. Samples are obtained with respect to gage height, not to time.

Ideally, a single-stage sampler would sample as accurately as a point-integrating sampler (Report No. 6)\*, sample at a depth where concentration represents that in the vertical section, sample on rising or falling stage as preset, preserve the sample until delivered to the laboratory, and be economical to build and maintain.

2. Need for automatic sampling equipment--Methods of sediment sampling now (1961) in use generally can provide an adequate record of suspended-sediment discharge at a cross section of a stream if personnel and equipment are at the site when necessary. However, advance warning of a flood is not always sufficiently early for personnel and equipment to reach the site at the time samples are needed. Also, personnel and equipment are not always available. For flashy and intermittent streams, especially at remote or not easily accessible sites, sampling has been seriously insufficient for some storms or even some seasons.

The single-stage sampler was developed because of the urgent need for a sampler that would sample without immediate attention. Even approximate information on the concentration of sediment between visits of personnel to the stream can be important if nothing better is available. Although single-stage samplers do not fully attain the ideal (see Secs. 43-45), they provide a means of obtaining (1) some information on suspended-sediment concentration for streams or storms for which data would not be obtained otherwise, (2) supplemental information where samples taken manually are inadequate, and (3) possible economies by reducing the number of visits to a stream.

3. Field development--Several devices could be considered part of the evolution of the single-stage sampler. The Anderson-Einstein sampler and some of the suspended-sediment samplers developed by the Corps of Engineers at Omaha,

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\* References to Inter-Agency reports are by number only.

Nebr., have features in common with the single-stage sampler. However, Geological Survey personnel at Austin, Tex., seem to have been the first to use a device to sample suspended sediment "automatically" as the stage of a stream rises.

Personnel of the Quality of Water Branch of the Geological Survey had difficulty obtaining samples of the high and rapidly changing suspended-sediment concentrations on rising flood stages. In the spring of 1954 an attempt was made to improve sampling on stream rises. C. T. Welborn and George Porterfield of the Austin office of the Quality of Water Branch designed an "automatic" sampler that was built by Mr. Welborn. Hardy Porterfield, a mechanic of the Surface Water Branch of the Geological Survey in Austin, also contributed to the development. This original sampler, shown in Fig. 1, has been used with some success.

Employees of the Quality of Water office in Lincoln, Nebr., recognized the possibilities of the "automatic" single-stage sampler, conducted some independent tests of the sampling action, and modified the design. (See Fig. 2.) Results of the tests and numerous modifications of the design were described by J. C. Mundorff in an open-file report entitled "An Automatic Suspended-Sediment Sampler," October 1957.

4. Personnel--The Inter-Agency Project is sponsored by the Subcommittee on Sedimentation of the Inter-Agency Committee on Water Resources. A Field Technical Committee, composed as follows, supervises the project:

Geological Survey	P. C. Benedict
Corps of Engineers	D. C. Bondurant
Soil Conservation Service	E. M. Thorp
Bureau of Reclamation	W. M. Borland
Agricultural Research Service	H. G. Heinemann
Forest Service	M. D. Hoover
Public Health Service	R. H. Holtje
Tennessee Valley Authority	E. N. Lesesne

The samplers were tested and calibrated by H. H. Stevens, Jr., B. C. Colby, and H. A. Jongedyk. The cooperation of F. S. Witzigman and R. P. Christensen is gratefully acknowledged. Many helpful suggestions and constructive criticisms were received from members of the Technical Committee. The report was written by Byron C. Colby.

Personnel of the Quality of Water Branch of the Geological Survey have been helpful in suggesting field usage of single-stage samplers. Sampler mounting and protection have been based on suggestions from J. C. Mundorff and Búrdge Irelan. A comment by D. W. Hubbell was partly responsible for the design of Fig. 44.

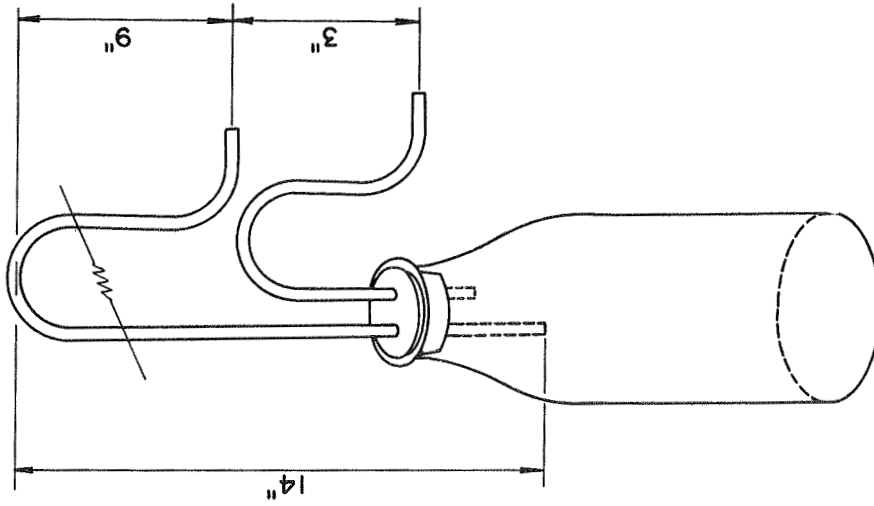


FIG. 2—"AUTOMATIC" SEDIMENT SAMPLER AS  
MODIFIED AT LINCOLN, NEBR.

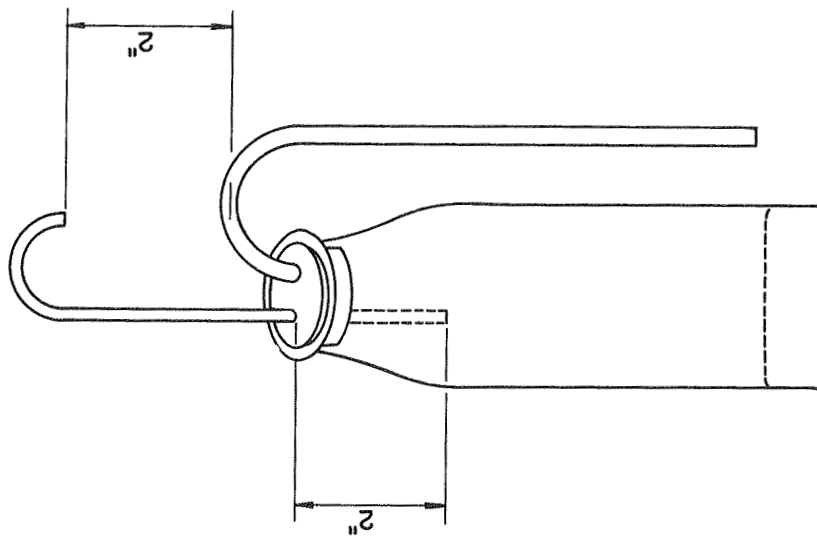


FIG. 1 -- ORIGINAL "AUTOMATIC" SEDIMENT SAMPLER,  
AUSTIN, TEX.

5. Scope of the general study--This study is part of the general project, "A Study of Methods Used in Measurement and Analysis of Sediment Loads in Streams," which has been sponsored by cooperating Federal agencies since 1939. The purposes of the project are to develop equipment and methods for collecting and analyzing sediment samples; to promote collection of basic engineering data and information on the characteristics and behavior of sedimentary materials transported by natural streams; and to gain a better knowledge of the fluvial-sediment problem and its solution as related to the development of water resources for industrial, agricultural, commercial, and domestic purposes. Equipment and methods of sampling and analyzing sediments have been emphasized. Various aspects of the problem that have been investigated are indicated by the titles of reports on pages 3 and 4 and by the brief annotations of the numbered reports on pages 104-105.

6. Definitions--A few terms that have special or restricted meanings in the report are defined as follows:

ACCRETION is either the water-sediment mixture added to the original sample by subsequent submergence or the process of addition.

EFFICIENCY or SAMPLING EFFICIENCY is the accuracy with which the sample reproduces the sediment content of the stream at the point and time of sampling. The relation of the sediment content at the time of sampling to the short- or long-time average at the sampling point or to the sediment in the entire cross section of the stream is not included in efficiency but must be considered carefully in evaluating the data for the sediment record.

ENRICHMENT is the addition of sediment to the sample from water-sediment mixture surging into and out of the intake nozzle or the exhaust port.

INTAKE or EXHAUST is the entire intake or exhaust tube. The intake nozzle is the tip or entrance section of the intake. The exhaust port is the outer opening of the air exhaust. The inner leg of intake or exhaust is the one that enters the bottle; the outer leg is on the stream side of the invert. (Fig. 3 is used as a general illustration of sampler dimensions and components.)

INTAKE RATIO is the ratio of average velocity in the nozzle to velocity approaching the nozzle along the axis of the intake. When the nozzle points directly into the approaching flow, the intake ratio is equivalent to the relative sampling rate of Report No. 5.

INVERT is the part of intake or exhaust that forms an inverted "U." The height of the inverts of Fig. 3 is BC for the intake and DE for the exhaust.

NORMAL SAMPLING VELOCITY is the intake velocity at which sampling starts or the sampling velocity in still water without surges.

**NORMAL TIME OF SAMPLING** is the time at which the water surface first rises to the sampling stage.

**ORIGINAL SAMPLE** is the sample in the container at the end of the normal sampling time; the primary sample as modified by presampling conditions; or the sample before it is altered by conditions subsequent to sampling, such as circulation, accretion, and surge enrichment.

**PRIMARY SAMPLE** is the sample collected from the stream at the normal time of sampling.

**SAMPLE CONTAINER** is assumed to be a one-pint glass milk bottle. Other containers could be used, but stoppers and bottle-holding devices were designed for the pint milk bottle.

**SEDIMENT SIZES** are as follows: clay and silt, < 62 microns; and sand, > 62 microns.

**SURGES** are the inward and outward movements or variations from uniform flow of the fluid in the intake or exhaust as a result of transient pressure changes. The size of surges is expressed in vertical height. (See Fig. 32.) However, surges may be present without an air-water interface in the tubes and also when the sampler is filling.

**WATER-SURFACE SURGES** are the pressure changes caused by two variables. Waves, undulations, or any short-time changes in water-surface elevation create changes in the pressure head that operates on a sampler in a stream. Also, velocity variations alter the velocity head pressure at the sampler.

**VELOCITY AT SAMPLING POINT** is the stream or flume velocity at the point of the intake nozzle.

## II. BASIC SINGLE-STAGE SAMPLING

7. Components of the sampler--A single-stage sampler installation consists of four basic parts (Fig. 3):

(1) A sample container. A one-pint glass milk bottle is satisfactory. The use of containers of other sizes, shapes, or materials depends on availability, economy, and size of sample desired.

(2) An air exhaust. A siphon-shaped tube having a smooth inside passage about 3/16 in. in diameter is required. Any material convenient for bending is satisfactory if it will then hold its shape and be sufficiently durable.

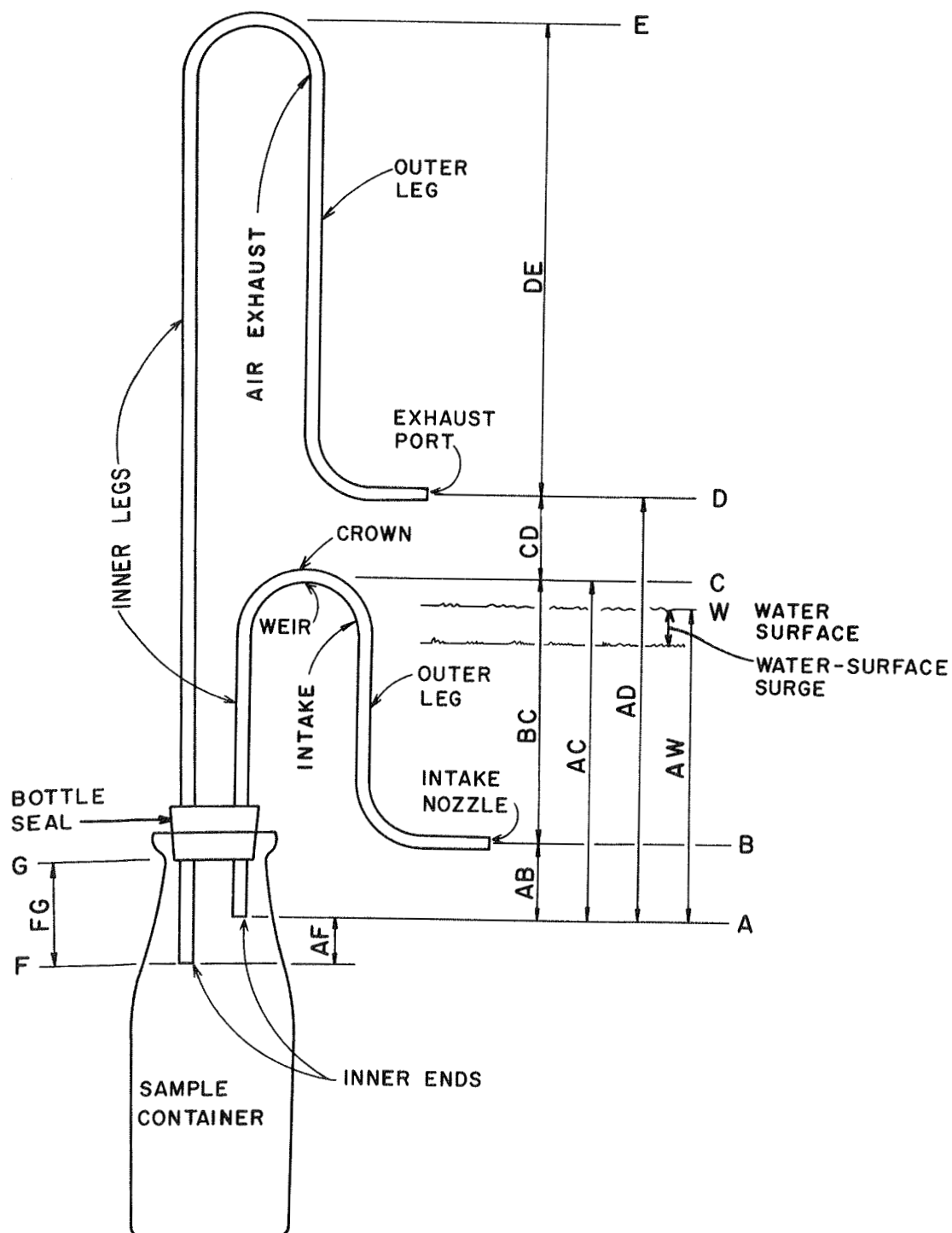


FIG.3—BASIC SINGLE-STAGE SEDIMENT SAMPLER



(3) An intake. A siphon-shaped tube having a smooth inside passage  $3/16$  in. in diameter at the nozzle and  $3/16$  or  $1/4$  in. in diameter from the nozzle into the bottle is needed. Material requirements are the same as those for the air exhaust.

(4) A bottle seal. A stopper having two holes is required. It must fit tightly in the top of the bottle and around the tubes.

8. Basic sampling operation--If the water surface is slowly rising and if no velocity or water-surface surge effects are present, the sampling operation is as follows:

When the stream surface rises to the elevation of the intake nozzle, water-sediment mixture enters; and as the water surface continues to rise in the stream, it also rises in the intake. (See Fig. 3. The general elevations and dimensions are expressed without regard to the inside diameter of the tube or without distinction between the weir and the crown of the siphon.) When the water-surface elevation  $W$  reaches  $C$ , flow starts over the weir of the siphon, primes the siphon, and begins to fill the sample bottle under the head  $AC$ . Filling continues until the sample rises to  $F$  in the bottle, and water is forced up the air exhaust to the elevation  $W$ . Actually, the momentum of flow in the tubes causes a momentary rise above  $W$  in the air exhaust. Water drains out of the inner leg of the intake. When the stream rises to  $D$ , air is trapped in the air exhaust. As long as sufficient air remains in the tubes, no flow can pass through to alter the original sample unless a differential head that exceeds the height of invert is built up. (If the legs of an invert are not symmetrical, the inverts have different effective air-trap heights resisting flow into and out of the bottle.) For conditions without significant surge and velocity effects at the intake nozzle or exhaust port, the heights  $BC$  and  $DE$  may be small.

If, after the normal time of sampling, the depth of submergence over the sample bottle increases, the air in the bottle is compressed and a small additional sample enters the bottle. This additional sample will enter through the tube having the smaller height of invert. Under variable submergence the entrance of water will compress the air in the bottle on rising stages, and some expanding air will escape on falling stages; thus the quantity of air in the bottle becomes less and less, and water rises in the bottle.

9. Influence of velocity and turbulence--Because the transportation of sediment involves velocity and turbulence, normal sampling action is not so simple as that presented in the preceding section.

Once the stream rises to the intake nozzle, the rise in the intake depends on the effective pressure at the nozzle. The pressure is the static pressure in the fluid as modified by transient dynamic pressure differences and velocity head. Dynamic pressure differences come from standing waves and vortexes, which are related to velocity and roughness. Whether the velocity head adds

to or subtracts from the pressure depends on the orientation of the nozzle with respect to the velocity. The sampling operation depends on pressures that are often highly variable.

Sampling operation in turbulent flow is as follows (see Fig. 3): Sampling starts when the pressure at the intake nozzle forces water up to C. If the intake points into the approaching flow and if the velocity head is greater than BC, sampling will start as soon as the intake is submerged, and sampling will be intermittent if the surging water surface alternately covers and uncovers the intake nozzle. For continuous sampling, BC should exceed the height of water-surface surge plus velocity head. Also, the height AB can be small or B can be below A, but AC should exceed the water-surface surge by a sufficient static head (perhaps 2 in.) to maintain a sampling velocity in the intake. Sampling ceases when the bottle is filled to the bottom of the air exhaust F, and the fluid is forced up the exhaust to the elevation that can be supported by the pressure at the intake nozzle.

Regardless of velocity and static head, the sampler always starts to fill under the head AC. Therefore, each sampler has a characteristic intake velocity. However, this characteristic velocity depends not only on the head AC but to some extent on the following factors:

- (1) Temperature causes changes of a few percent in intake velocity.
- (2) The average head during the 20 to 40 sec. of sampling may be less than AC because surges in water surface and velocity are at a maximum when sampling starts.
- (3) If the velocity head exceeds BC and the energy head is greater than that required to start sampling, the effective head during sampling will exceed AC.
- (4) Debris on the intake may cause abnormal intake velocities.

If circulation through the sampler is to be prevented, DE must exceed any combination of differential dynamic pressure heads that can develop between the nozzle and the exhaust port at any moment; an allowance must be made for momentum in the tubes and unbalance in a siphon because of a water-over-air interface. Generally, the pressure difference for a horizontal intake nozzle and horizontal exhaust pointing into the stream is maximum when the intake nozzle is submerged but the exhaust port is not.

If a sampler may be subject to highly variable submergence, AF should be a large part of FG (80 percent is suggested) to minimize the danger of surge enrichment.

10. Advantages and disadvantages of the sampler--Single-stage samplers have the following advantages:

- (1) No one need be present at the time of sampling.
- (2) Samples may be obtained at predetermined stages of the stream.
- (3) Sampling apparatus is inexpensive.
- (4) The sampler may be left for a few days after sampling without significant contamination of, or evaporation from, the sample.

The use of single-stage samplers has several limitations that depend on the nature of the device and on the sediment sizes to be sampled. For clays and fine silts the limitations are not likely to be critical, but for coarse silts and sands the limitations may be significant unless unanticipated improvements are possible.

- (1) Samples are collected at or near the stream surface, and adjustments for vertical distribution of sediment are necessary.
- (2) Samples usually are obtained near the edge of the stream or near a pier or abutment, and adjustments for lateral variations in sediment distribution are required.
- (3) Proper sampling action limits intake and air-exhaust elements to sizes, shapes, and orientation that may fail to provide intake ratios sufficiently close to unity to sample sands accurately.
- (4) Covers or other protection from trash, drift, and vandalism often create unnatural flow lines at the point of sampling.
- (5) Water from condensation may accumulate in the sample container prior to sampling.

In the present state of use, the sampler has two other limitations that may be removed by further modifications:

- (1) Sometimes the sediment content of the sample changes during subsequent submergence.
- (2) The device is not adapted to sampling on falling stages or secondary rises.

11. Sampling efficiency--In this report the sampling efficiency is the basic criterion for satisfactory sampler design. The sampling efficiency may be affected by adverse conditions prior to, during, and subsequent to sampling. Prior to sampling, water may condense in the sample container and the settling out of coarse sediment may dilute or enrich the subsequent sample (Sec. 12). During sampling, the intake velocity may not equal the stream velocity; the intake may be poorly oriented in the flow; or conditions at the sampling point may be abnormal because of disturbance by the sampler, its support, or protecting structure.

Subsequent to sampling, errors may result from circulation of water-sediment mixture through the sampler, accretion, enrichment, and contamination or loss of the sample by exposure to the elements or by improper handling and storing of the sample.

### III. LABORATORY INVESTIGATIONS OF THE SINGLE-STAGE SAMPLER

12. Conditions prior to sampling--Before sampling begins, the intake nozzle is usually submerged intermittently, or continuously, for several minutes. During submergence, water-sediment mixture surges in and out of the nozzle and some of the coarse sediment (sands especially) settles from suspension. The quantity that settles depends on the duration and intensity of the surges and on the concentration and fall velocity of the sediment. At the instant sampling begins, the water-sediment mixture in the intake enters the sampler and becomes part of the original sample.

After the intake is submerged, settling of the coarse material from suspension in the intake may affect sampling in one of two ways. If the material washes out of the intake, the sample will be diluted. Because the volume in the intake is small and contains part of the sediment concentration in the stream, the dilution will be small. If the material accumulates in the intake, the sample may be greatly enriched.

Presampling errors are usually insignificant unless their effect is made cumulative by intermittent sampling. Intermittent sampling can be avoided by making the height of the outer leg of the intake greater than the combined height of water-surface surge and velocity head.

13. Apparatus for studying presampling deposits in the intake--The apparatus used for investigating presampling deposits in the intake is shown in Fig. 4. The sediment chamber was a glass jar 12 in. in diameter and 12 in. in depth. A heavy-duty kitchen-type mixer was fitted with a simple propeller for agitating the water-sediment mixture in the sedimentation jar. A holder for the sampler was mounted against the side of the jar opposite the mixer. A straight glass tube marked every half inch replaced the usual exhaust tube. An air line connected the outer end of the straight tube to a rubber bulb. Compression of the bulb created surges in the straight tube and in the intake. During preliminary tests, the bulb was squeezed by hand; later, a solenoid mechanism compressed the bulb for about one-third of each second. The height of surge in the glass tube could be controlled by limit screws on the solenoid mechanism. Several sampler intakes of glass tubing were made and tested. (See Fig. 5.)

The sedimentation jar was filled with tap water and with sufficient sediment to give a concentration of 1,000 or 10,000 ppm of the desired sieve-size range.

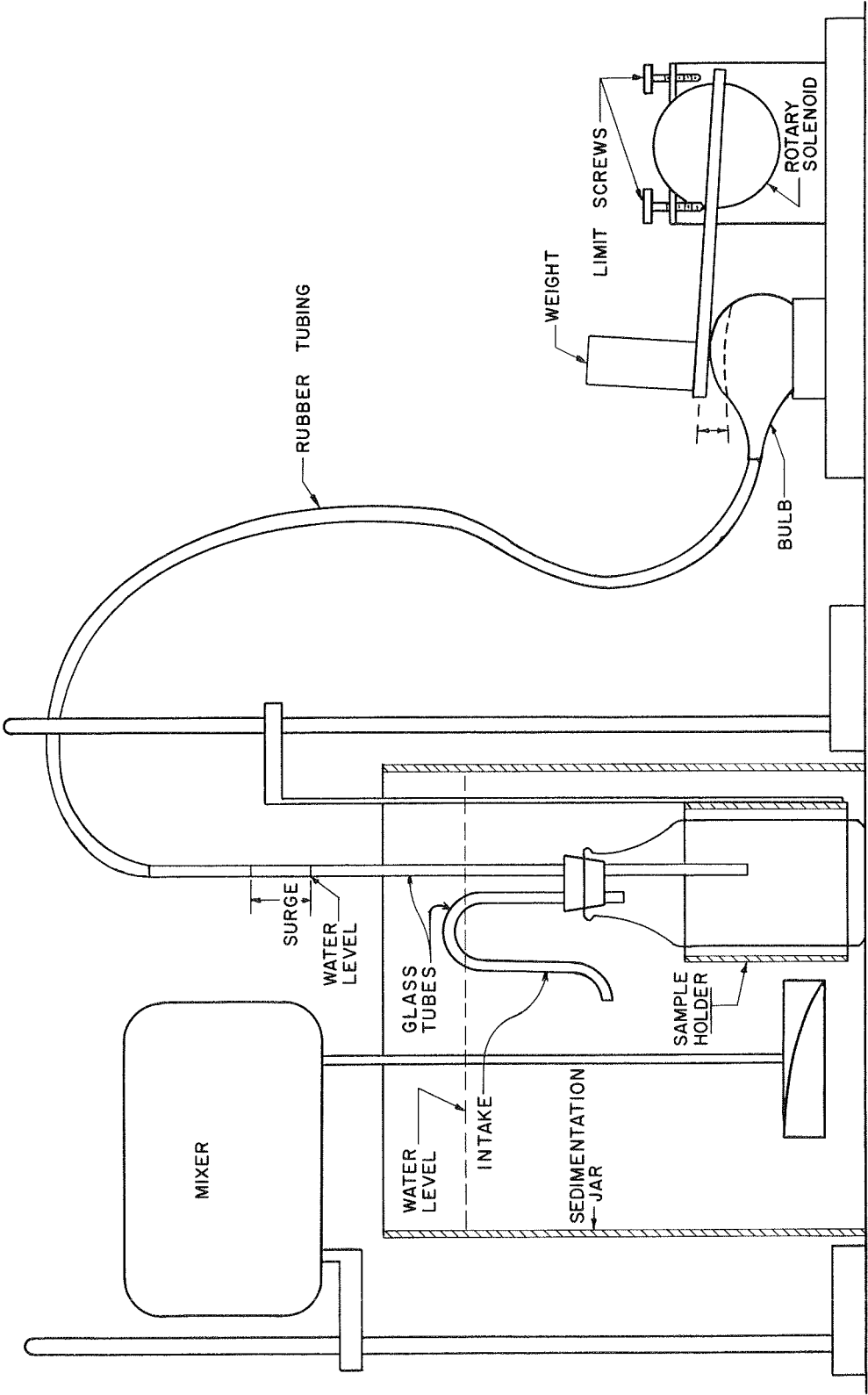


FIG. 4 — EQUIPMENT FOR SAMPLER TESTS

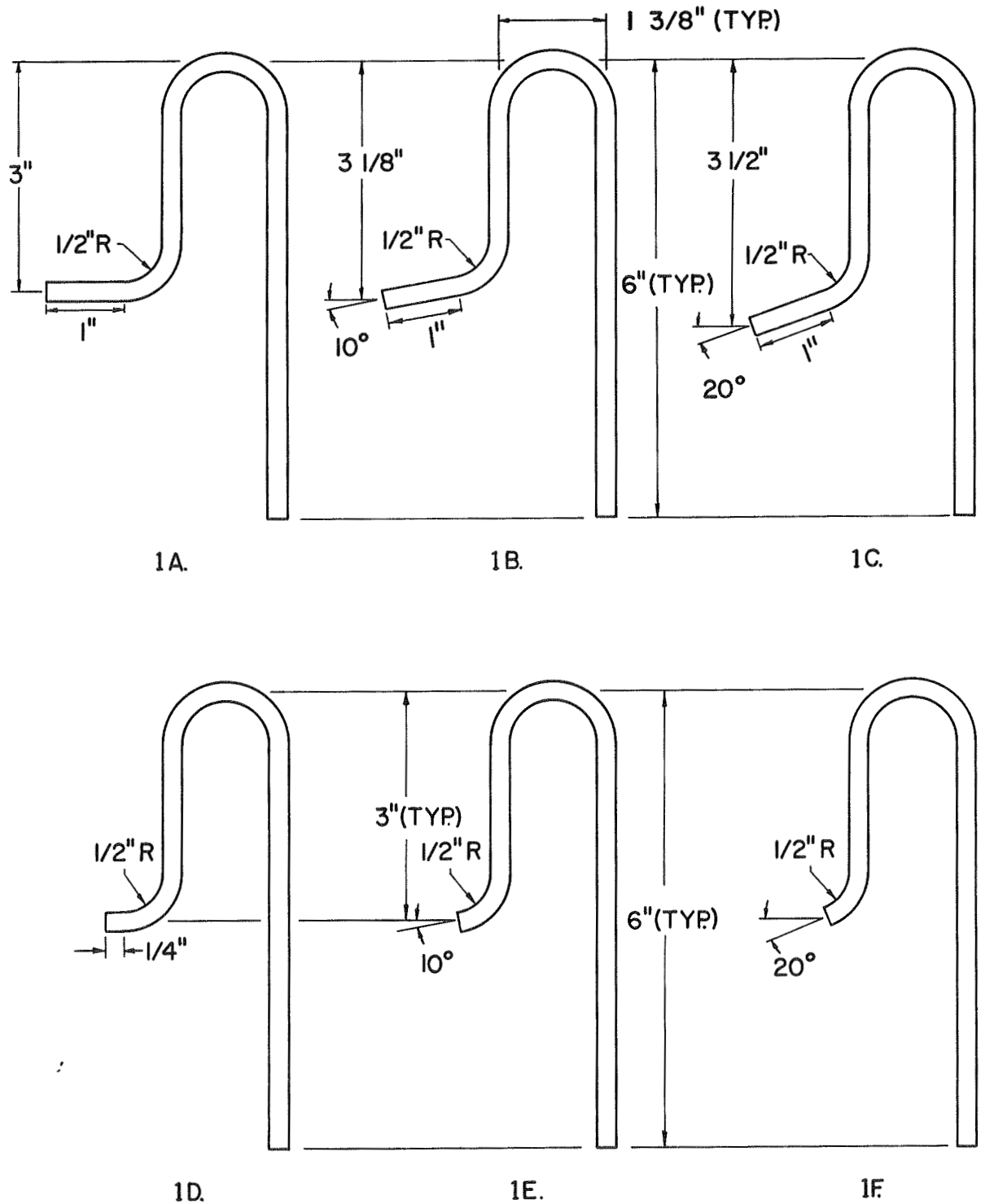


FIG. 5 - INTAKES TESTED FOR SEDIMENT DEPOSITS

The mixer was operated for a few minutes to place the sediment in suspension. The intake nozzle of the sampler was submerged 1 in. below the surface of the water-sediment mixture for a timed interval of 1, 3, 5, 10, or 30 min. During the interval, water-surface surges of 1/2, 1, or 2 in. were maintained in the sampler intake. At the end of the time interval the intake was quickly capped; the sampler was removed from the jar; and the sediment deposit in the intake was washed out, dried, and weighed.

14. Presampling deposits in the intake--Intake deposit data were obtained for concentrations of 10,000 ppm of 125- to 250-micron sediment and of 1,000 ppm of 62- to 125-micron sediment. (See Figs. 6 and 7; also Table 1, in the appendix.) The data are somewhat inconsistent because (1) the sedimentation apparatus was not adequate to maintain a uniform concentration at the intake nozzle, (2) the cycle of accumulation and flushing of sediment in the nozzle was erratic, and (3) the intake was not always capped at the same point in the cycle.

The deposit in intake 1A (Fig. 5) was large and varied with length of surge (Fig. 6). The deposit probably builds up to a maximum that is limited by the capacity of the horizontal section of the intake. As the intake fills with sediment, the velocity over the sediment deposit is locally increased by the constriction until no further deposit occurs or until the addition to the deposit becomes very slow. The time required for a given deposit to accumulate was greater if the sediment concentration was low, but at the end of 10 min. the accumulation was equal to about 10 percent of the sediment in a one-pint sample from the jar. (See Figs. 6 and 7.)

A reduction in length of the horizontal section at the outer end of the intake resulted in a reduction of the sediment deposit. (See Fig. 6.) The angle of repose with surge in the intake seemed to be less than 20°, and the sediment deposit was greatly reduced if the horizontal section was inclined downward only 10°.

The concentrations in samples collected after the intake had been submerged for 10 min. were compared with those in check samples that were not subject to presampling deposits in the intake. (See Fig. 8, also Table 2.) If the intake had a horizontal or nearly horizontal section, significant errors were caused by presampling deposits that washed into the sample.

15. Elimination of presampling deposits in the intake--Enrichment from presampling deposits in the intake can be prevented by making the horizontal section of the nozzle very short, by eliminating it, or by inclining the intake nozzle downward. The intake designs finally adopted are shown in Figs. 39 to 42. The intakes for high velocities were not inclined downward at as steep angles as those for low velocities, because large surges associated with high velocities tend to limit intake deposits.

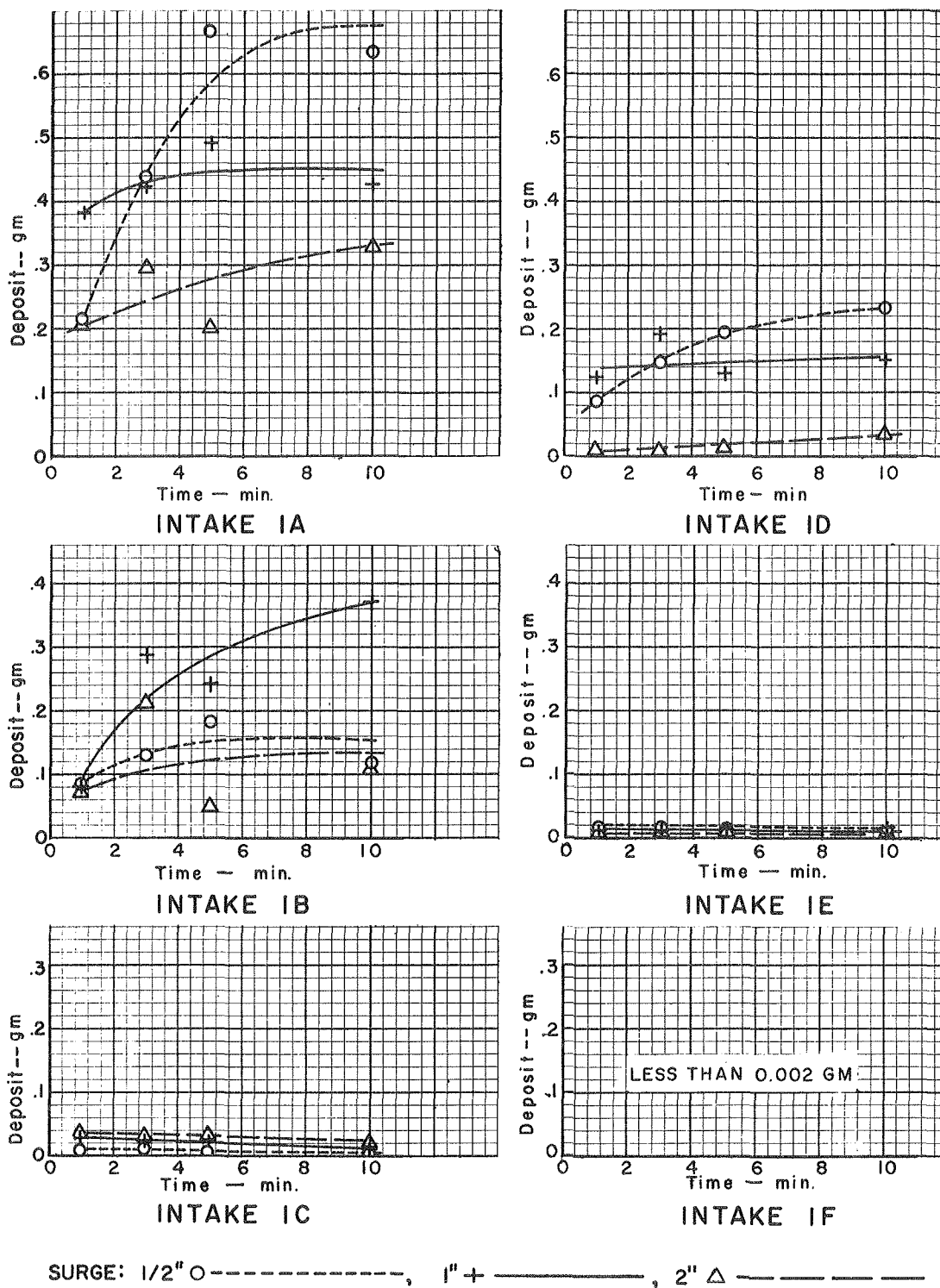
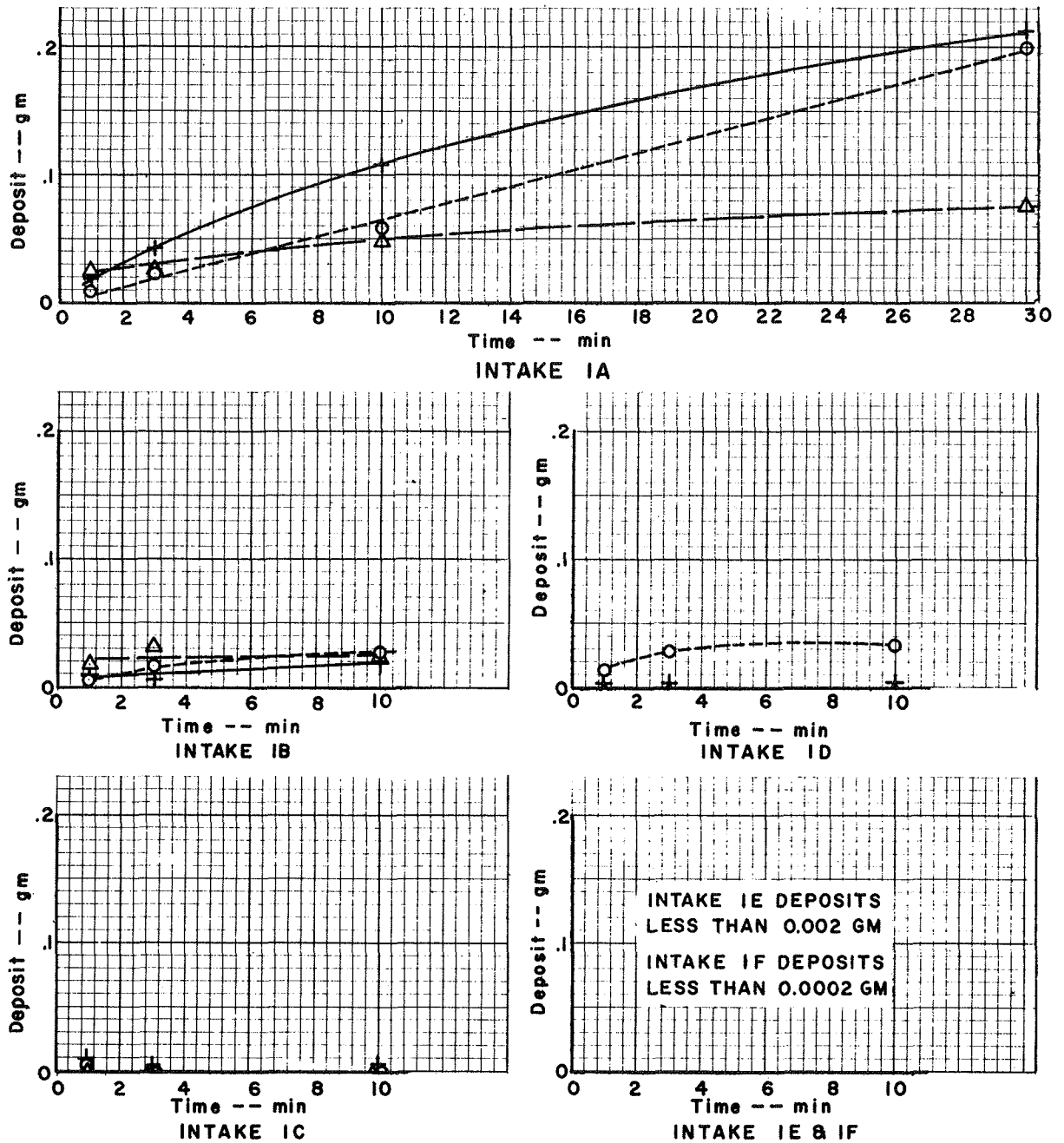


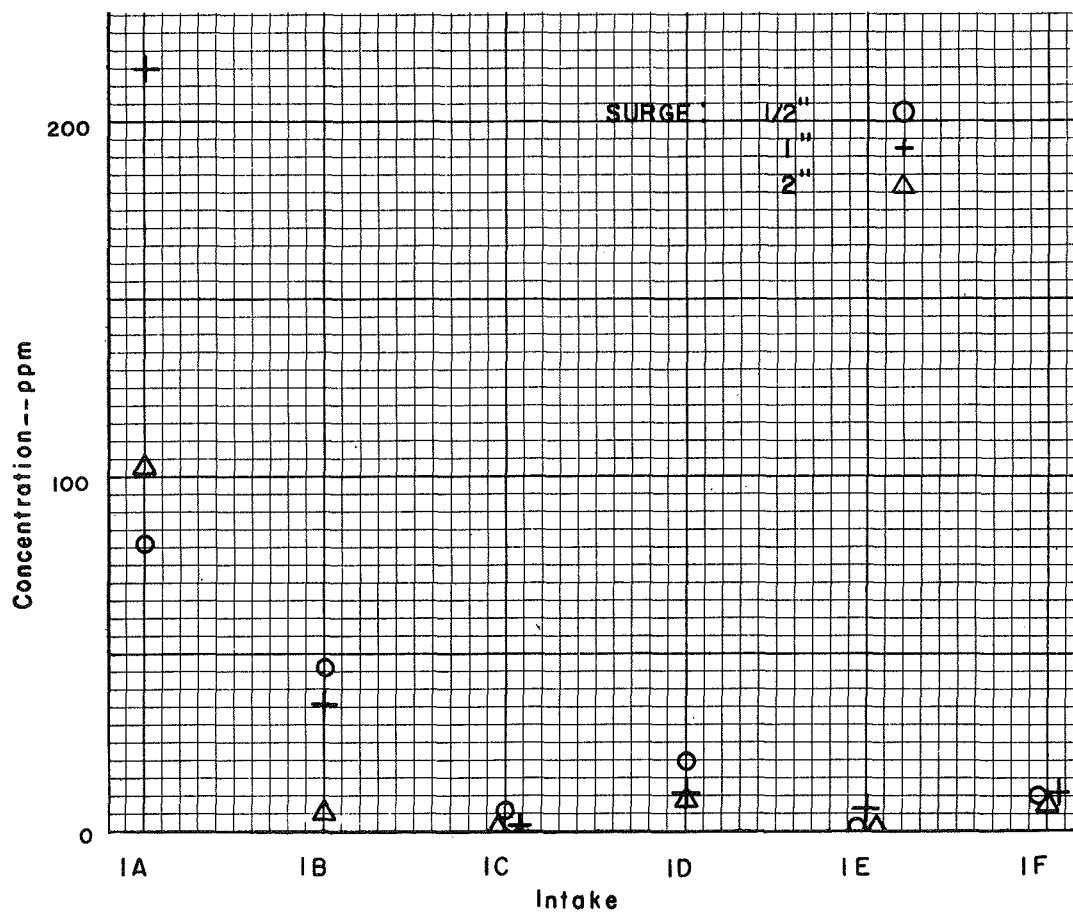
FIG. 6 - SEDIMENT DEPOSITED IN INTAKE,  
125 - 250 MICRONS, 10,000 PPM





SURGE: 1/2" ○ -----, 1" + —————, 2" △ —————

FIG. 7—SEDIMENT DEPOSITED IN INTAKE,  
62 - 125 MICRONS, 1,000 PPM



(From Fig. 5)

FIG. 8 - EXCESS CONCENTRATION FROM INTAKE SUBMERGENCE PRIOR TO SAMPLING

(10-MIN. SUBMERGENCE PRIOR TO TESTING, CONCENTRATION IN JAR ABOUT 900 PPM, 62-125 MICRON SEDIMENT)

Report F showed that deposits of sediment were insignificant in the nozzle of the U. S. P-46 sampler even though it was submerged prior to sampling. Tests of the P-46 indicated that a valve in the intake prevented sediment deposit in the intake. Probably, however, a valve in the air exhaust of a single-stage sampler would be ineffective because the volume of air in the bottle would contract and expand sufficiently to allow surges in the intake.

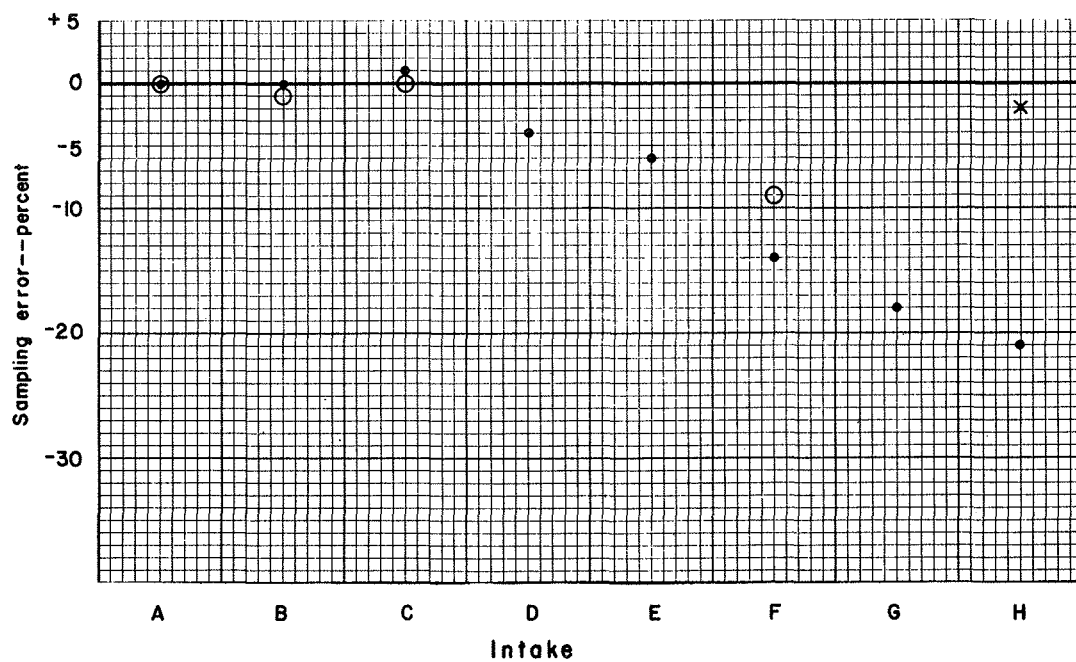
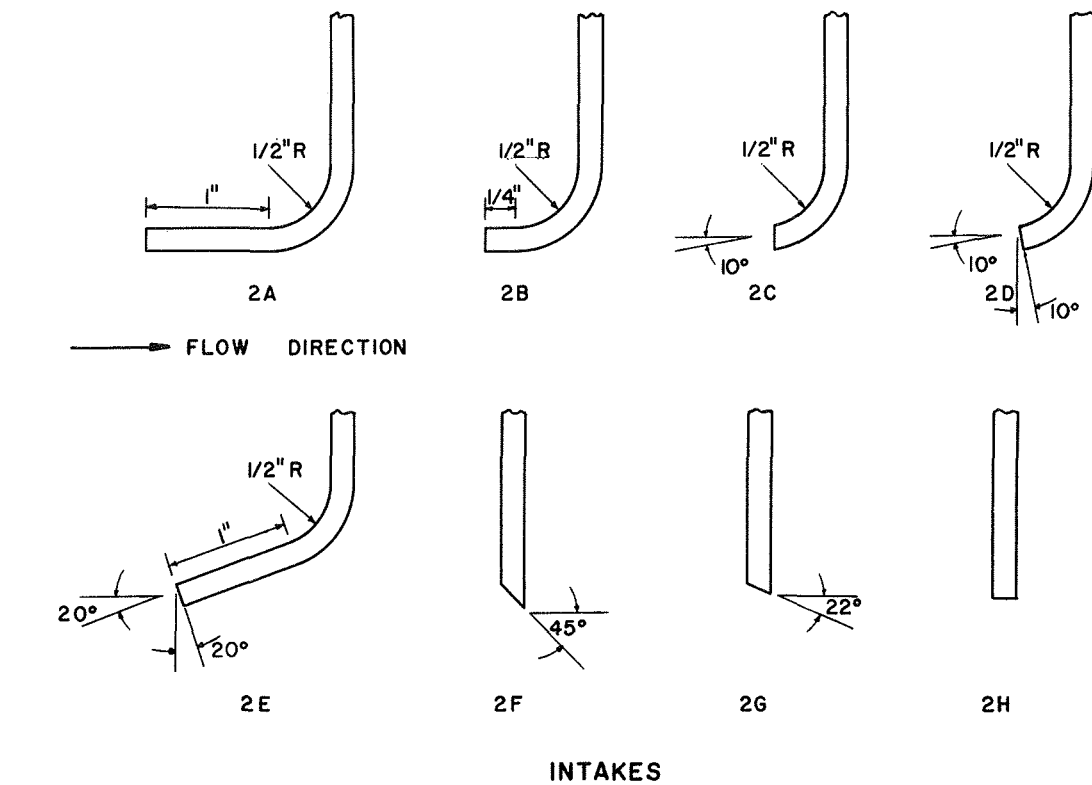
16. Orientation of intake nozzle--Fig. 3 of Report No. 6 indicates that for angles up to  $30^\circ$  the deviation of the intake from the exact angle of the approaching streamflow has little effect on the sampling accuracy even for coarse suspended sediment. The angle of approach is not likely to introduce errors in sampling if the intake points approximately into the flow.

Some tests of the effect of intake orientation were made with the equipment described in Section 13. They show a wide range of sampling error (Fig. 9) for different intakes. The horizontal velocities in the jar were only about 1 fps, but the turbulence was intense. The data for samplers 2A to 2E of Fig. 9 are for intake velocities equal to the velocities at the sampling point. For samplers 2F to 2H the intake velocities were about 1.8 fps, or nearly twice the velocity at the sampling point. For vertical-intake samplers, such as 2H and modifications 2F and 2G, changes from 1 to 1.8 fps in intake velocity did not make major differences in sampling accuracy at stream velocities of about 1 fps and for sediments smaller than 250 microns. However, an intake velocity of 1 fps is too low to raise coarse sands through the vertical intake satisfactorily.

For stream velocities near 1 fps, the effect of orientation of the intake opening is fairly well defined by Fig. 9. The effect for high velocities and for medium and coarse sands is not defined. Report No. 5 indicates that sampling efficiency is likely to decrease as the sediment size increases. Also, the sampling efficiency of a vertical intake probably decreases as the stream velocity increases.

The vertical-intake samplers are not dependably accurate for sediments much coarser than 62 microns unless the sampling accuracy can be established for the given sampling conditions. Fig. 9 (2F to 2H) and Fig. 28 of Report No. 5 indicate that vertical-intake sampling will be reasonably accurate for sediments finer than 62 microns. Actually, Fig. 28 of Report No. 5 may not apply directly because conditions around the intake of the single-stage sampler are abnormal. If the intake nozzle is either upstream or downstream from the bottle, the velocities at the sampling point will be low; and if at the side, the velocities will be high. Departures from the normal will be especially significant at high stream velocities. Usually the intake will be upstream from the bottle, and sampling in that position may be satisfactory even for sediments coarser than 62 microns.

In excessively turbulent flow the orientation between sampler and flow varies rapidly so that horizontal and vertical, or combinations of, intake angles have



X < 62-micron sediment, O 62 to 125-micron sediment, • 125 to 250-micron sediment

**FIG. 9— EFFECT OF INTAKE ORIENTATION ON SAMPLING EFFICIENCY AT VELOCITIES OF ABOUT 1 FPS**

only a very general influence. If samplers are enclosed in shielding devices, the stream conditions may not be representative of those at the sampler nozzle.

17. Ratio of intake to stream velocity--Ideally, the velocity in the intake nozzle should be the same as that in the approaching filament of streamflow, and the intake should point directly into the approaching flow. Any departure from the ideal may introduce sampling errors, because the streamlines bend at the tip of the nozzle and because the sediment particles tend to migrate from their respective filaments of flow. If the intake points directly into the flow, the intake ratio is an indication of the degree of bending of the streamlines.

When the intake ratio is not unity, the sampling errors depend on the sedimentation size of the particles, the intake ratio, the stream velocity, and the nozzle diameter. The nozzle diameter is not critical within the limits of usual nozzle sizes, and only data for nozzles having a 3/16-in. inside diameter will be presented. Report No. 5 covers intake efficiency in detail. Data from that report and from some special tests were used to define Figs. 10 to 12, which show sampling errors for three sizes of sediment and for a range of stream and intake velocities. The errors should be adequately defined for stream velocities of 3, 4, and 5 fps even though many of the original data were for a 1/4-in. nozzle. The extension of the relation to velocities greater than 5 fps is based on the special tests reported in the next section and may be inexact. Extensions to velocities less than 3 fps are likewise questionable, but two considerations limit the errors at low velocities: (1) The intake ratio of the single-stage samplers usually exceeds unity at stream velocities less than 3 fps, and sampling errors are relatively small when the intake ratio is greater than unity. (2) Normally, sampling errors increase as sediment size increases, but large concentrations of the coarse sands will not be in suspension at velocities much less than 3 fps.

18. Special high-velocity tests--Data of Report No. 5 were supplemented by a series of special tests in an open flume; turbulent velocities were about 8.5 fps, and the mean sedimentation size was 550 microns. The tests were made in the hydraulic laboratory of the Colorado State University at Fort Collins, Colo., in May 1959. The test equipment was not designed and constructed so elaborately as that on which Report No. 5 was based; but the results, though somewhat erratic, were usable. (See Figs. 13 and 14.)

At intake ratios of 0.4 and smaller, the samples were erratic and some sample concentrations were much too low. The samples were taken out over the top of the flume, and at intake ratios of less than 0.4 the sediment did not keep moving uniformly from the nozzle to the point of sample collection. Vertical intakes did not sample at 8.5-fps velocity because cavitation behind the vertical tube allowed air to enter the intake.

Results of the special tests may be compared with those for 450-micron (0.45-mm) sediment of Report No. 5. The special tests showed that at an intake ratio of unity a smoothed (or slightly flattened) horizontal nozzle sampled 5 percent high in 550-micron sediment.

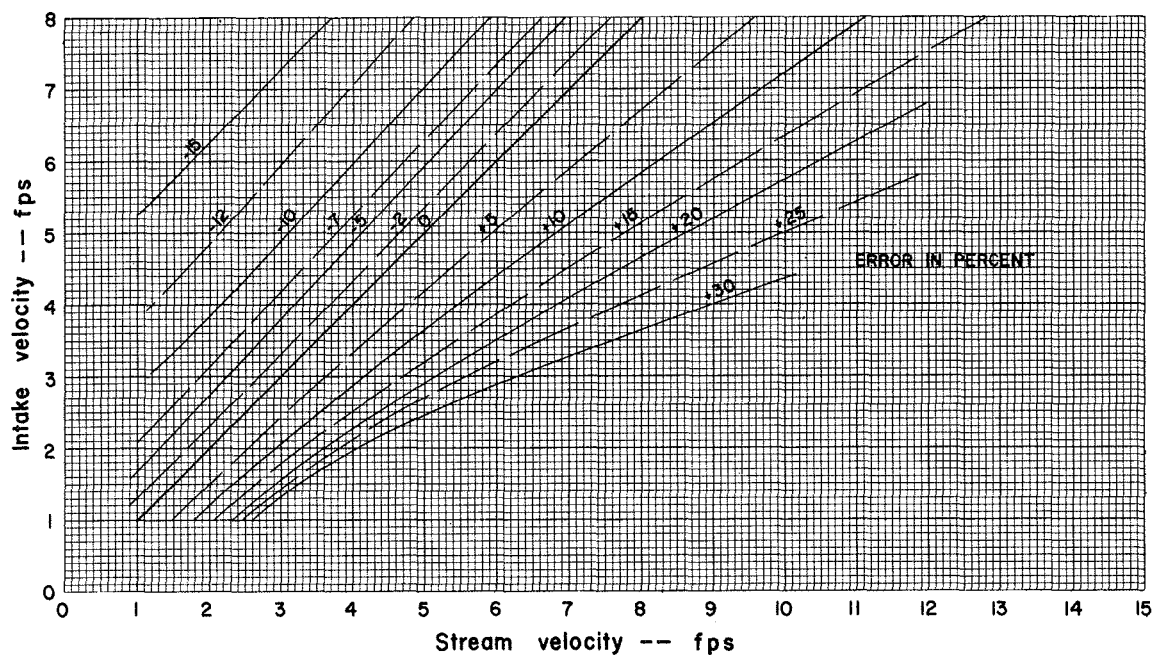


FIG. 10 - ERROR IN CONCENTRATION OF A SEDIMENT SAMPLE AS A FUNCTION OF INTAKE AND STREAM VELOCITIES, 450-MICRON SEDIMENT

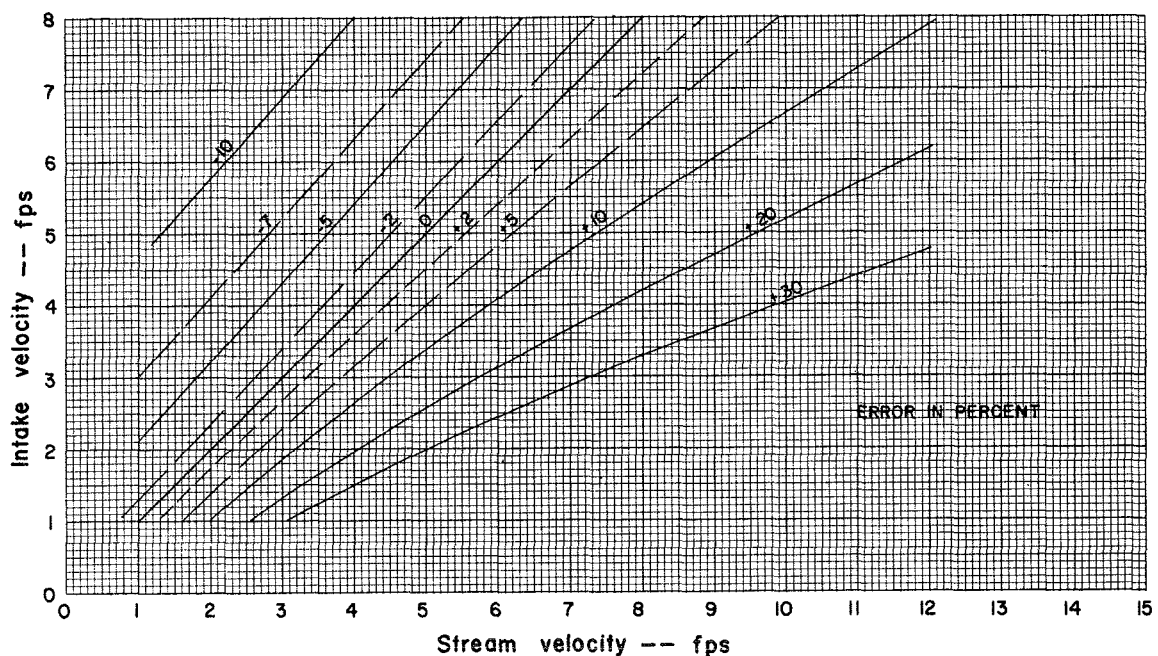
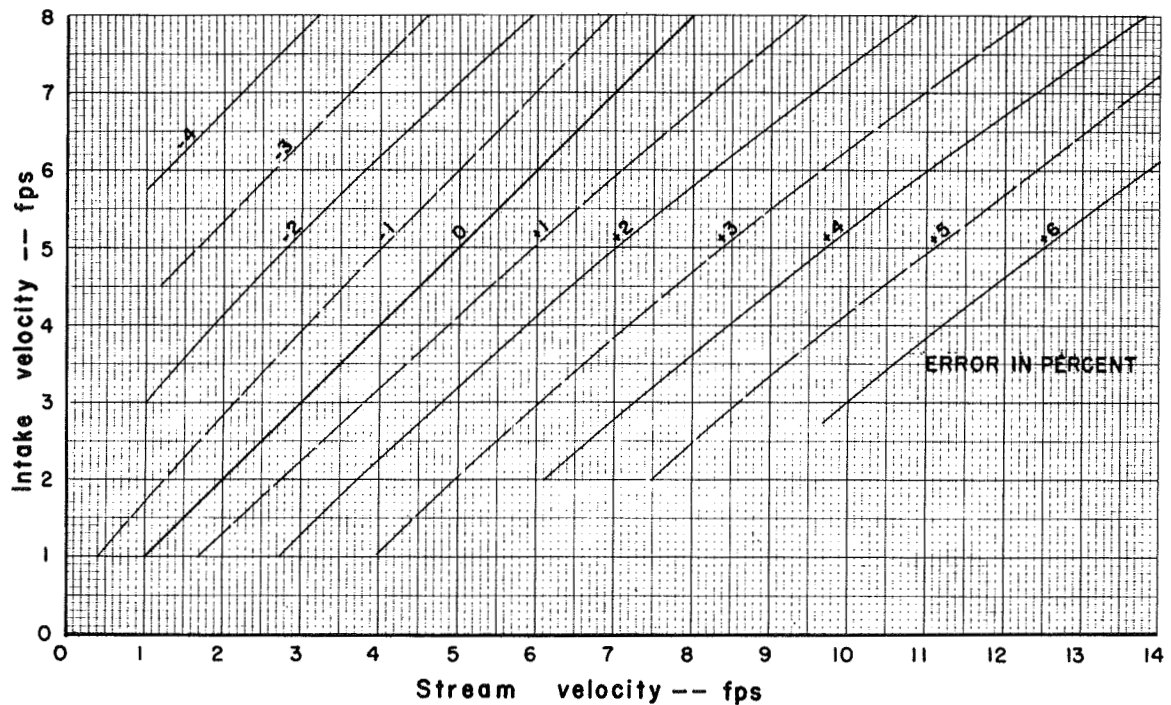


FIG. 11 - ERROR IN CONCENTRATION OF A SEDIMENT SAMPLE AS A FUNCTION OF INTAKE AND STREAM VELOCITIES, 150-MICRON SEDIMENT



**FIG. 12- ERROR IN CONCENTRATION OF A SEDIMENT SAMPLE AS A FUNCTION OF INTAKE AND STREAM VELOCITIES, 62-MICRON SEDIMENT**

19. Intake-velocity calibration of single-stage samplers--The primary sampling rates for various single-stage samplers (Figs. 15 and 16) were obtained by calibration in a flume where water temperature and velocity of flow were known. The velocity in the flume was determined with a small Price current meter. Intake velocity was computed from the rate of sample collection and the area of nozzle tip. Because the maximum depth of submergence was only a few inches, the sampler was lowered rapidly to the sampling depth, held for the desired time of sampling, and then raised rapidly to the water surface. (When the depth of submergence was less than that necessary to start sampling, the procedure was modified. The sampler was lowered sufficiently to start sampling, then raised to the proper sampling depth, and held for the remainder of the sampling time.) The recorded static head was the difference in elevation between the water surface and the inner end of the intake. The flow velocity of interest in the calibration is that at the sampling point; it will be called flume velocity. Generally, at low flume velocities the static head was the most effective, but at high velocities the velocity head was the most effective. Except for vertical-intake samplers, the intake was always pointed upstream. Calibration data for water temperatures of about 37° and 73° F are shown in Tables 3 and 4, respectively, and data for several samplers are plotted in Figs. 17 to 21. Because of the methods of placing the samplers in the flow, these tests represent a broader combination of static heads and flume velocities than field sampling will represent. Calibration at abnormally deep submergence has no direct

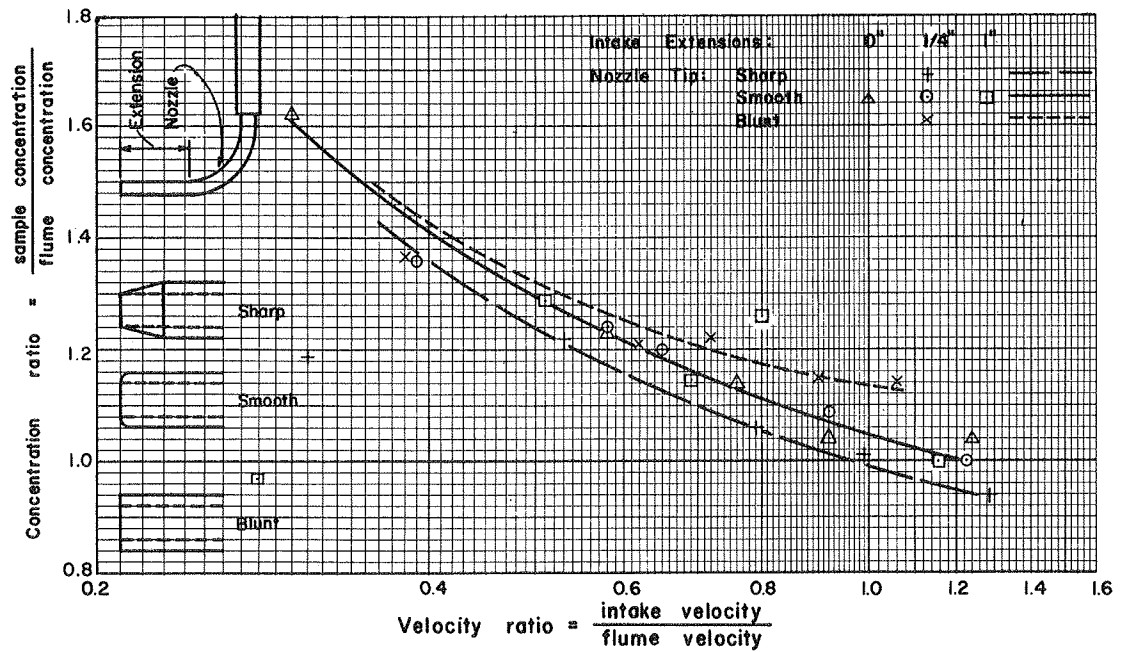


FIG. 13 — SAMPLING ACCURACY OF 3/16" HORIZONTAL INTAKE NOZZLES  
(SAMPLING VELOCITY 8.5 FPS; 550 MICRON SEDIMENT)

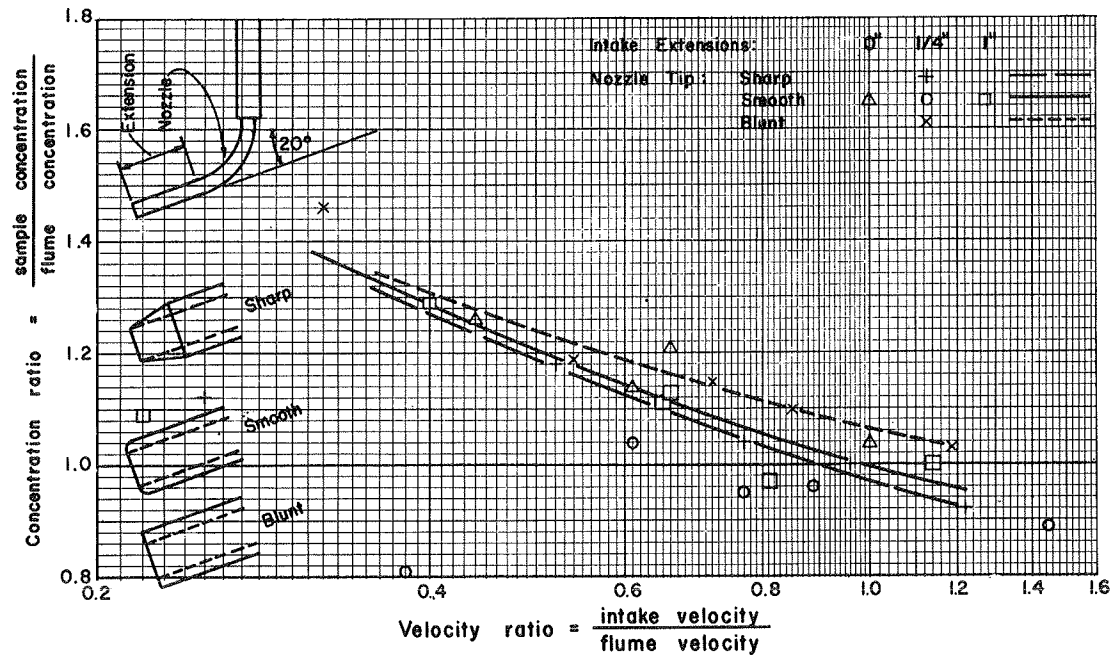
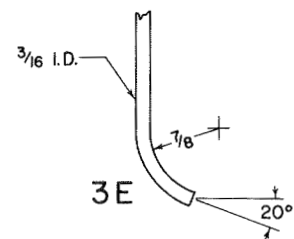
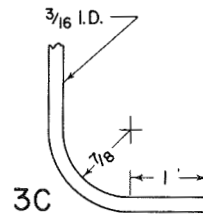
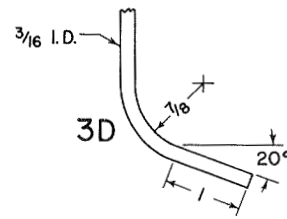
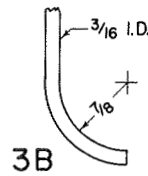
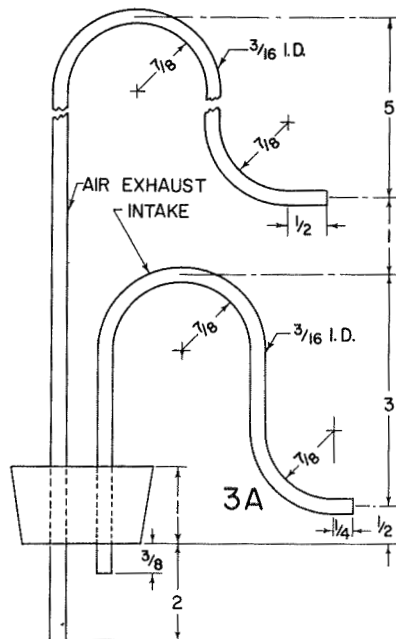
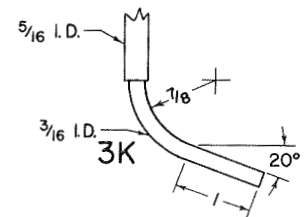
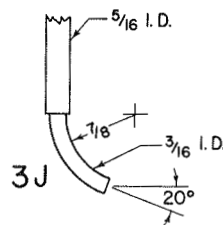
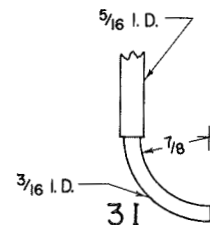
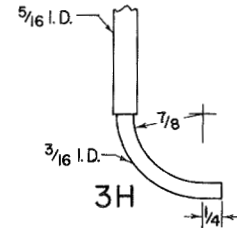
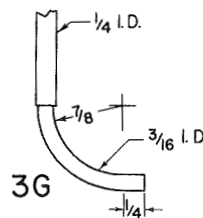
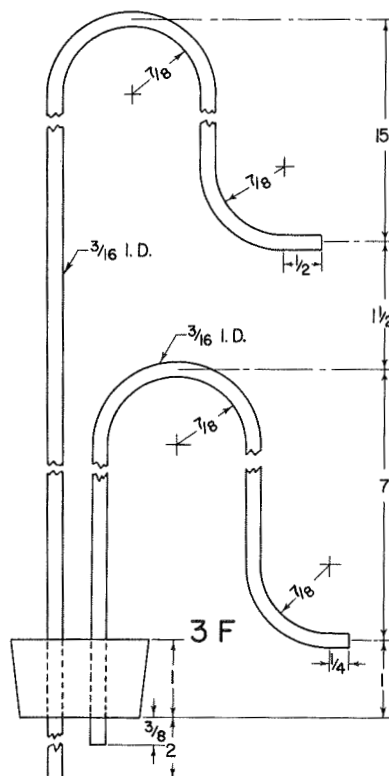


FIG. 14 — SAMPLING ACCURACY OF NOZZLES INCLINED 20° DOWNWARD  
(SAMPLING VELOCITY 8.5 FPS; 550 MICRON SEDIMENT)





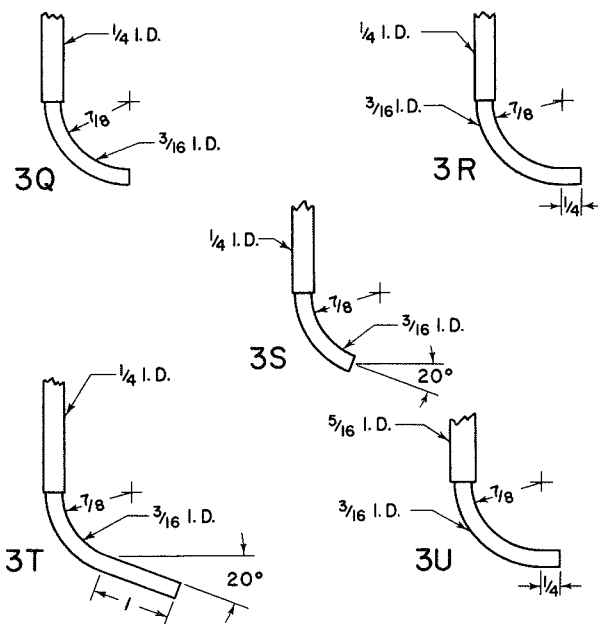
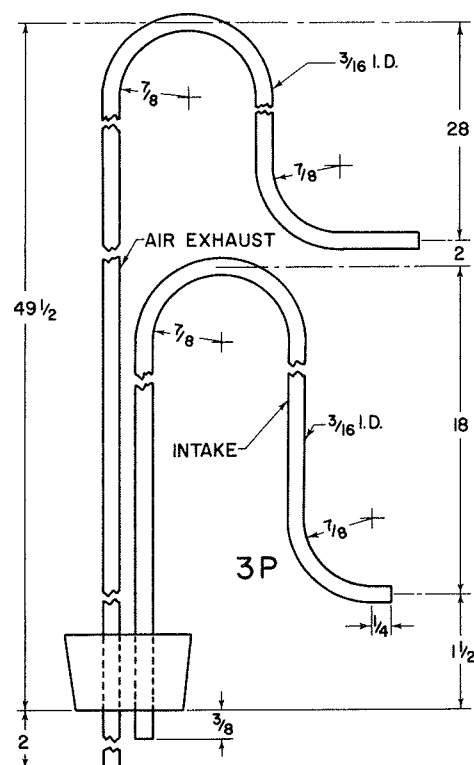
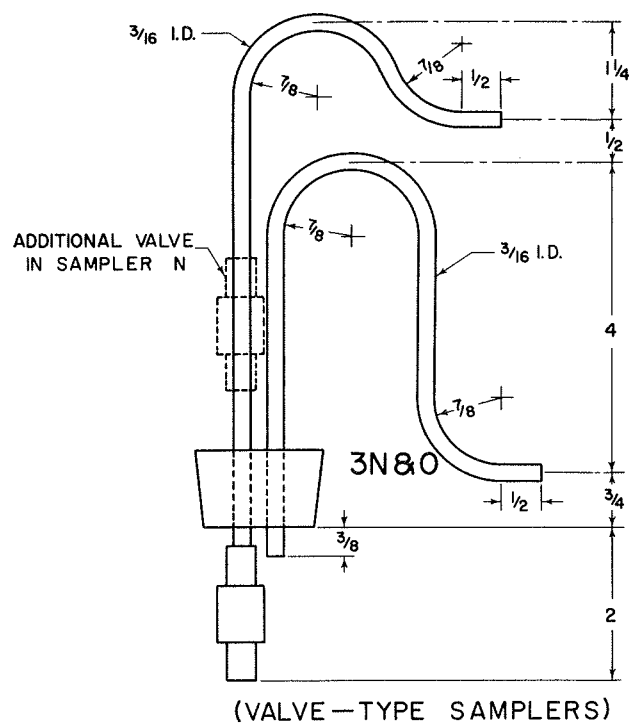
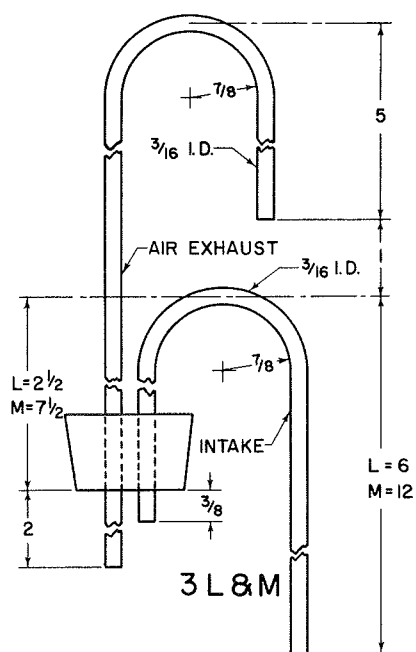
ALTERNATE INTAKES FOR SAMPLER "A"



ALTERNATE INTAKES FOR SAMPLER "F"

ALL DIMENSIONS IN INCHES

FIG. 15— SAMPLERS FOR INTAKE CALIBRATION,  
TYPES 3A TO 3K



ALTERNATE INTAKES FOR SAMPLER P

ALL DIMENSIONS IN INCHES

FIG. 16 - SAMPLERS FOR INTAKE CALIBRATION,  
TYPES 3L TO 3U

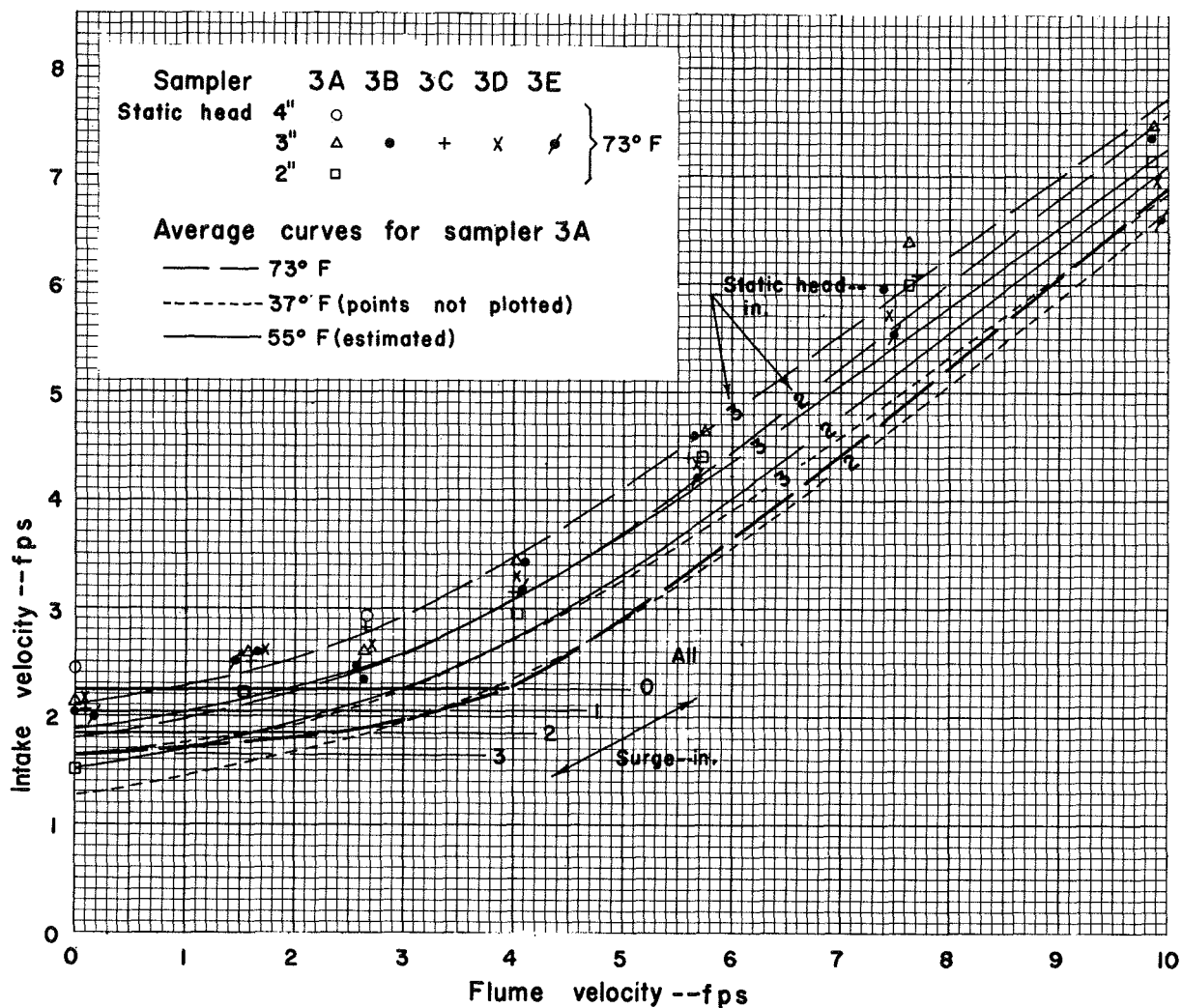


FIG. 17 - CALIBRATION OF LOW-VELOCITY SAMPLERS,  
TYPES 3A TO 3E

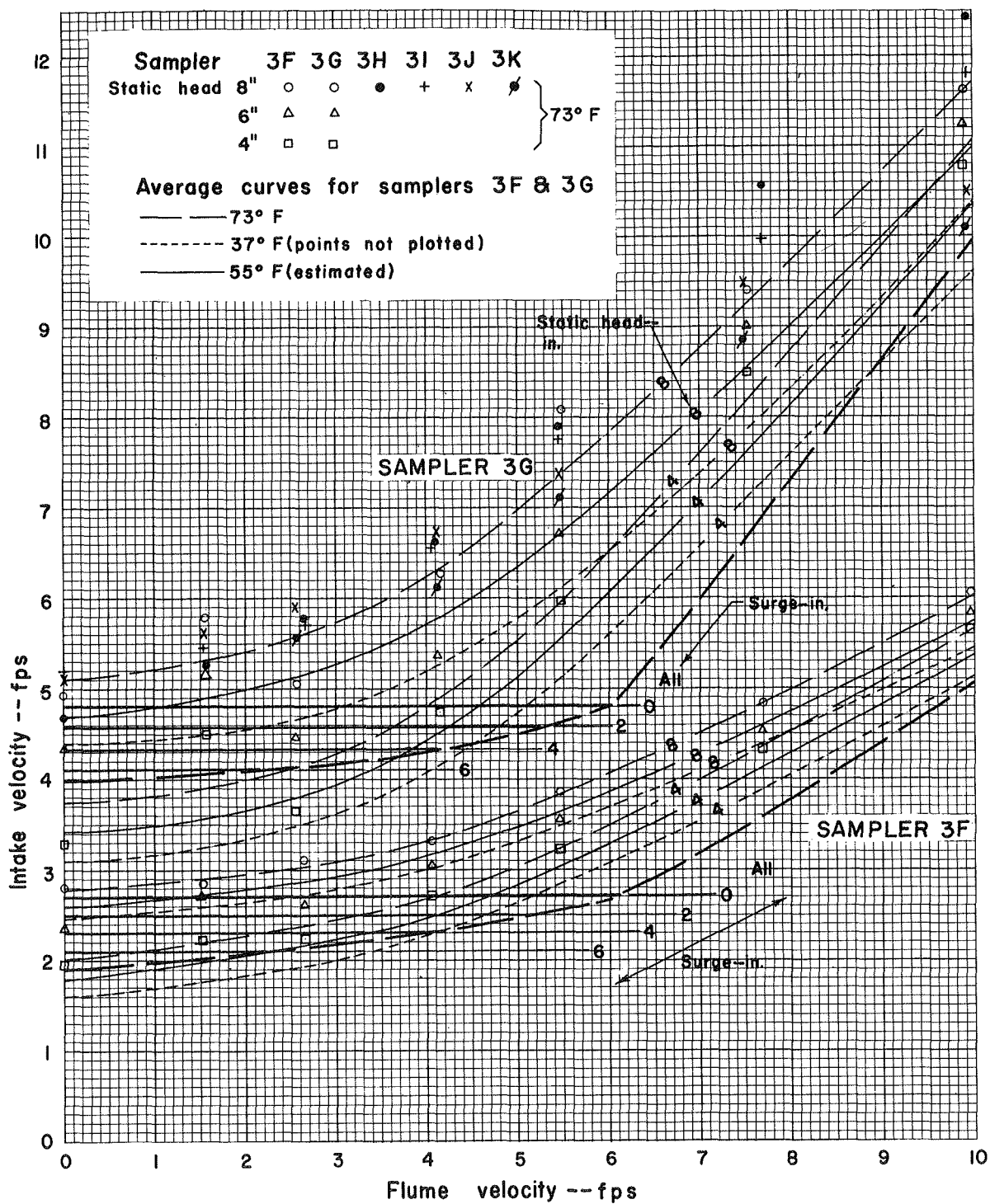


FIG. 18 - CALIBRATION OF MEDIUM-VELOCITY SAMPLERS,  
TYPES 3F TO 3K

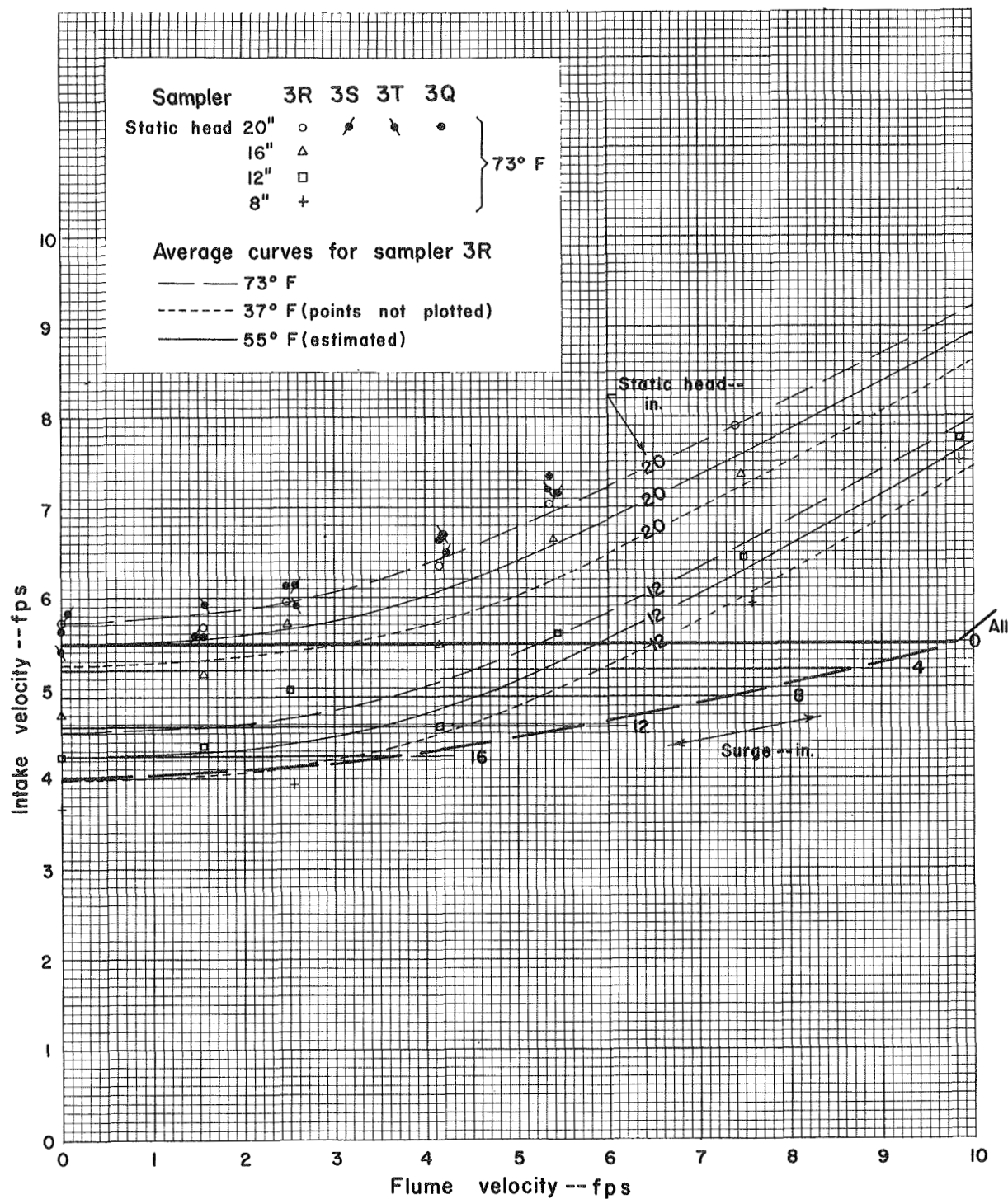


FIG. 19 — CALIBRATION OF HIGH-VELOCITY SAMPLERS,  
TYPES 3R, 3S, 3T, AND 3Q

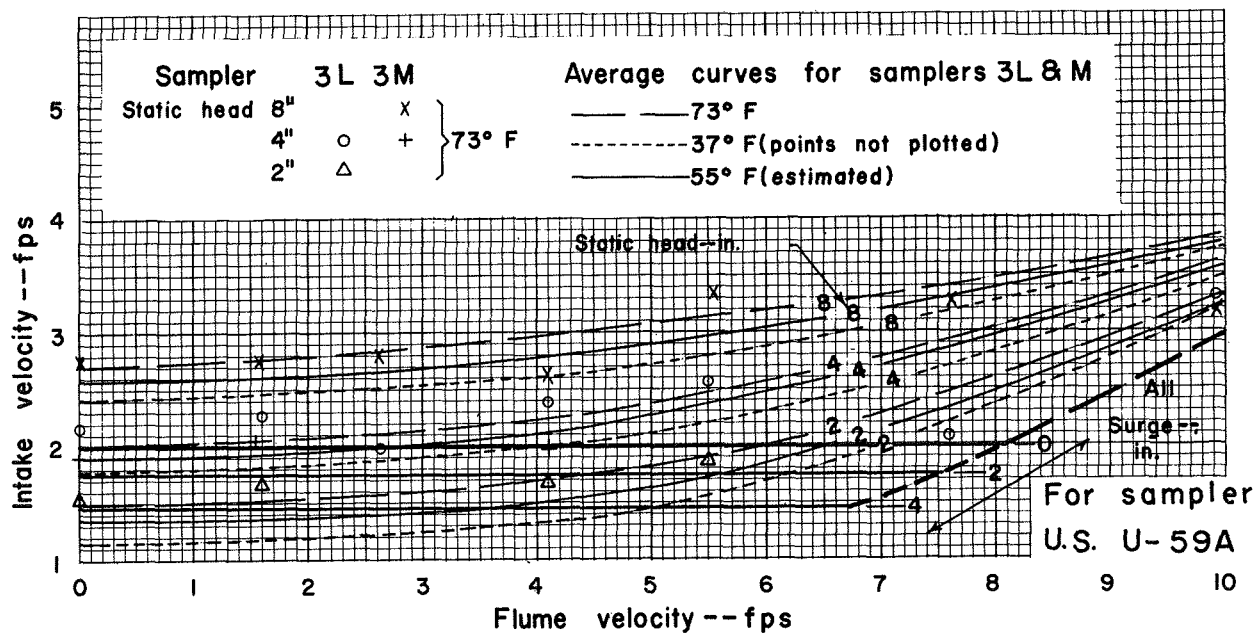


FIG. 20-CALIBRATION OF VERTICAL-INTAKE SAMPLERS,  
TYPES 3L AND 3M

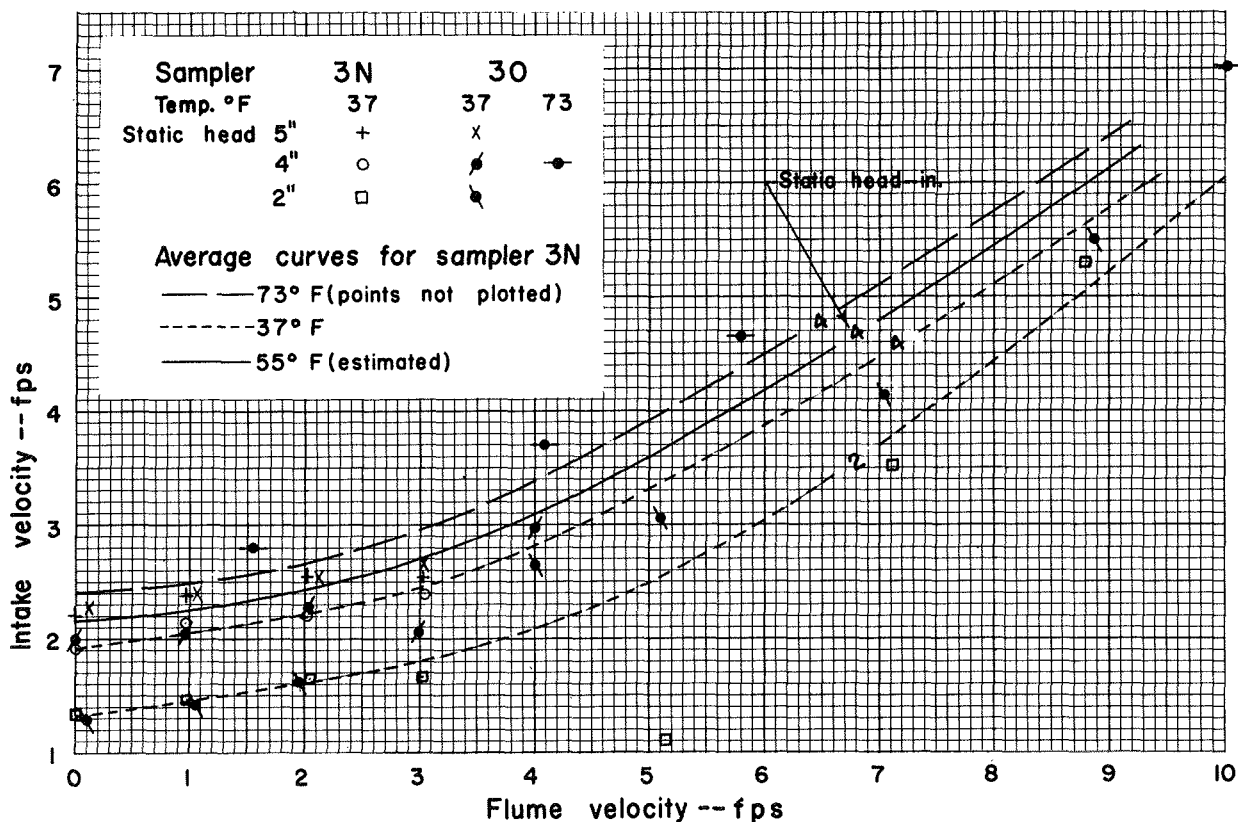


FIG. 21-CALIBRATION OF VALVE-TYPE SAMPLERS,  
TYPES 3N AND 30

application to normal sampling but indirectly helps to define intake velocities at some normal combinations of static head and flume velocity. Data obtained by starting sampling action and immediately changing to a lesser submergence, which is maintained for the remainder of the sampling time, show what happens when the average submergence is less than the starting submergence because of water-surface surges.

The intake velocity of a horizontal-intake sampler depends on the total of static head and velocity head during sampling. At the moment sampling is established, the total, or sampling, head is the difference in elevation between the crown and the inner end of the intake. If the velocity is zero, the total head is the static head, and sampling starts when the water surface rises to the elevation of the intake crown.

For the range of flume velocities over which the heavy horizontal (zero surge) line of Figs. 17 to 19 extends, the elevation at which sampling will start depends on the flume velocity. At higher flume velocities the velocity head exceeds the height of intake invert, and sampling begins when the nozzle first becomes submerged. At these high velocities the static head becomes relatively less important, the intake velocity is a function of the flume velocity, and sampling is intermittent from near the surface. (See the heavy broken lines of Figs. 17 to 19.) Sampling from the water surface starts at lower flume velocities and is at higher intake ratios when the intake invert (BC of Fig. 3) is short.

For a given temperature each sampler has a single characteristic sampling velocity or a normal velocity. The normal sampling velocity is the intake velocity at which sampling starts; also the sampling velocity in still water without surge; and, approximately, the sampling velocity for all continuous sampling without surge. The calibration data show that for a 3/16-in. intake the normal sampling velocities at 55° F are 2.25 (Fig. 17) and 2.7 fps (Fig. 18, sampler 3F) for sampling heads of about 4 and 8 1/2 in., respectively. For an intake that is 1/4 in., except at the tip which is 3/16 in., the normal sampling velocities are 4.8 (Fig. 18, sampler 3G) and 5.5 fps (Fig. 19) for sampling heads of 8 1/2 and 20 in., respectively.

A large increase in intake velocities can be obtained by using an intake tube 1/4 in. in diameter and a short nozzle 3/16 in. in diameter. A tube size of 5/16 in. further increased intake velocities, but the tubes did not always sample properly because of incomplete siphon action.

Minor changes in the outer end of the intake did not change the calibration significantly. Pointing the intake 10° or 20° downward made only slight differences. Increasing the length of the nozzle extension reduced the intake velocity only slightly.

Fig. 20 shows calibration data for vertical-intake samplers. Lines of normal sampling velocity and lines of velocities for sampling with surges are shown for

the U.S. U-59A sampler when the intake was upstream from the bottle. (The U.S. U-59 series of samplers is shown in detail in Figs. 39 to 42.) The calibrations of Figs. 17, 18 (3G), 19, and 20 are assumed to apply directly to the U.S. U-59B, U.S. U-59C, U.S. U-59D, and U.S. U-59A samplers, respectively.

Calibration for valve-type samplers (Fig. 21) is shown for comparison with calibration for the other horizontal-intake samplers.

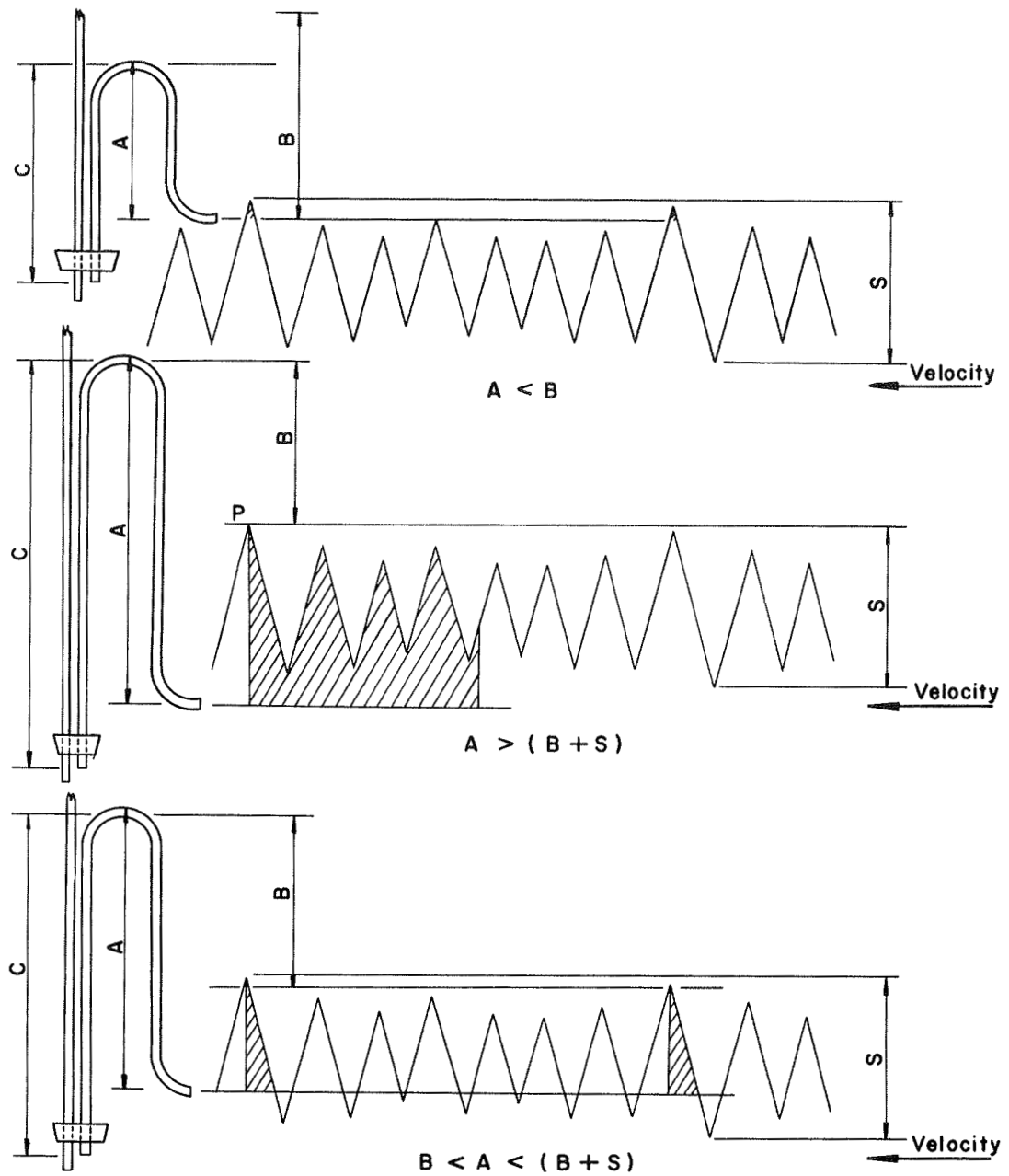
An example may make Figs. 17 to 20 easier to understand. For sampler 3G, (Figs. 15 and 18) the total head at which sampling starts is  $8 \frac{3}{8}$  in., which is the difference in elevation between the crown and the inner end of the intake. The minimum static head is  $1 \frac{3}{8}$  in. when the intake nozzle is just submerged. For the  $8 \frac{3}{8}$ -in. sampling head the intake velocity in still water at  $55^{\circ}$  F is 4.8 fps--extrapolated from 4.7 at a static head of 8 in. For a water temperature of  $55^{\circ}$  F and any flume velocity up to 6 fps the intake velocity will be 4.8 fps (with-out water-surface surges). For sampling in still water the water surface is at the crown of the intake; but as the flume velocity increases, the water-surface elevation for sampling becomes lower by the velocity head corresponding to the flume velocity. At a flume velocity just greater than 6 fps the velocity head is 7 in. (equal to the height of the outer leg of the intake), and sampling will start as soon as the water surface covers the intake. At higher flume velocities the sampling head is the velocity head of the flume flow plus a constant static head, and the intake velocity increases rapidly as flume velocity increases. For sampler 3G the intake velocity appears to equal the flume velocity at 10 fps. The two could not be equal if the intake were of uniform size throughout. The velocity is 10 fps only in the  $\frac{3}{16}$ -in. nozzle tip and about 6 fps in the  $\frac{1}{4}$ -in. main part of the intake.

20. Sampling from a surging water surface--In a surging water surface three types of sampling can occur. The type depends on the relation of sampler design to stream conditions. (See Fig. 22.)

If the velocity head  $\underline{B}$  is greater than the height  $\underline{A}$  of the intake invert, the sample is collected intermittently from water near the surface; it consists of small increments from the tops of the highest water-surface surges. The sampling head approximately equals the velocity head (actually the sampling head is the velocity head plus the difference between  $\underline{C}$  and  $\underline{A}$ ), and the intake velocity is a function of the stream velocity. Sampling starts at an average water-surface elevation about half of the surge height  $\underline{S}$  below the outer end of the intake.

If  $\underline{A}$  is greater than  $\underline{B} + \underline{S}$ , sampling is continuous. Sampling starts at a point  $\underline{P}$  and continues until the sample is complete. The intake nozzle is below the bottom of the surges. The average sampling head is approximately  $\underline{C} - \underline{S}/2$ . Sampling starts at an average water-surface elevation at a distance approximately  $\underline{B} + \underline{S}/2$  below the crown of the intake. The stream velocity that starts sampling is probably greater than the average during sampling.





$A$  = height of outer leg of intake  
 $B$  = velocity head  
 $C$  = height of inner leg of intake  
 $S$  = height of water-surface surge  
 /// = sampled portion

FIG. 22- SAMPLING FROM A SURGING WATER SURFACE

A third type of sampling that is intermediate between the other two occurs when  $\bar{A}$  is greater than  $\bar{B}$  but less than  $\bar{B} + \bar{S}$ . Errors caused by acceleration and deceleration, by nozzle deposits, and by low concentration in the intake can be disregarded for a single cycle of sampling. However, errors may be significantly large and unpredictable for several cycles of sampling.

Figs. 17 to 20 show the relation of intake velocity and flume velocity for a water temperature of 55° F and for different water-surface surges. Data of Fig. 19 are used for illustration. The samplers had an inner leg height  $\bar{C}$  of 20 in. and an outer leg height  $\bar{A}$  of 18 in. (nomenclature of Fig. 22). For a surge of 16 in. the average sampling head was  $20 - 16/2$ , or 12 in., and the intake velocity was 4.25 fps at zero flume velocity. For an intake surge of 8 in. the average sampling head was  $20 - 8/2$ , or 16 in., and the intake velocity was 4.9 fps by interpolation between the intercepts of the 55° F calibration curves for static heads of 12 and 20 in. on the zero flume velocity line. The 4.9 fps was the intake velocity for all continuous sampling at a surge height of 8 in., and sampling was continuous (second condition of Fig. 22) for all flume velocities below 7.3 fps. The velocity head at 7.3 fps is 10 in., which added to an 8-in. surge was equal to the height of the outer leg of the intake.

Horizontal lines for other surges were drawn in similar manner, and each represents an intake velocity for continuous sampling over a range of flume velocities. Between zero and maximum surges, the heavy broken line was defined by the maximum flume velocity for continuous sampling at different surges--that is, the flume velocity for which the corresponding velocity head added to the surge height equaled the height of the outer leg of the intake invert. At zero surge the velocity head alone (9.8-fps flume velocity) equaled the height of the outer leg of the intake. Thus, between flume velocities of 7.3 and 9.8 fps, sampling was of an intermediate type (third condition of Fig. 22); the intake velocities increased slowly as the flume velocities increased; and a sample was composed of more and smaller increments as the flume velocity increased. At flume velocities larger than 9.8 fps, sampling starts whenever the water surface covers the outer end of the intake, sampling is from the tops of the water-surface surges only, and the relation of intake velocity and flume velocity is the same for all surges (first condition of Fig. 22). For flume velocities exceeding 9.8 fps, the heavy broken line was obtained from 5.5-fps intake velocity and 9.8-fps flume velocity, and it was extended upward as an extrapolation of the calibration data for higher static heads down to a static head of about 2 in. (the difference in elevation between the intake nozzle and the inner end of the intake).

21. Errors in primary sampling--In Figs. 23-25, errors in concentration to be expected of horizontal-type samplers U.S. U-59B, U.S. U-59C, and U.S. U-59D, respectively, are plotted against the velocity at the sampling point. The errors are the effects of unfavorable intake velocity or nozzle orientation on the primary sample. These errors were computed from data of Fig. 17 sampler 3A, Fig. 18 sampler 3G, and Fig. 19 sampler 3R together with Figs. 10 to 12. As an example, consider sampler 3G of Fig. 18: For a stream velocity of 4 fps

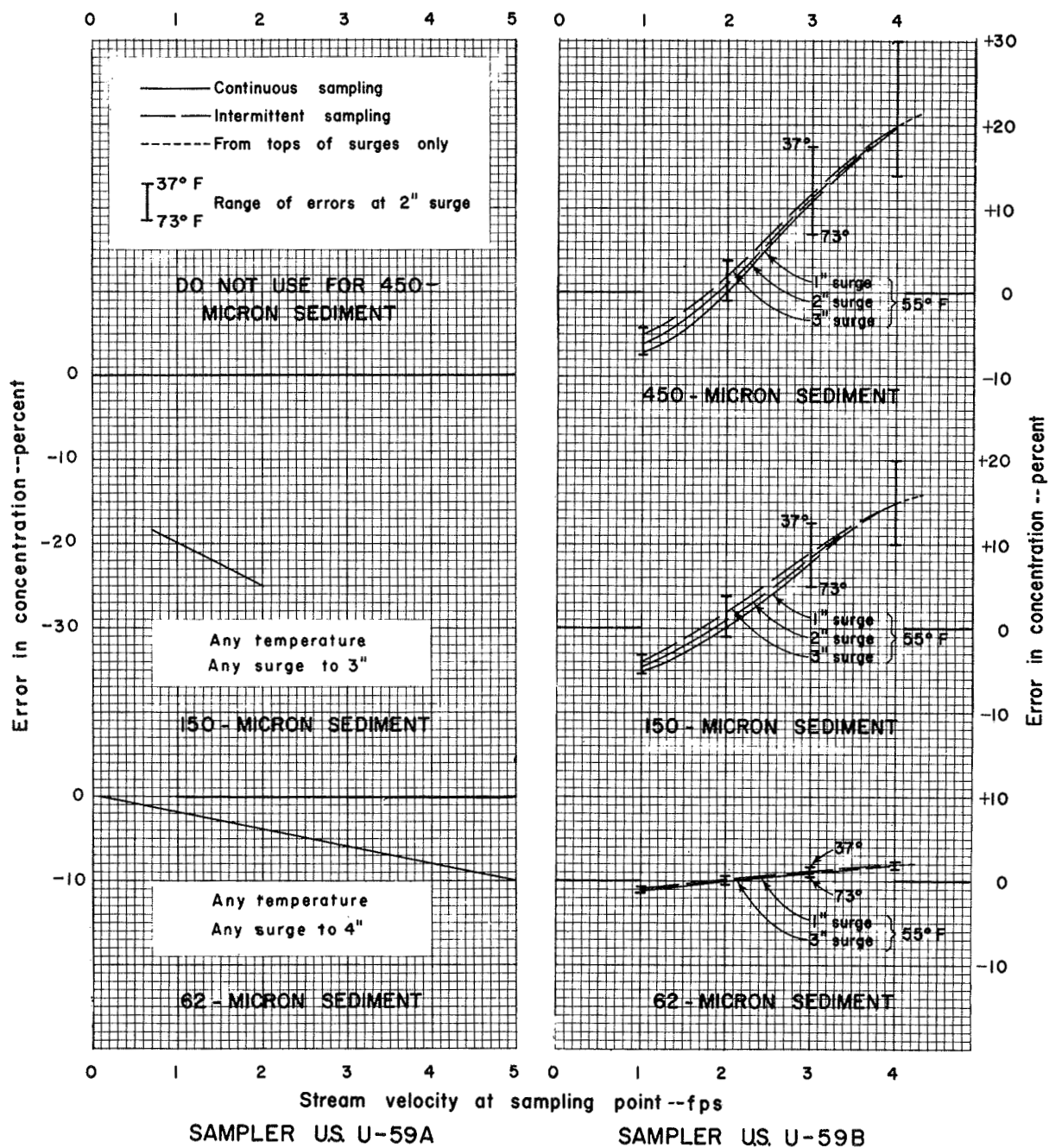


FIG. 23- SAMPLING ERRORS FOR LOW-VELOCITY SAMPLERS

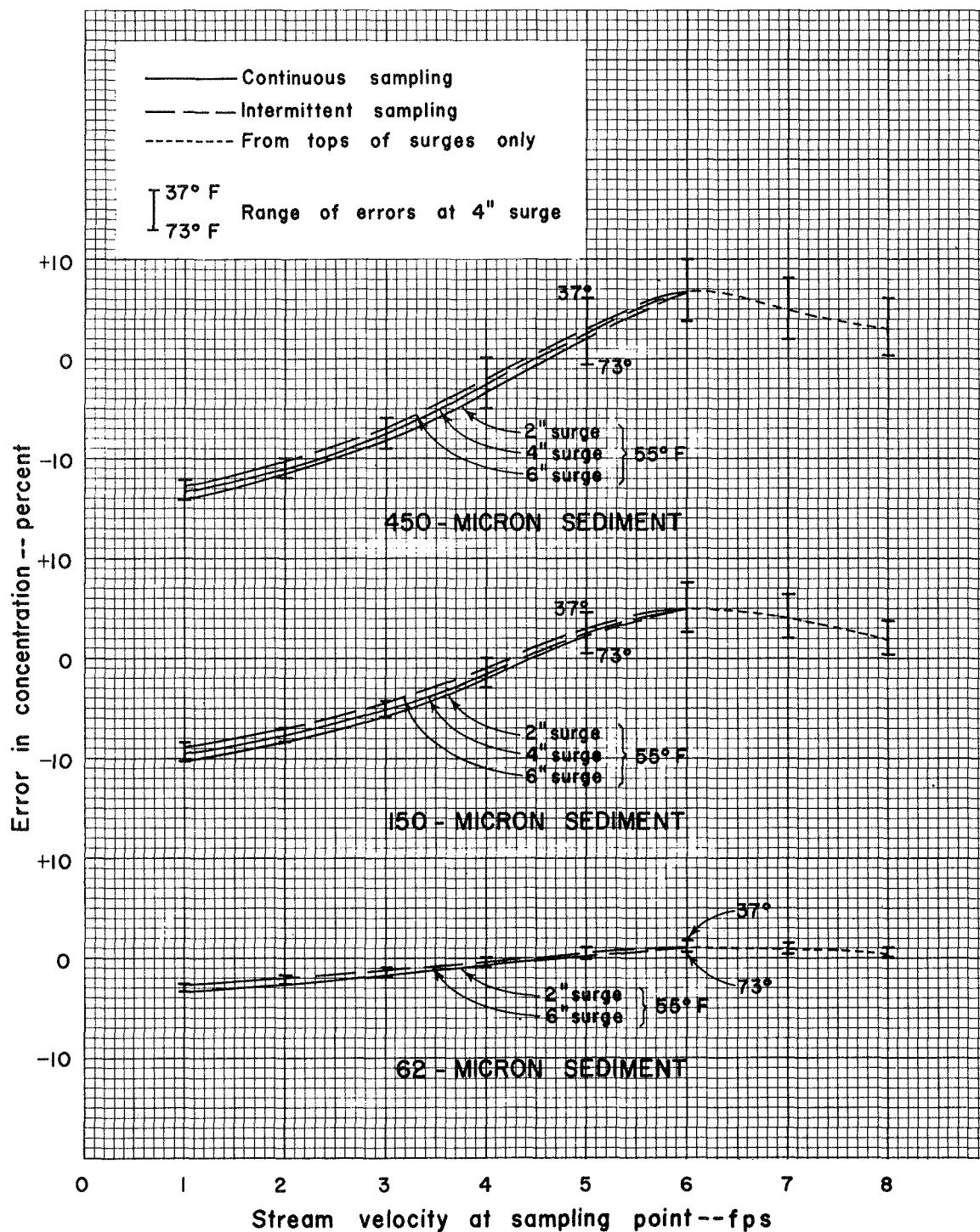


FIG. 24- SAMPLING ERRORS FOR MEDIUM-VELOCITY SAMPLER, U.S. U-59C

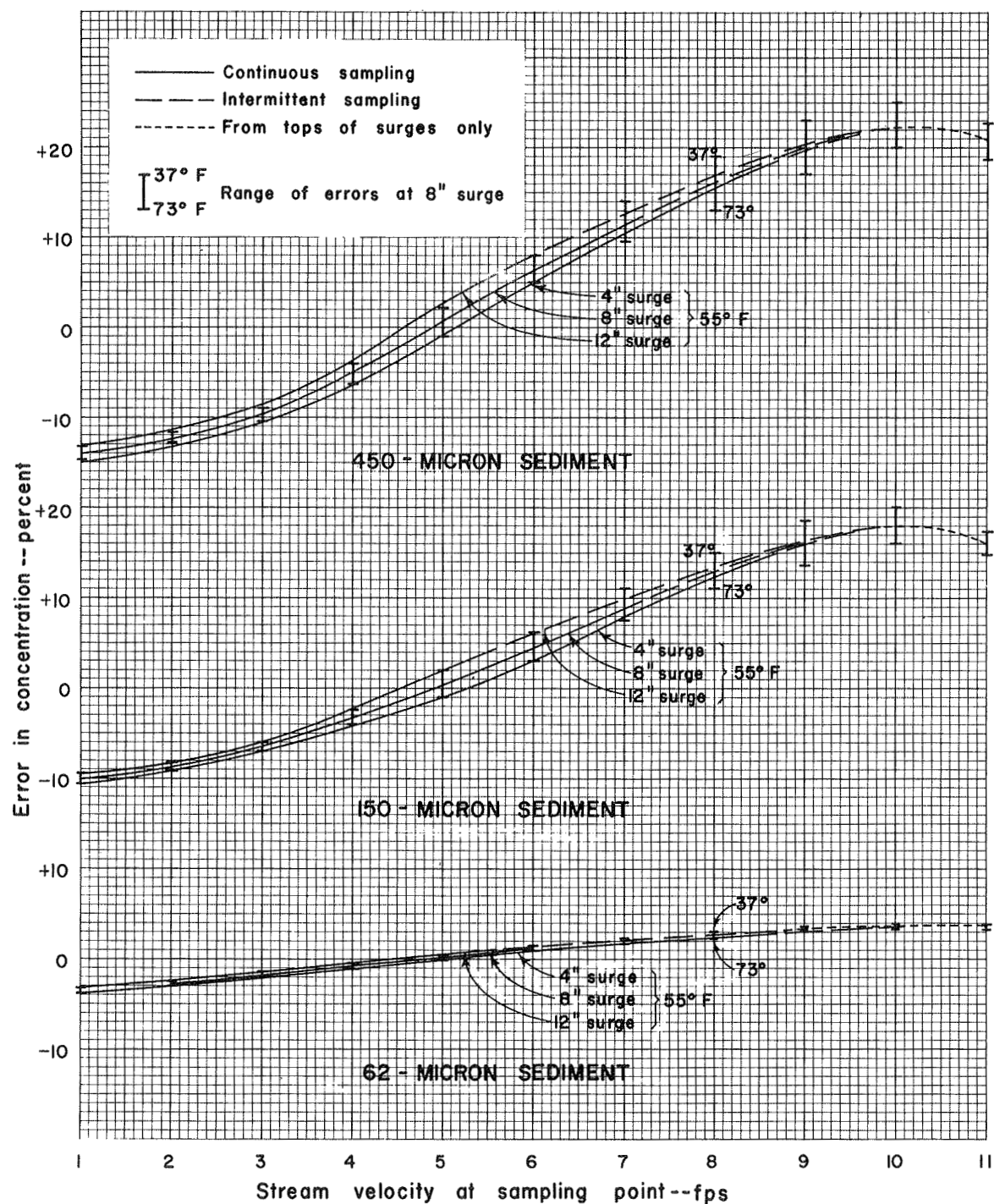


FIG. 25 - SAMPLING ERRORS FOR HIGH-VELOCITY SAMPLER, U.S. U-59D

and a water-surface surge of 4 in. the intake velocity is 4.3 fps at 55° F; and if temperature corrections are made, the intake velocities are 4.0 and 4.7 fps at 37° and 73° F, respectively. From these intake velocities and Fig. 11 the errors for a stream velocity of 4 fps, 4-in. water-surface surge, and 150-micron sediment are 0, -1.5, and -3 percent at 37°, 55°, and 73° F, respectively, as shown in Fig. 24.

Errors in concentration for vertical-intake samplers were estimated from Report No. 5 and from a few tests made recently (Fig. 9).

The expected errors of Figs. 23 to 25 are those of the sample in relation to the concentration at the sampling point. The percentage error for the total sample may be much less than that shown for the coarse sediments if the total sample contains only a small portion of coarse sediments. The correction to the sample to obtain the stream concentration is not numerically the same as the errors shown in Figs. 23 to 25. At low corrections the difference is minor; but if the indicated error for the sample is +20 percent, the concentration in the sample is 1.2 times that in the stream. However, the sample concentration should be reduced by 16.7 percent to obtain the concentration in the stream at the sampling point. Corrections can be made only if the stream velocity at the time of sampling is known within reasonably close limits.

Suppose sampler 3R (or a U. S. U-59 D sampler) is used in a stream having a temperature of 65° F and a velocity of 7 fps at the sampling point. What will be the error in sampling 250-micron sediment if the water-surface surge is 6 in. ? From Fig. 25 the error for a 6-in. surge and 450-micron sediment at 55° F is +11 percent. The temperature correction is -2 percent from 55° to 73° F (the temperature effect is about the same for all surges) so 65° F gives an error of +10 percent. Similarly, the error for 150-micron sediment is +8 percent. The concentration of 250-micron sediment in the sample will be 9 percent high and should be reduced by 8 percent to obtain the concentration at the sampling point.

The errors shown in this section are expressed precisely because they are for sampling conditions that are known exactly. However, corrections for errors in field sampling may not be justified because the conditions at the time of sampling are not known accurately or because errors other than those of the primary sample are large.

22. Circulation through the sampler--If, after the original sample is taken, the difference in pressures between the nozzle and exhaust port exceeds the resistance to flow through the sampler, water-sediment mixture will enter the port having the higher pressure and discharge from the other port. The forces that resist flow through the sampler are: (1) inertia of the fluid, (2) friction, and (3) unequal pressures in the two legs of the inverted U-tubes. The inertia of the fluid is effective only against a rapid acceleration or deceleration of flow and may be disregarded. Similarly, friction merely retards flow and cannot prevent circulation if flow is incipient. There is no static resistance to flow

through a U-tube if the tube is completely filled with either air or water. Because the intake is full of water at the time of sampling and may be full at other times, it does not offer any dependable resistance to circulation.

Circulation can occur if the pressure difference between nozzle and exhaust port exceeds the resistance of the air exhaust to flow. When the water surface is just below the outer end of the air exhaust, a velocity head greater than DE of Fig. 3 will cause circulation. If at any time during submergence of both nozzle and exhaust port the unbalance of velocity heads on horizontal ports exceeds DE, circulation may occur. When the exhaust port is submerged, an air bubble is trapped in the inverted U-tube. The bubble will not be lost unless circulation occurs. However, deep submergence reduces the volume of the bubble--50-percent reduction at a submergence of 32 ft. If the bubble becomes too short to fill the outer leg of the exhaust, the head required to start circulation becomes less than DE of Fig. 3.

Horizontal velocity across an intake nozzle pointed vertically downward will create a negative pressure that may approach the velocity head. Both intake and exhaust openings should point in the same direction to avoid unbalanced pressures when the sampler is fully submerged.

Circulation of water-sediment mixture through a sampler can result in greatly increased concentrations of sediment in the sample. At the time of circulation, the sediment concentration in the stream is probably as high or higher than at the time the original sample was taken. The water that enters the sampler during the circulation cycle has about the same sediment content as the stream; but in the comparatively still water in the sampler, much of the sediment settles to the bottom. The water-sediment mixture that escapes from the sampler is relatively clear water from the top of the sample. Consequently, the original sample will be enriched, especially in the coarse sizes of sediment.

Circulation may not be detectable in the sample because the volume is unchanged; therefore, every possibility of circulation should be eliminated.

23. Prevention of circulation--Circulation of water-sediment mixture through the sampler can be prevented by making the height of the air exhaust invert greater than the maximum possible differential head between the intake and exhaust ports. Velocity heads corresponding to various velocities are shown in Fig. 26. The air exhaust could be subject to a differential pressure equal to the velocity head at the intake nozzle so that the height DE of Fig. 3 should exceed by a reasonable margin of safety the maximum velocity head just before the air-exhaust port is submerged.

Valves arranged as shown in samplers 3N and 3O of Fig. 16 have been used to prevent circulation. Although most valves make an undesirable obstruction if used in the intake, a self-closing valve can be used in the air exhaust. The valves were intended to allow the escape of air through the exhaust

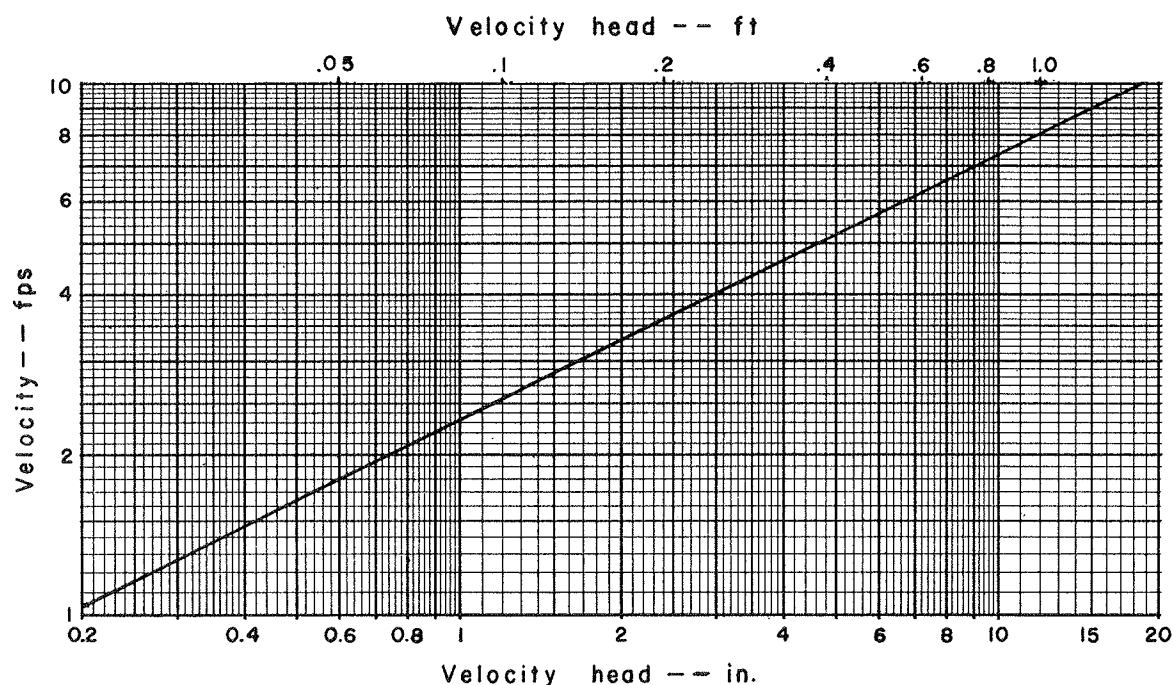


FIG. 26— VELOCITY HEAD

but to prevent the passage of water. One type of self-closing valve was tested extensively, and other ideas and designs were investigated; but none were satisfactory. Sometimes the valves closed prematurely because of the high air velocities in the exhaust, and sometimes they failed to close completely. Even though the valve closed prematurely, it generally leaked; therefore, the volume of sample was normal, but some of the sample was collected at an abnormally low intake velocity. The use of a valve in the exhaust does not allow reduction of the height of intake invert and does not reduce accretion to the sample during submergence subsequent to sampling.

A suggestion to point the intake upstream and the exhaust downstream to increase the pressure on the valves and seat them securely was investigated. The problems (1) of increasing the intake-invert height to prevent intermittent sampling, (2) of water-surface drawdown at the exhaust port at high stream velocities, and (3) of maintaining the exhaust port at an adequate height above the inner end of the intake required a sampler almost as tall as a sampler without any valves. At low stream velocities the samplers often failed to fill, and at high stream velocities the valves tested generally snapped shut before an adequate sample was taken. If the exhaust pointed downstream, sampling was sensitive to stream velocity and, therefore, was not dependable unless the stream velocity was close to that for which the sampler was designed. The stage at which sampling will begin is often difficult to predict.



24. Sample changes due to subsequent submergence--After the primary sample has been taken, the water surface in the sample container stands at approximately the elevation of the inner end of the air exhaust, and the intake is full of water-sediment mixture. Because of momentum in the filling operation the sample will have a volume about 2 ml greater than that required to fill the sample container to the elevation of the inner end of the exhaust. A few moments later the water in the inner leg of the intake may have drained into the bottle, but the volume of air in the sampler is not changed. (The approximate volume per inch of length is about 0.45 ml for a 3/16-in. tube and 0.8 ml for a 1/4-in. tube.) For this discussion, assume that the inner leg of the intake drains completely. The original sample leaves an air pocket of about 60 ml if the inner end of the exhaust is 2 in. below the stopper.

If the sampler is submerged by a continued rise in the stream, the pressure on the sampler is increased and the volume of air between F and G (Fig. 3) is reduced. As the air volume decreases during normal operation, additional water-sediment mixture enters the sampler. When the depth of submergence is decreased, the air in the sampler expands and forces air or water from the sampler. If the height of the air-exhaust invert is greater than the height of the intake invert or if the air exhaust is completely closed by a valve, the expansion will force air into the intake and may cause air bubbles to be expelled at the nozzle. Accretion due to submergence subsequent to primary sampling can be eliminated only by completely closing both the intake and the exhaust.

Assume that atmospheric pressure is 32 ft of water.

Then,

$$V_h = \frac{32 V_o}{32 + h} \quad (\text{Boyle's Law})$$

If

$$V_h = \text{volume at a submergence } h \quad (h \text{ is in feet})$$

and

$$V_o = \text{volume at } h = 0$$

This relation of volume and submergence is shown in Fig. 27.

The volume of accretion for any sampler and a single submergence cycle can be found from Fig. 27 by locating the air volume  $V_o$  (60 ml for the U. S. U-59A and the U. S. U-59B) and following the curves of reduction in volume out to the depth of submergence. At a submergence of 20 ft, the original 60 ml has been reduced to 37 ml. The accretion to the sample--that is, the volume that will enter to replace the reduction in air volume--is  $60 - 37$  or 23 ml.

An abnormal situation can occur if the air-exhaust invert is not taller than the intake invert and if the air-exhaust tube is not completely closed by a valve.

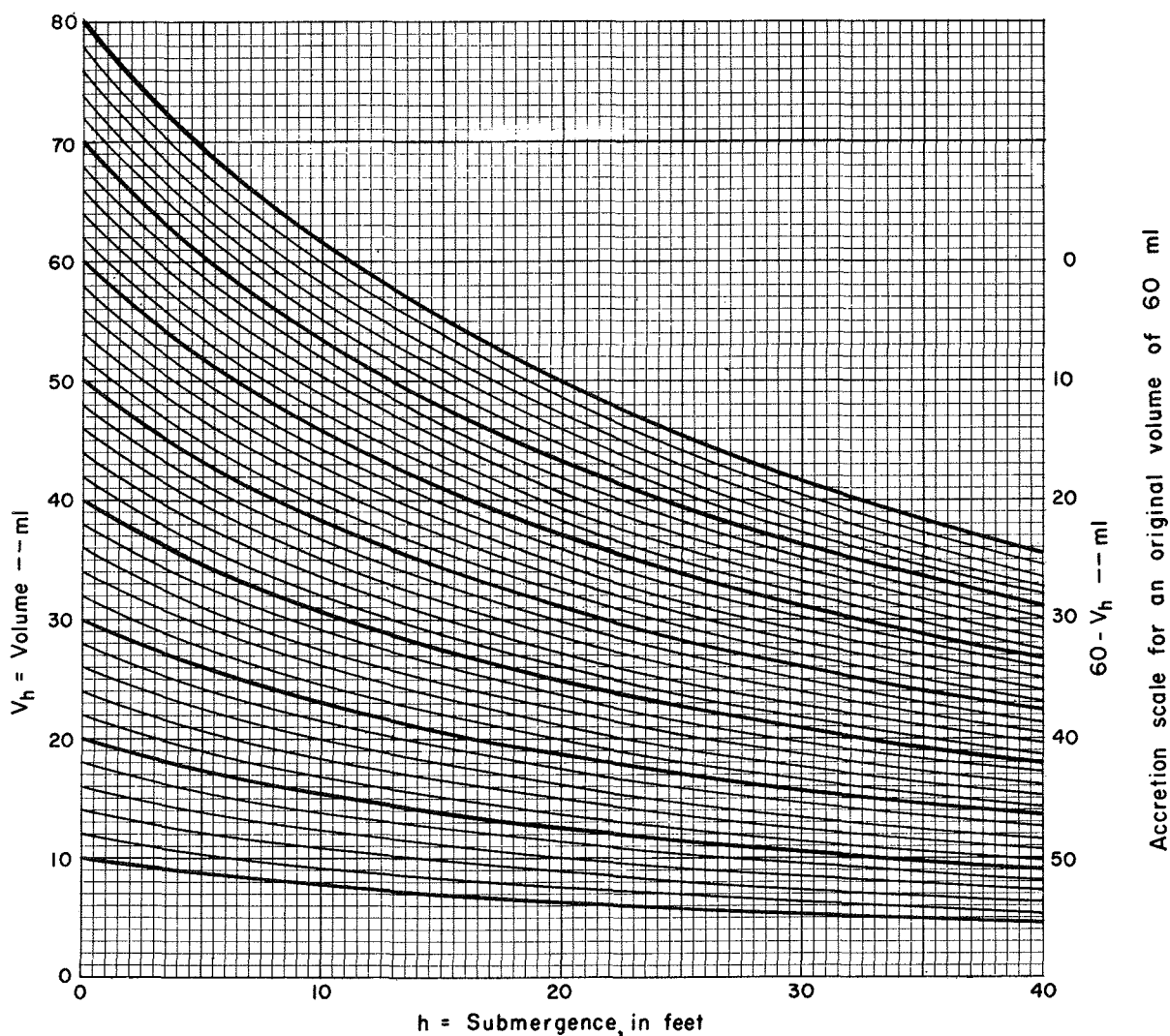


FIG. 27 - CHANGE OF AIR VOLUME WITH SUBMERGENCE

Then increased submergence causes water to enter the sampler through the air exhaust. If the air exhaust fills with water, surge enrichment can begin immediately and circulation through the sampler may occur later. After submergence the volume of the sample may be normal, although the sediment concentration in the original sample may have changed radically.

25. Accretion from repeated submergence--Fig. 28 shows computed accretions to a sample during three consecutive submergence cycles at 0-5, 0-10, 0-20, and 0-40 ft for the U.S. U-59B, U.S. U-59C, and U.S. U-59D samplers.

The computation for the U.S. U-59B sampler subjected to three cycles at 0-20 ft is as follows: The curve for a  $V_0$  of 60 ml (Fig. 27) shows an accretion

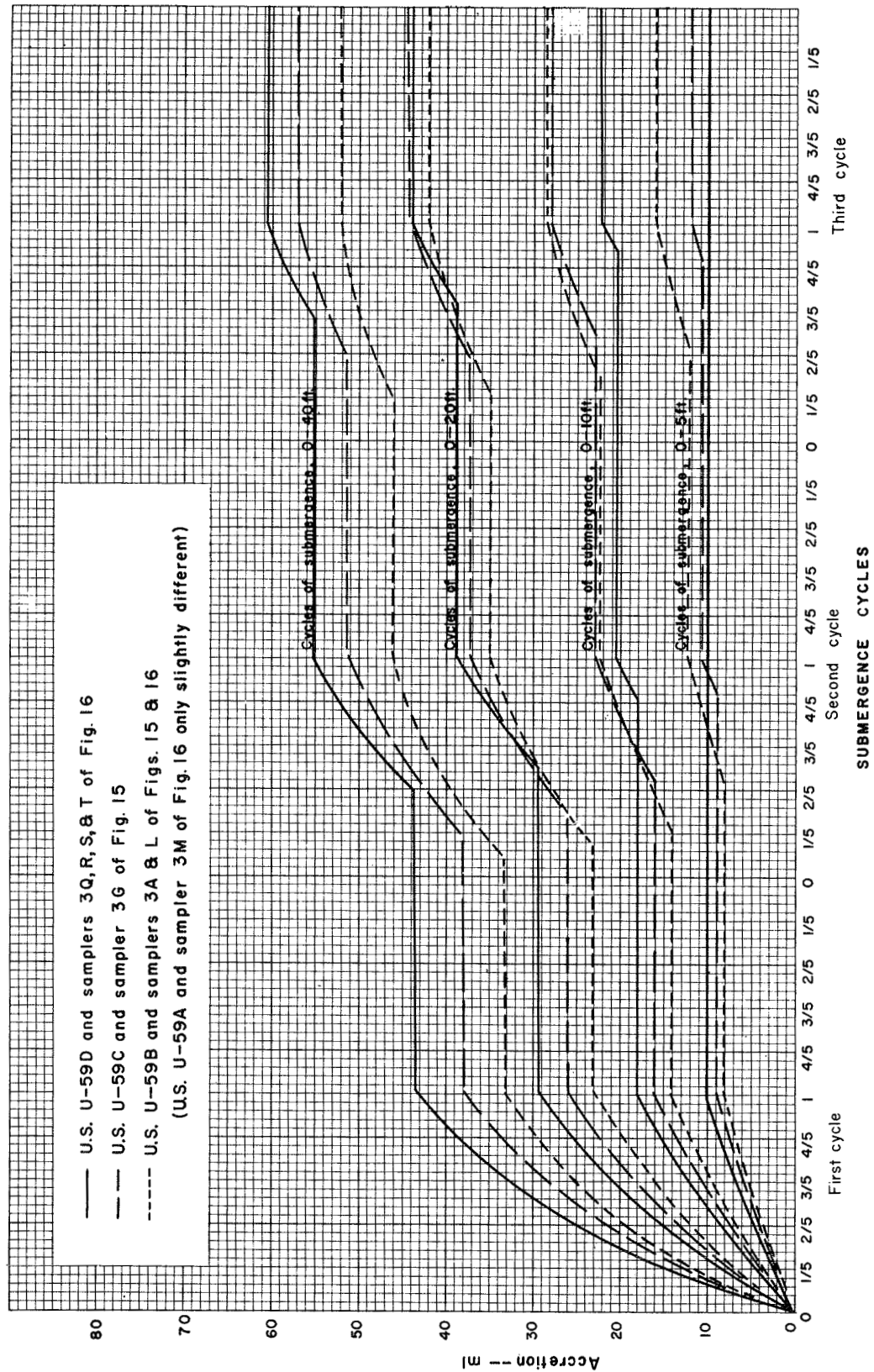


FIG. 28—ACCRETION FROM CONSECUTIVE CYCLES OF SUBMERGENCE

of 23 ml at a submergence of 20 ft. As the submergence decreases to zero, the accretion does not change. However, the remaining 37 ml of air expands and fills the outer leg of the intake, which has a volume of 3 ml. The rate of expansion in relation to submergence is the same as that on the increasing submergence side of the cycle. The air volume follows the  $V_O = 60$  ml curve of Fig. 27 back to 40 ml at 16-ft submergence. Further decreases in submergence cause air to discharge from the sampler intake so that the volume of air in the container at the end of the submergence cycle will be less than that at the beginning of the cycle. On a second submergence cycle the reduction in air volume follows the  $V_O = 40$  ml curve. The accretion remains 23 ml until the submergence equals 2.5 ft and then increases to 35 ml at a submergence of 20 ft. As the second cycle of submergence subsides, the accretion remains at 35 ml but the air volume of 25 ml increases to 28 ml at 14-ft submergence and stays at 28 ml to zero submergence. The accretion on a third cycle can be computed from the accretions along a curve for a  $V_O$  of 28 ml.

The following procedure illustrates accretion for an irregular cycle. After an initial submergence to 20 ft, the curve for  $V_O = 60$  ml still applies. If the submergence subsides to 19 or 17 ft, or to any depth greater than 16 ft, and then increases again, no air is lost through the intake and the accretion remains 23 ml. If the submergence then increases beyond 20 ft, the accretion increases as though the initial rise had not been interrupted. If the original submergence to 20 ft had subsided to 10 ft and then increased, the  $V_O$  curve for the second rise would have been the curve for 40 ml at  $h = 10$  ft extended back to  $V_O = 52.5$  ml. The air volume for additional submergence above 10 ft would follow the  $V_O = 52.5$  curve. The accretion remains 23 ml to a submergence of 13.5 ft and then increases.

Accretions shown in Fig. 28 for the U. S. U-59C sampler under repeated submergence were computed by the preceding methods except that the volume in the outer leg of the intake was assumed to be 7 ml and the original volume of air 68 ml. In the previous computations the volume of air in the exhaust was disregarded. The effect for air exhausts that have a 6-in. invert amounts to about 1 or 2 ml at most, and this is partly offset by surges that keep an inch or two of water in the ends of intake and exhaust. As the air in the outer leg of the exhaust is compressed, it is replaced by water from the stream; and as the air expands, the water returns to the stream. The water does not stay in the sampler, and the unbalance of pressure at the top of the air exhaust is minor. So the outer leg of the air exhaust can be disregarded. However, the compression and expansion of air in the inner leg of the exhaust draw water into the intake and cause air to be expelled at the nozzle. For the U. S. U-59C the volume of the inner leg of the exhaust cannot be ignored. The volume of about 11 or 12 ml consists of about 3 or 4 ml of water and about 8 ml of air after the inner leg of the intake has drained and the exhaust has partially drained. The original  $V_O$  for the U. S. U-59C is 60 ml in the bottle and intake plus 8 ml in the exhaust, and the accretion is based on 68 ml minus  $V_h$ .

Similar procedures, with a  $V_o$  of 78 ml, were used to compute accretion for the U. S. U-59D sampler.

26. Apparatus for studying accretion to the sample--Although many of the effects of pressure on submerged single-stage samplers seemed to be obvious, other effects could not be predicted accurately. Therefore, a pressure tower was constructed to permit observations of the action of the samplers under conditions approximating those in a river. (See Fig. 29.) A 18-in. pipe tee was attached to the bottom of a 12-in. standpipe 20 ft long. Two opposite ends of the tee were covered with 3/4-in. plexiglas windows to permit observation. Two 6-in. pipes were welded into the other sides of the tee so that a horizontal jet could discharge parallel to the windows.

River water was supplied to one 6-in. connection through an elbow meter in which the flow could be measured. Valves controlled the supply and the discharge. The horizontal jet could discharge freely across the tee, or the pressure could be built up by partly closing the outlet valve so that water would rise in the standpipe. The water-supply portal could be modified from a 6-in. diameter to an elongated orifice. The samplers were introduced at the top of the standpipe, lowered to the test location in the 18-in. tee, and supported in place.

Sediment could not be circulated in the pressure tower. The effects of velocity, surge, and submergence were observed in terms of air and water elevations and surges in the intake and exhaust tubes of the sampler. The pressure-tower turbulence, as shown by variations in velocity head, was of the magnitude expected in a stream. The eddies were smaller than those in most streams.

27. Computed and experimental accretion--Fig. 30 shows curves of computed accretion for sampler 3L of Fig. 16 and for a special sampler that was similar to sampler 3A of Fig. 15 except that the air exhaust extended only 1 3/4 in. below the bottle stopper and the intake extended 1 in. below the stopper. The accretions determined in the test tower (see Sec. 26) for sampler 3L were almost identical with those computed from Fig. 27. The accretions for sampler 3F in the test tower are 2 and 3 ml greater than the computed accretions for sampler 3L for the second and third submergence cycles, respectively, because the computations did not include the volume in the air exhaust, which is about 5 or 6 ml greater than that in the inner leg of the exhaust of sampler 3L. The tests proved the validity of the computation procedures.

The test data for the special sampler also followed the computed accretion closely. An accretion of only 23 ml raised the sample surface to the inner end of the intake. When submergence that had produced an accretion of 23 ml or more subsided, the accretion fell back to 23 ml. After the sample reached the inner end of the intake, it was unreliable because of surge enrichment.

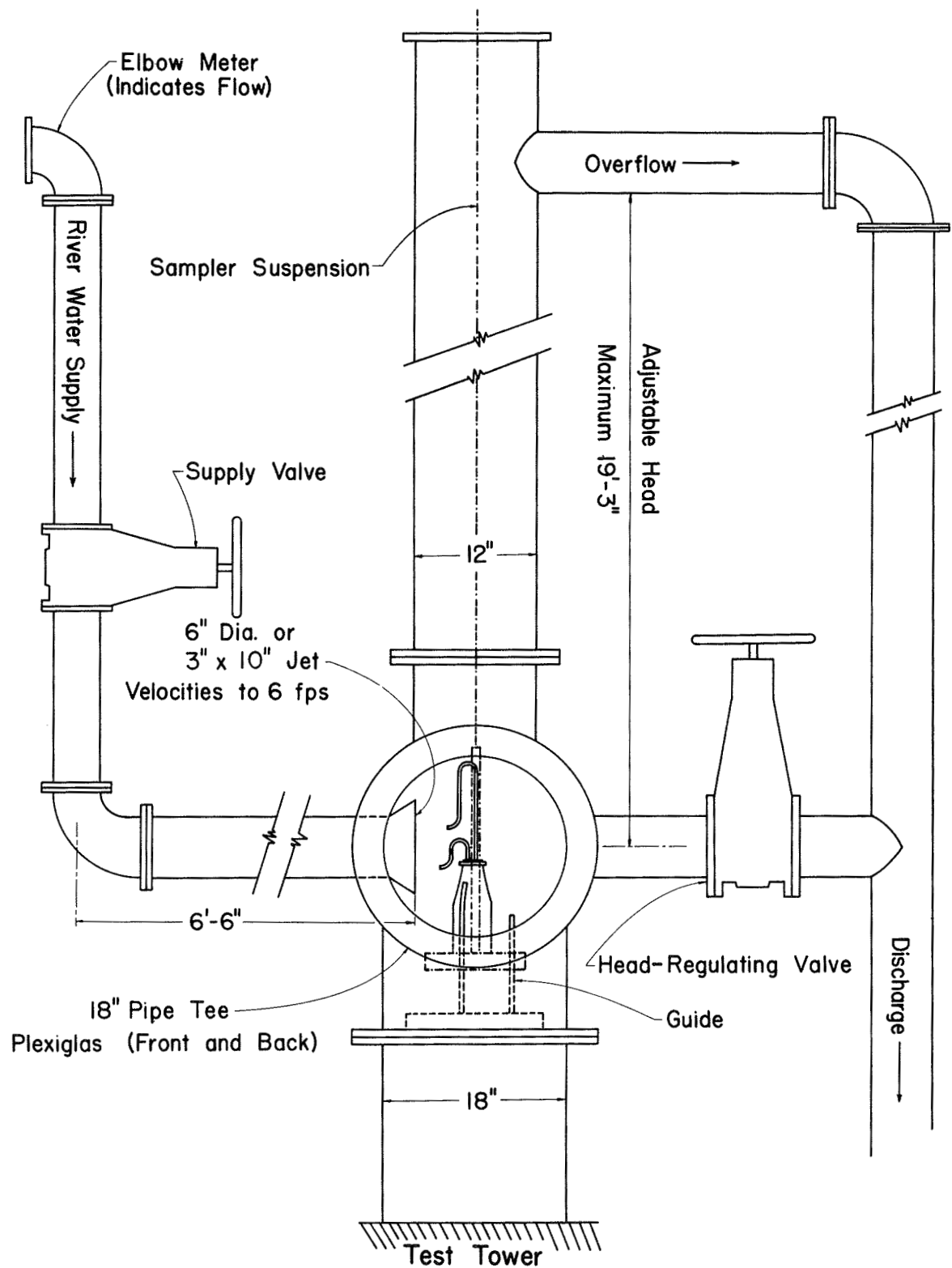


FIG. 29- TOWER FOR SUBMERGENCE TESTS

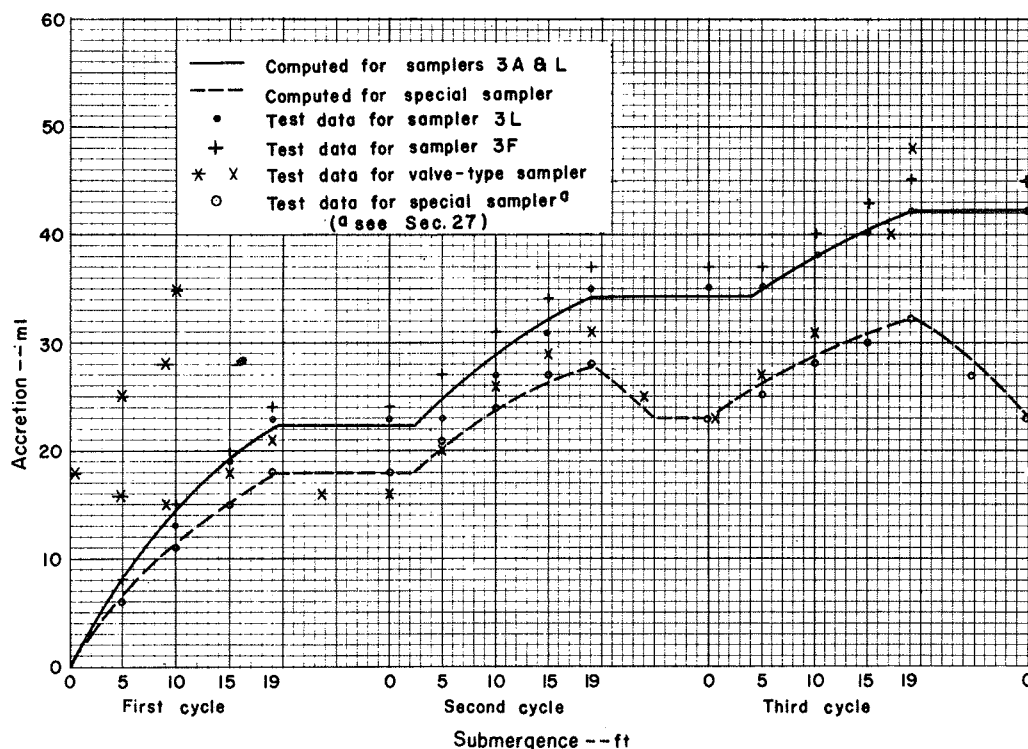


FIG. 30-TEST TOWER DATA ON SAMPLE ACCRETION

Samplers having valves in the exhaust were also tested for accretion (3N of Fig. 16). Generally, the valves did not close tightly; and if the closure was incomplete and if the exhaust invert was relatively short, the samplers filled rapidly and erratically. The x points of Fig. 30 were from the test for which valve operation was the most satisfactory. When the valves closed completely, the test data followed the solid curve as they did on the increasing submergence part of the first cycle. However, the valves leaked and permitted part of the sample to discharge through the air exhaust whenever the submergence decreased. Near the end of the increasing submergence part of the third cycle, the valves failed completely. Sometimes the valves failed on rising submergence and sometimes on falling submergence. In field sampling, failure of the valves probably could not be detected. Whenever water enters or discharges through the exhaust, the sample may be quickly ruined by surge enrichment.

Table 5 shows the basic data for Fig. 30 and additional test data for other conditions. If allowance is made for variations in intake drainage, the test data check the computed accretions within the probable accuracy of the accretion measurements. The volume of accretion can be kept small by making the original air pocket in the container small, but such a solution increases the possibility of surge enrichment, which is a far more critical source of error. (See Secs. 30 to 32.)

An accretion of 53 ml in any of the samplers of Figs. 15 or 16 raises the sample to the inner end of the intake and causes the intake to fill with water. Then intakes having inverts only a few inches high quickly fill with water, but intakes having higher inverts can withstand greater depths of submergence. Any sample that has reached the inner end of the intake is of questionable accuracy; and if the intake invert is low, surge enrichment has probably occurred. Although submergence can raise the water surface above the inner end of the intake, the water surface will go back to about the inner end of the intake when the submergence subsides unless there is leakage around the top of the bottle.

The volume of accretion can be determined within general limits either by computation or by measurement. It will seldom exceed 10 percent of the volume of the original sample and will usually be much less. Because the change in stage of a stream is relatively slow and a rise of 1 ft causes only about 2 ml of accretion, the water is added to the sample a drop or two at a time. Such addition carries very little coarse sediment.

Temperature affects the air volume in the sampler. However, because a temperature change of 50° F makes a difference of only about 10 percent in air volume, the effect of temperature has been disregarded in this discussion.

28. Sediment added by accretion--Concentrations of sediment that enter the sampler under conditions simulating accretion in stream sampling are shown in Fig. 31. For the accretion tests, sampler 3A of Fig. 15 was filled with distilled water to just above the inner end of the exhaust and then immersed in the sedimentation jar described in Section 13. Three size ranges of sediment at concentrations of 1,000 and 10,000 ppm were used at different times. A surge of either 1 or 2 in. was imposed on the intake. Water was slowly withdrawn from the bottle so that water-sediment mixture was drawn into the intake at a rate of about 2/3 ml per minute, which is the accretion rate for a stream rise of about 1/2 fpm at low submergence. Fluid entered the sampler a few drops at a time. The average concentration in the water added from the 10,000-ppm mixture was about 6,500, 2,700, and 1,600 ppm for size ranges finer than 62, 62-125, and 125-250 microns, respectively. The concentration was greater for the 2-in. surges than for the 1-in. surges.

The height of the surges is significant in relation to the height of the outer leg of the intake invert. In the tests a 2-in. surge is 2/3 of the invert height. (The height of the invert should exceed the surge height.) The height of surge in the intake is approximately equal to the height of water-surface surge only when the intake is submerged and the air exhaust is not. During accretion both intake and exhaust are submerged, and the surge depends on differential pressures between the two. The pressures are functions of the scale and intensity of turbulence in the stream. Normally, a sampler having a high intake invert would be used in a fast turbulent stream so that the invert would be much higher than the surge in the intake.

The concentration of sediment in the accretion is shown in Fig. 31. For sediment finer than 62 microns the concentration is about 0.7 of that at the



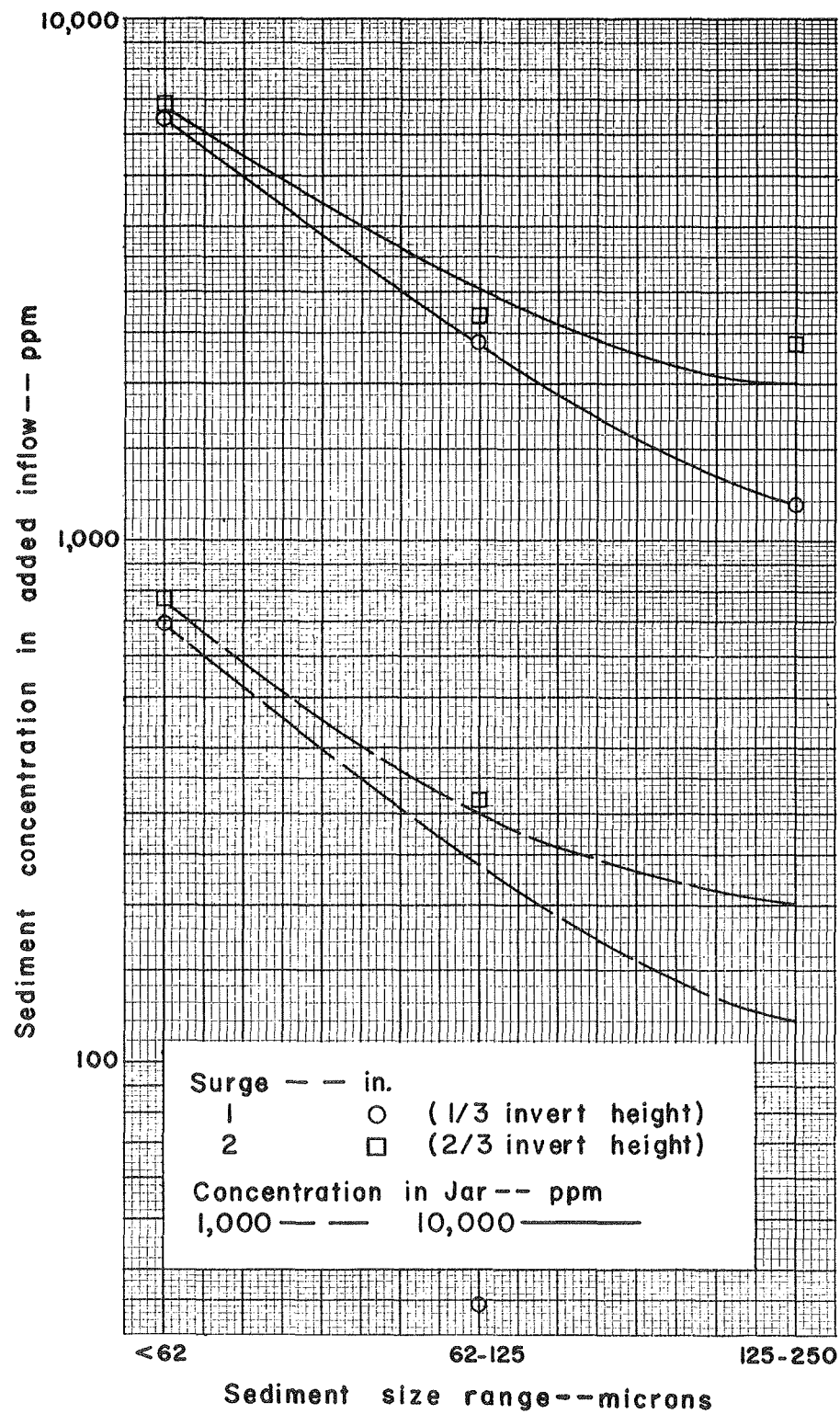


FIG. 31- SEDIMENT CONCENTRATION IN INFLOW  
 ADDED BY ACCRETION  
 (SAMPLER 3A OF FIG. 15)

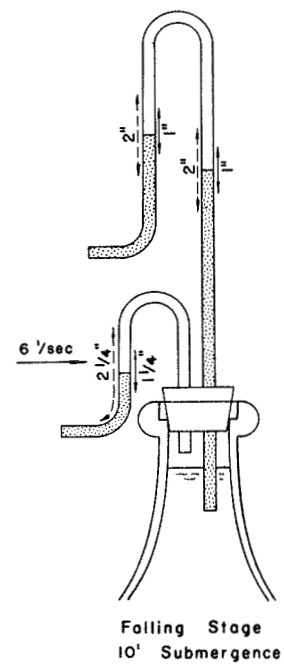
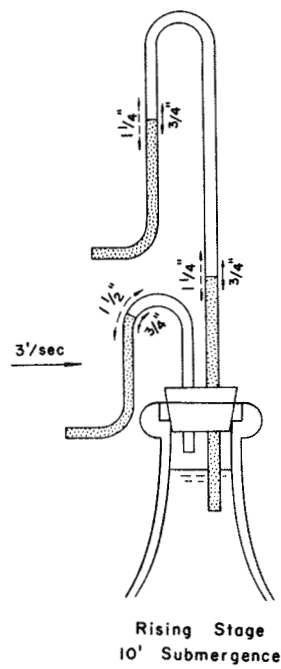
intake. The sample dilution is equal to an addition of about 0.3 of the accretion volume of clear water. The dilution by accretion is about 0.7 of the accretion volume for 62-125 microns and is about 0.8 of the accretion volume for 125-250 microns. These simple relations are based on the assumptions that the volume of accretion is not over 10 percent and that the concentration of sediment in the stream at the time of the accretion is about the same as the concentration in the original sample. If the sediment concentration in the stream at the time of accretion is greater than that in the original sample, these simple relations do not hold. Whether they hold or not, the concentration in the original sample can be determined approximately by deducting from the final sample the volume of accretion and the estimated weight of each size range of sediment added by that volume of accretion. The sediment weight for each size range is computed from the estimated stream concentration of the size range at the time of accretion and the estimated accretion concentration from Fig. 31. The concentration from Fig. 31 is multiplied by the volume of accretion.

If a sampler, such as 3A of Fig. 15, has been submerged 16 ft subsequent to sampling, the accretion volume added by submergence is 20 ml (Fig. 27). Assume that the concentration of 62-125 micron sediment at the intake was approximately the same throughout the sampling time and the rising stage that produced the accretion. The accretion diluted the sample by about 0.7 of 20 ml, or 14 ml, of clear water. For a 414-ml final sample the original concentration can be computed from the weight of sediment in the final sample divided by the weight of 400 ml of water. (The concentration in the original sample was about 3.5 percent higher than that in the final sample.)

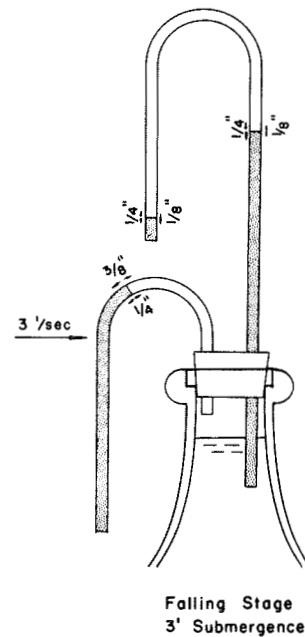
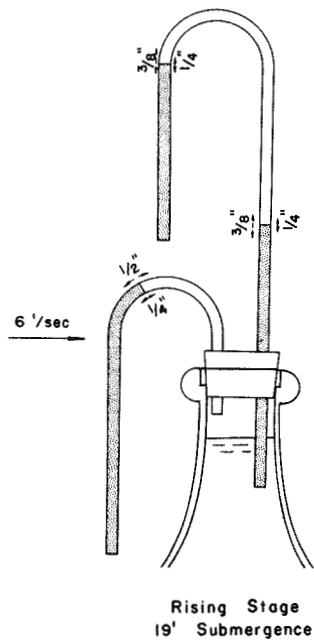
If the concentration of 62-125 micron sediment at the intake during accretion were assumed to be 5,000 ppm (0.005), the sediment added by accretion would be  $0.005 \times 0.3 \times 20$ , or 0.03 gm. (From Fig. 31, 0.3 is the approximate ratio of concentration in the accretion to concentration at the intake.) The final sample should be reduced by 20 ml, or grams, of water and 0.03 gm of 62-125 micron sediment. The ranges of sediment sizes can be treated separately, or a representative size can be selected as a basis of correction for the sample.

29. Characteristics of surges in the intake--Just as a change in submergence causes water to flow through the intake, momentary changes in dynamic pressure at the ends of intake and exhaust cause water to surge back and forth in the sampler intake. Intake surges result mainly from changes in velocity head. This can be inferred from concepts of fluid flow and is shown by the effect on the surges of any change in the orientation of the intake and exhaust ports in the flow. Fig. 32 illustrates some typical surge conditions.

Several samplers were tested in the pressure tower for observation of intake surges. The surges in the tower may have been very different from those in a normal stream. The surges in the tower had periods varying from 1/2 to 1 sec; at least 10 sec was required to observe a fairly representative average of the surges; and about 1 min was required to observe representative maximum surges.



HORIZONTAL INTAKE



VERTICAL INTAKE

Surge: Maximum ————, Average ————

Air in Tube ————, Water in Tube ————

FIG. 32 - TYPICAL SURGE CONDITIONS

When the surge moves into the intake, it moves outward through the exhaust. The compressibility of the air in the sampler causes minor secondary effects.

30. Surge enrichment of original sample--Under some circumstances, surges may enrich the original sample by carrying sediment from the stream through the intake and into the bottle. Water having a high sediment concentration enters the bottle, but the reverse surge removes water from the top of the sample where sediment in suspension generally is little.

Whenever the intake is full of water and immersed at both ends, any changes in pressure between the ends of the intake will cause surges that may enrich the original concentration in the sample.

When a sampler first fills, the intake is full of water; and if the inner end of the exhaust is not lower than the inner end of the intake, the sampler fills to the inner end of the intake and enrichment from surging can begin. If the inner end of the exhaust is considerably below the inner end of the intake, water drains from the inner end of the intake and is replaced by air. Slow changes in submergence or moderate surges do not wash out the air bubble, which stays at the crown of the intake. Very fast rises or large fast surges may flush the bubble from the intake; and, if water covers both ends, the bubble cannot reform. A large bubble in the intake prevents surge enrichment; a small one retards it.

If the exhaust invert is shorter than the intake invert and is not completely closed with a valve, an abnormal condition may develop in which water surges through the air exhaust. This type of sampler should not be used, and only surge enrichment through the intake will be discussed here.

31. Laboratory investigation of surge enrichment--The equipment described in Section 13 was used to investigate surge enrichment. A sedimentation jar (Fig. 4) having a diameter of 12 in. was filled with tap water to a depth of 10 1/4 in. Sufficient sediment of a given size range was added to provide a concentration of 1,000, 5,000, or 10,000 ppm by weight. The following particle sizes were used: < 62, 62-125, 125-250, and 250-500 microns. (Coarser sizes could not be maintained in suspension.) The sediment was placed in suspension by operating the mixer for a few minutes before the test and continuously during the test.

The sampler to be tested was filled with distilled water to just above the inner end of the intake. The straight glass tube was partly filled with water and connected to the bulb by an air line. The solenoid was started, and the movement of the solenoid arm was adjusted to the desired surge. Then, with the intake nozzle covered, the sampler was immersed in the jar. The intake was uncovered. At the end of either 5 or 30 min, the sampler was removed from the jar. The concentration of sediment in the sampler was determined by drying and weighing the sample.

The results of the surge-enrichment tests were not entirely consistent. (See Table 6.) A uniform concentration could not be maintained at the outer end of the intake. Concentrations in the jar, as reported in Table 6, were based on the weights of fluid and sediment in the jar. At times the concentration at the intake may have exceeded, but usually it was less than, the average for the jar. The sediment distribution was more uniform for the finer sediment and seemed to be more uniform for the lower concentrations.

The mechanics of the transportation of sediment through the intake is not clearly understood. Visual examination of intake conditions was difficult or impossible during the tests. For surges of less than about 1 in. the concentrations of sediment in the samples were extremely low; this fact indicates that contamination from outside the bottle was very small. At surges of 1 or 2 in. some enrichment of the samples occurred, but the enrichment in 30 min was less than 6 times that in 5 min. At moderate surges some sediment deposited in the horizontal intake nozzles and accumulated rapidly after submergence.

If 1 ml of water-sediment mixture having a concentration of 10,000 ppm enters the sample, it adds over 20 ppm of sediment to the sample in the bottle. For 1-in. and larger surges, enrichment of a few to 50 ppm is probably inherent in each sample.

32. Results of surge-enrichment tests--The surge-enrichment data will not be analyzed completely, but some of the most significant relations will be discussed.

Fig. 33 shows the effect of sediment concentration on surge enrichment as indicated by data for a 3/16-in. horizontal intake and for the two finest sieve fractions of sediment. For the 2-, 4-, and 6-in. surges and 30-min submergence the concentrations in the samples were approximately proportional to the concentrations in the jar, but for the 1-in. surge the concentrations in the samples were more alike than those in the jar. Probably, the initial enrichment is partially independent of the concentration in the jar; but over a time long enough to accumulate a maximum concentration, the concentration in the sample would be proportional to that in the jar.

The relation between time of submergence and surge enrichment is shown by Fig. 34. Data for the 3/16-in. intake, both horizontal and vertical, for a 3/16-in. exhaust tube, and for the two finest sieve fractions of sediment were used. Other data from the series of tests would show a similar relationship. Concentrations in the sedimentation jar were 1,000, 5,000, and 10,000 ppm by weight. The samples from the 1,000- and 5,000-ppm concentrations were multiplied by 10 and 2, respectively, to place all data on a comparable basis before plotting Fig. 34.

Data for the 6-in. surge indicate that the concentrations in the samples varied almost as the time of submergence. The concentration ratio of the 5-min

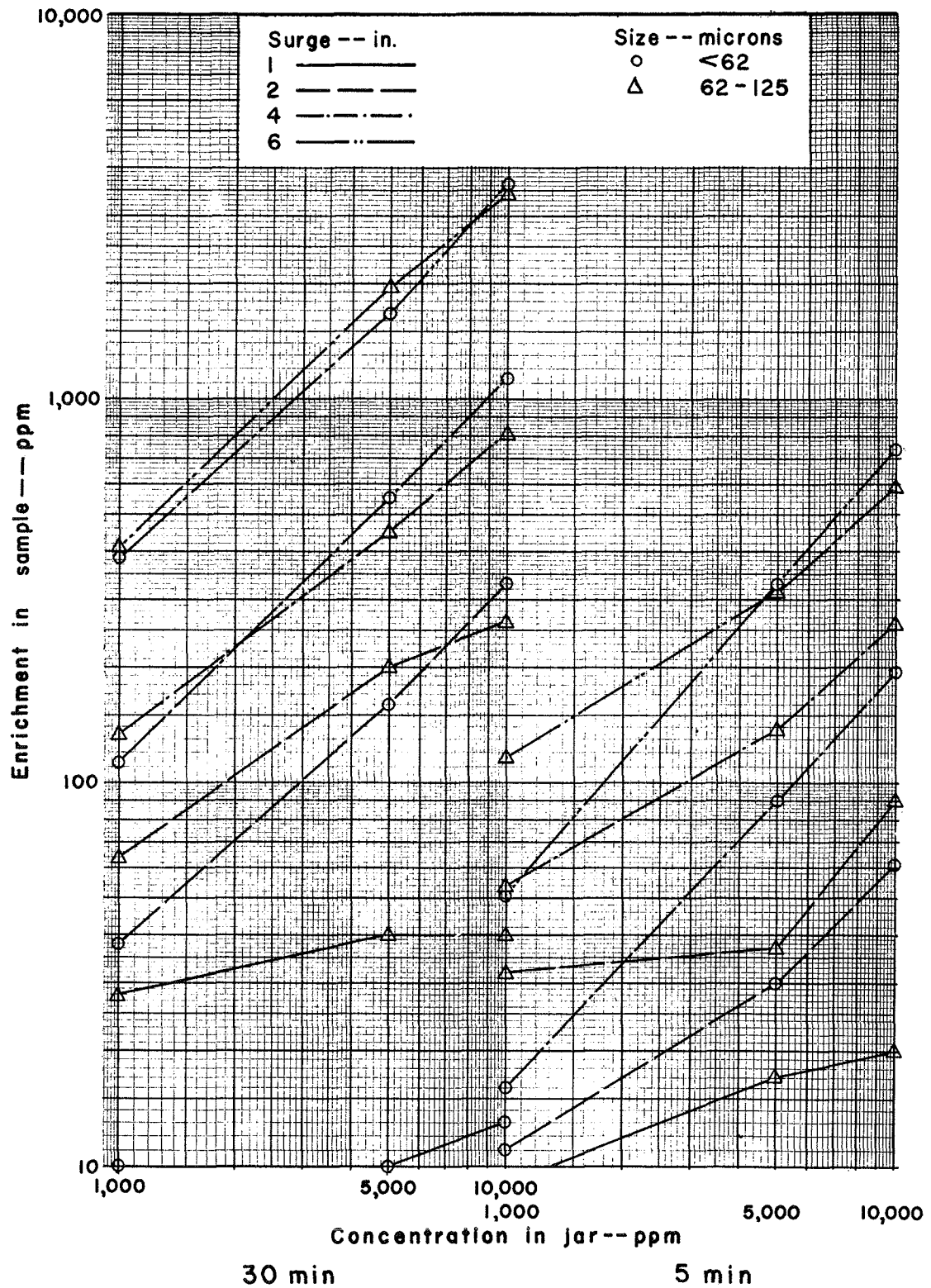


FIG. 33—SURGE ENRICHMENT VS CONCENTRATION  
(3/16" HORIZONTAL INTAKE)

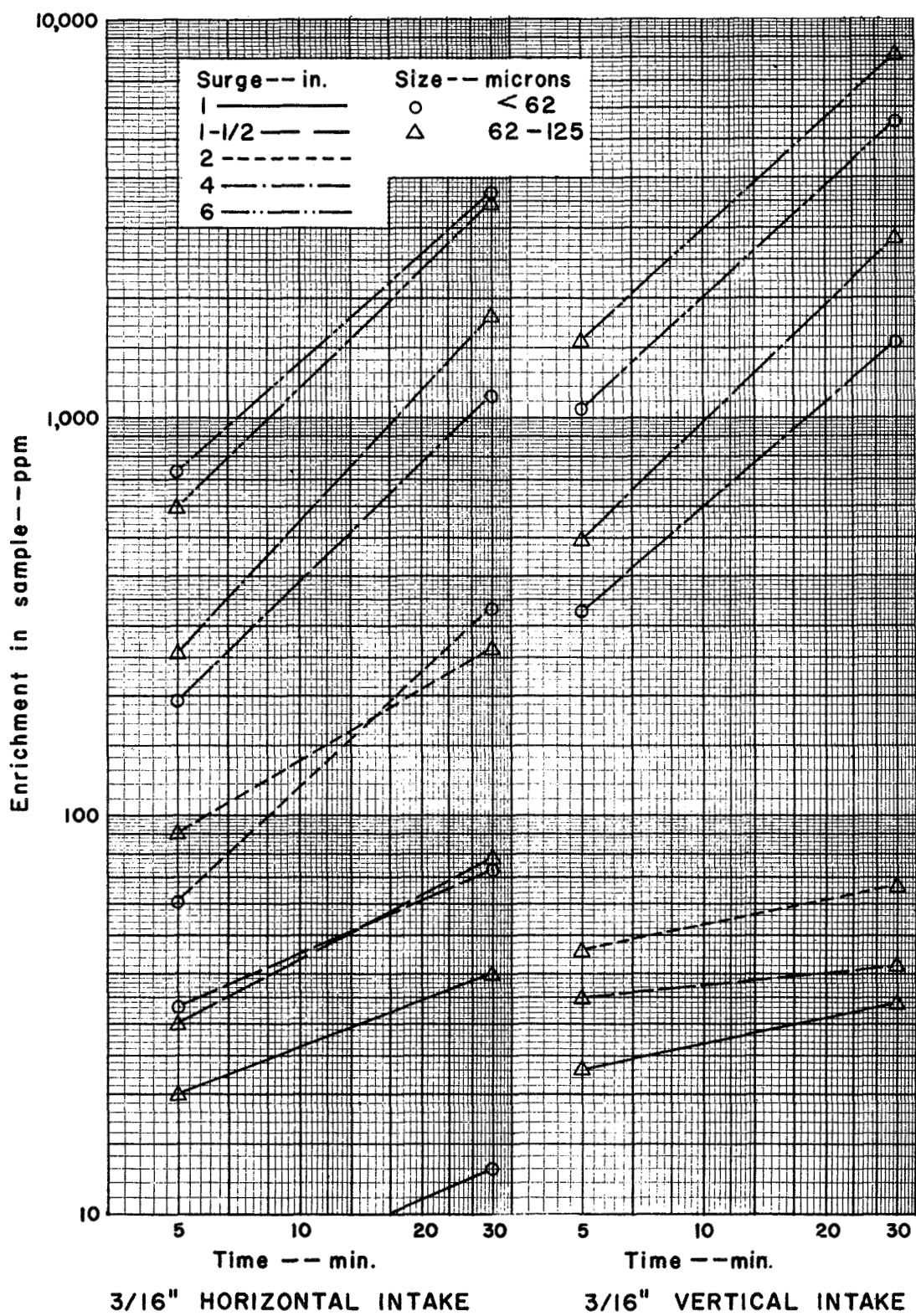


FIG. 34 - SURGE ENRICHMENT VS TIME OF SUBMERGENCE

to the 30-min samples was about 1 to 5 1/2 compared to a time of submergence ratio of 1 to 6. At the 2-in. surge the concentration ratio was about 1 to 4. The reduction in concentration ratio with respect to surge may be the result of the smaller amounts of sediment in the samples--that is, the inherent error in the samples becomes more significant at smaller concentrations. Enrichment would probably be proportional to the time of submergence, if the time of submergence was long.

In Fig. 35 an attempt is made to show the effect of sediment size on surge enrichment. Unfortunately, the comparison is made less conclusive by a change in apparatus. Sediment finer than 125 microns was maintained in suspension by a mixer blade having an upward thrust. To keep the larger sediment in suspension necessitated setting the blade to drive downward. The resulting sediment distribution was less uniform; and the flow pattern, which was generally downward past the intake for the finer sizes, was upward for the coarser sizes.

The apparent effect of sediment size on enrichment, indicated in Fig. 35, may be only a reflection of the differences in concentration at the nozzle and in direction of movement of the water-sediment mixture at the intake. Within the ranges of sizes studied, sediment size probably has little relation to sample enrichment. The range in size of sediments in most streams would include sizes that can contribute to surge enrichment.

Fig. 36 is plotted with magnitude of surge as the abscissa. For test data shown in Fig. 36 the intake invert was about 3 in. high and about 6 in. long from nozzle to intake crown. At surges of 1/2 in., very little sediment entered the bottle; at surges of 1 or 2 in. the amount varied widely, but probably over a long time appreciable amounts of sediment would enter. At surges of 4 and 6 in., sediment washed directly through the intake and enrichment was more rapid. Sample enrichment was obviously a function of the surge, probably a function of the ratio of surge height to height of intake invert. In stream sampling, normal surges in the intake are probably 1/2 to 2 in.

The enrichment obtained with four types of intakes is shown in Fig. 37 for sediment sizes from 62-125 microns and for 30-min submergence. The data for the 1/8-in. exhaust are plotted on the basis of height of surge in the intake. The surge in the intake was approximately half as much as that in the 1/8-in. air exhaust.

In stream sampling, the surges developed in the vertical intake will be less than those in the horizontal intake. Also, the surge in the intake of samplers having a 1/8-in. exhaust will be slightly less than that of samplers having a 3/16-in. exhaust. Therefore, for minimum surge enrichment in normal stream sampling, the vertical intake is best, followed in order by the horizontal intake and by a special sampler intake (Fig. 38) containing an inverted siphon.



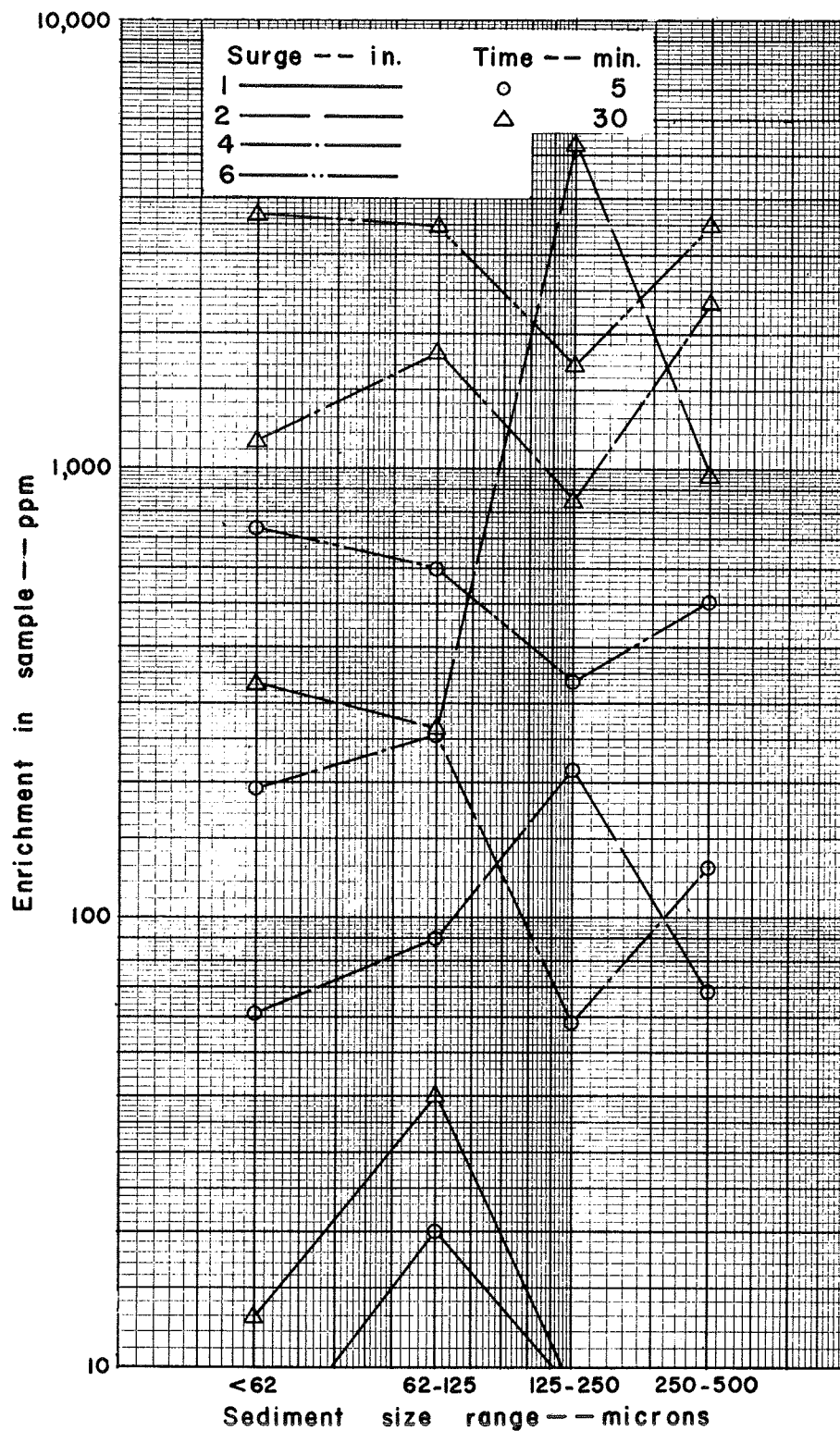


FIG. 35 - SURGE ENRICHMENT VS SEDIMENT SIZE  
(3/16" HORIZONTAL INTAKE, SEDIMENT  
CONCENTRATION 10,000 PPM)

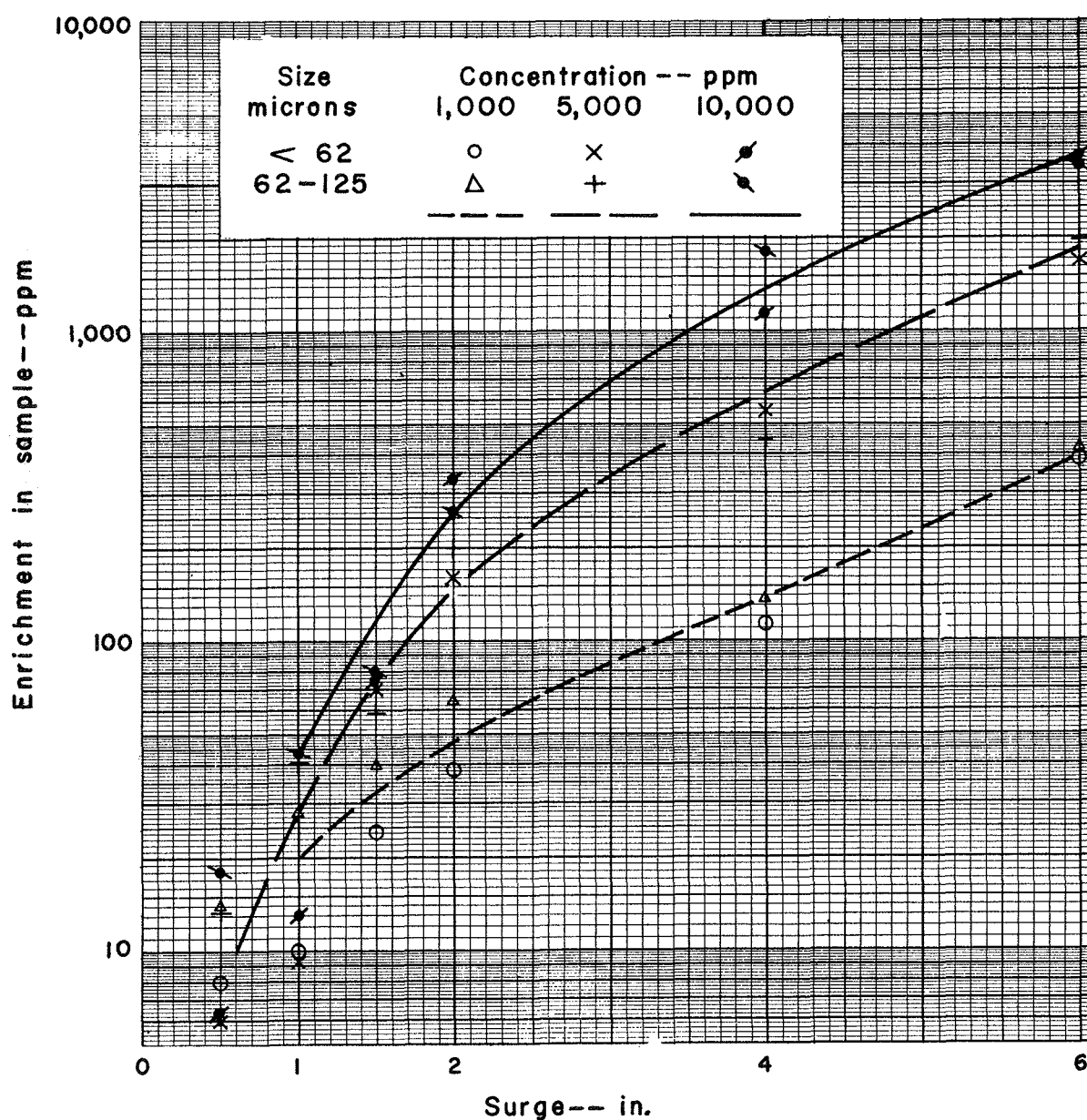


FIG. 36- SURGE ENRICHMENT VS SURGE HEIGHT  
( 3/16" HORIZONTAL INTAKE, 30 MIN.)

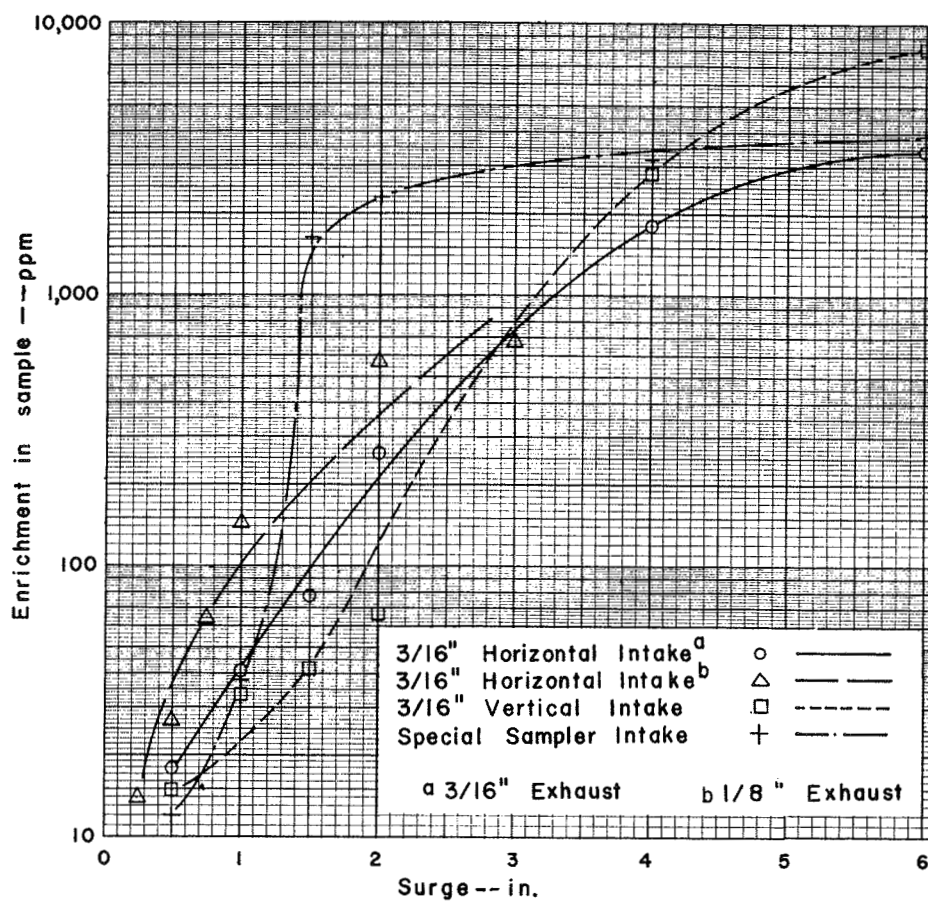


FIG. 37 - SURGE ENRICHMENT VS SAMPLER TYPE  
( 62-125 MICRON SEDIMENT,  
10,000 PPM, 30 MIN.)

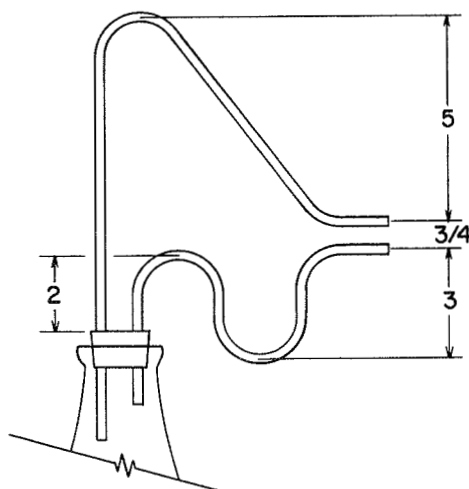


FIG. 38- SPECIAL SAMPLER INTAKE

Enrichment from surges in the intake depends on many factors, such as magnitude of surges, time of submergence, sediment concentration at the outer end of the intake, and shape of the intake. However, if a sampler is exposed to conditions that cause surges through the intake, these factors cannot be controlled sufficiently to avoid surge enrichment. Surge enrichment can be avoided only by designing the sampler so that accretion cannot fill the bottle to the inner end of the intake and also fill the inner leg of the intake tube.

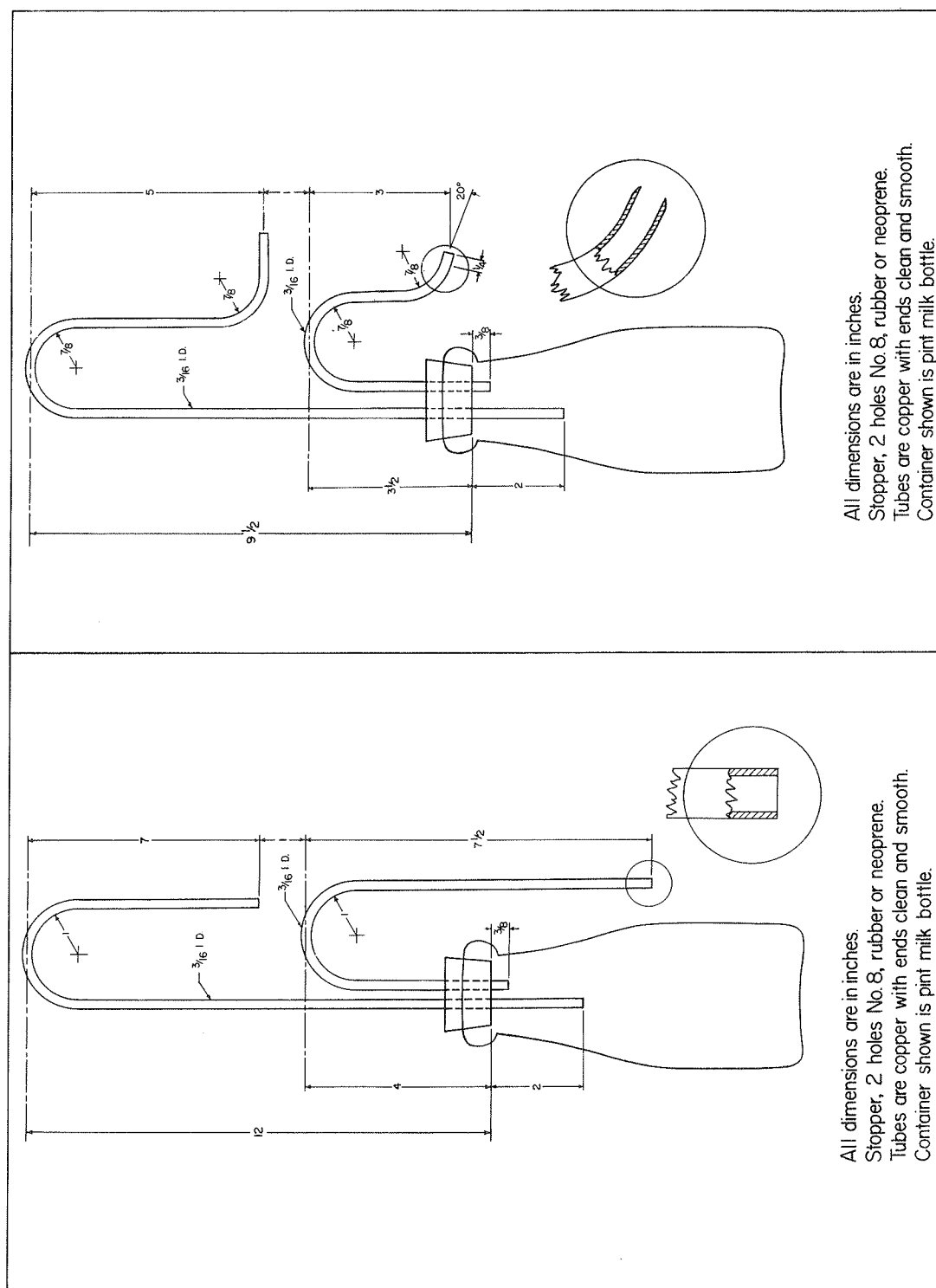
#### IV. USE OF SINGLE-STAGE SAMPLER

33. Selection of a suitable sampler--Single-stage samplers are not so accurate as manually operated samplers; therefore, manual samplers should be given primary consideration at every station. The single-stage samplers are used most effectively as a supplement to other types of sampling, but they may be used alone to provide data where reasonable manual coverage cannot be provided. Whether or not single-stage samplers should be used in a given program depends on (1) adequacy and cost of records obtained by other means, (2) usability of samples from a point near the water surface, (3) cost of an adequate single-stage sampler installation plus servicing, and (4) availability of personnel who understand and follow proper single-stage sampler usage.

Single-stage samplers should be selected or designed to satisfy the specific sampling conditions at the proposed site. A sampler should never be selected just because it is readily available. Different samplers may be required for different stages of the same stream. Because the exact sampling conditions cannot always be predicted, the samplers may be selected or designed on the basis of the possible maximum velocity, surge, or sediment size. Such selection may not provide samples of maximum accuracy but would ensure usable samples of lower accuracy.

34. Approved types of samplers--For standardization and accuracy, four models of single-stage samplers have been designed for different ranges of sampling conditions. The samplers are designated as the U.S. series; general type U for unistage, or single stage; 59 for the year of origin; and A, B, C, D for standard or adopted models. Some of the approximate limiting conditions of use are given for each model. Velocity, water-surface surge, and sediment size are the principal factors that govern the range of use. So many combinations of primary variables and secondary variables, such as temperature and turbulence, must be considered that a set of precise limiting conditions would be too restrictive and too difficult to apply.

The single-stage sampler U.S. U-59A shown in Fig. 39 is recommended for fine sediments. It is highly resistant to the effects of drift and debris and to both surge enrichment and circulation through the sampler. This vertical-intake

FIG. 40 – SINGLE-STAGE SAMPLER  
US U-59BFIG. 39 – SINGLE-STAGE SAMPLER  
US U-59A

sampler is accurate only for sediments finer than 62 microns, for water-surface surges less than 4 in., and for velocities that are reasonably low at the sampling point during primary sampling (Fig. 23). The sampler may be protected with any type of shielding that does not significantly alter the sediment concentration at the intake nozzle.

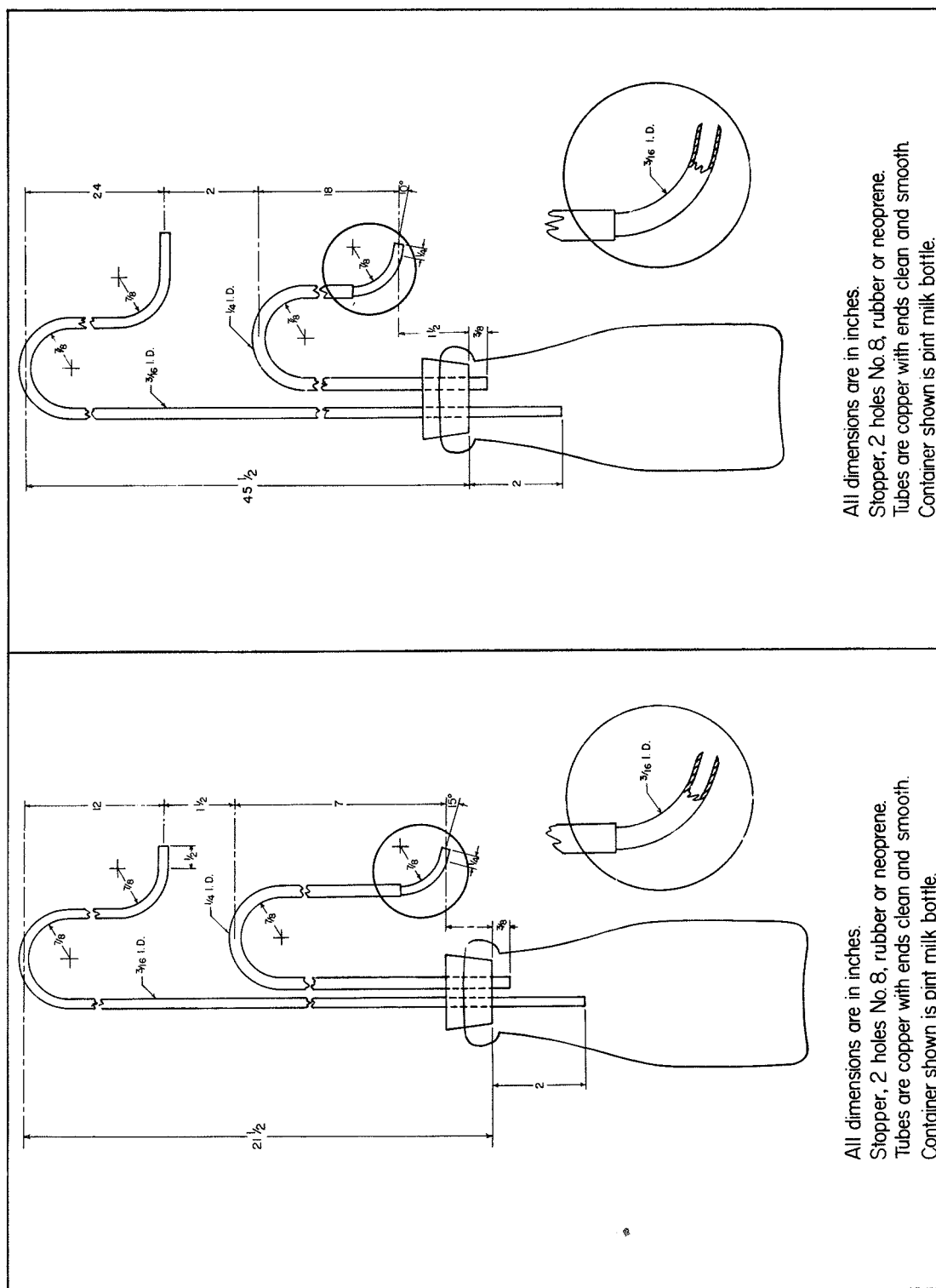
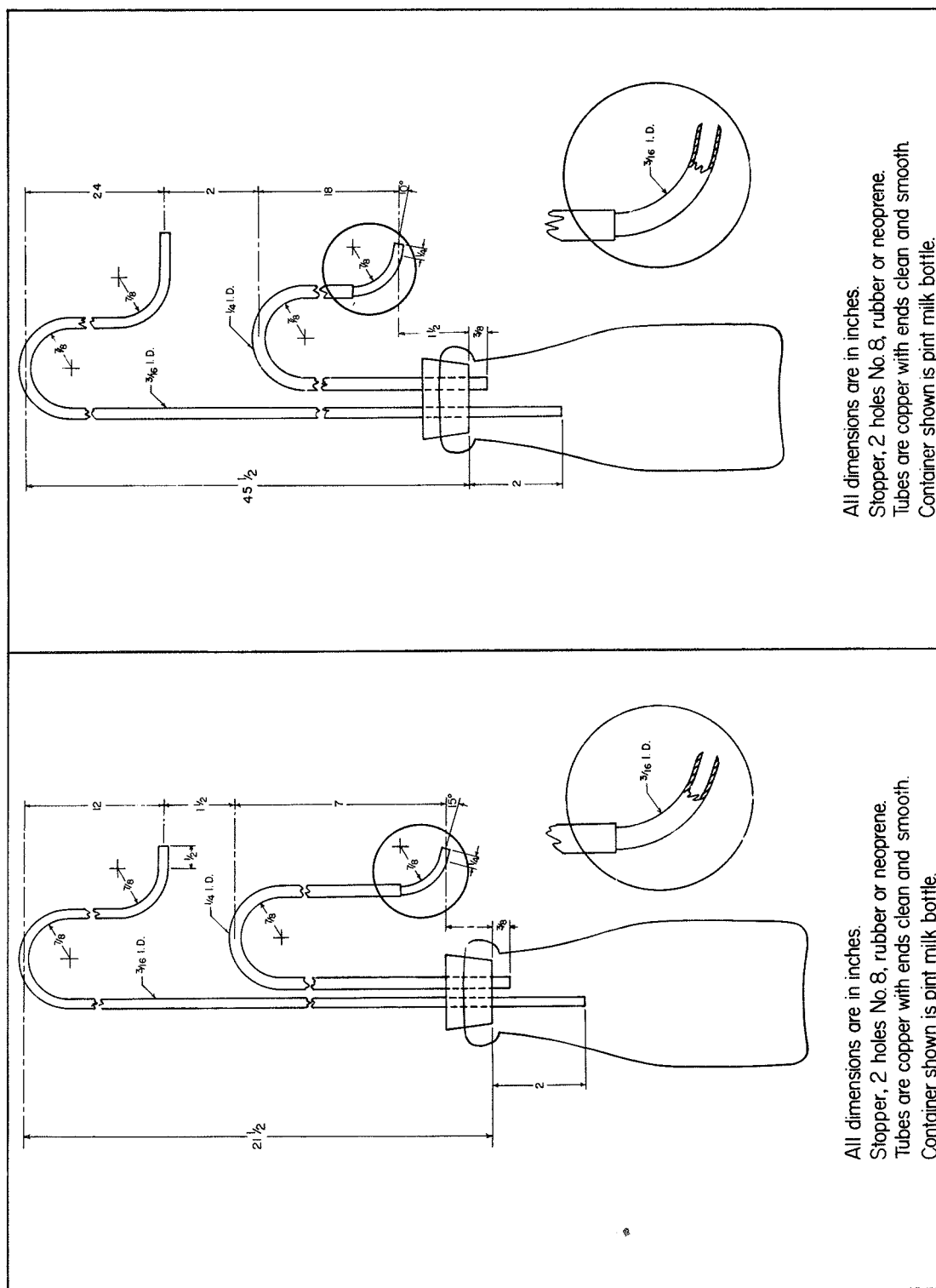
Horizontal-intake samplers U.S. U-59B, U.S. U-59C, and U.S. U-59D, shown in Figs. 40, 41, and 42, respectively, may be used to sample sands as well as finer sediments. The nozzles are smooth and sharp and are inclined downward at 20°, 15°, or 10°, respectively, to prevent sediment deposits in the intake prior to sampling. The smaller angles are used in the higher velocity samplers because the greater surges associated with the high velocities reduce the tendency for sediment to deposit. The angles are not large enough to reduce sampling efficiency.

Samplers having nozzles that point into the stream operate satisfactorily only within limited ranges of stream velocity and water-surface surge. Continuous sampling is desirable. The limiting velocity for continuous sampling depends on the height of water-surface surge. If velocities or water-surface surges slightly exceed the limits, sampling is intermittent. At higher velocities, sampling starts as soon as the intake nozzle is submerged and the sample is skimmed from the tops of water-surface surges.

The U.S. U-59B (Fig. 40) may be used for low-velocity sampling. Sampling velocities should not be greater than 4 fps, and water-surface surges should not exceed 3 in. Preferably, velocities should be about 3 fps or less, and surge heights 2 in. or less. For a 2-in. surge, sampling will be intermittent for stream velocities greater than 2 fps (Fig. 23). Model U.S. U-59B should not be used as a general purpose or utility sampler.

The U.S. U-59C (Fig. 41) is a medium-velocity sampler that may be used for sampling at velocities up to 6 fps if water-surface surges are less than 2 in. Velocities less than 5 fps and water-surface surges less than 5 in. are better general limits (Fig. 24). Because the volume of water in the intake prior to sampling is greater than that for the A and B models, intermittent sampling may produce significant errors. Samples taken with the U.S. U-59C at velocities between 6 and 8 fps might be usable, but they would be skimmed from the tops of water-surface surges. The U.S. U-59C has a 1/4-in. diameter intake and a 3/16-in. diameter nozzle. The combination of diameters increases the velocity in the nozzle.

Except for height, the U.S. U-59D sampler (Fig. 42) is similar to the U.S. U-59C. The sampler should never be used for velocities greater than 10 fps and for water-surface surges exceeding 16 in. Sampling will be intermittent for many combinations of velocity and surge that are greater than 7 fps and 8 in., respectively. (See Fig. 25.) The volume of water in the intake just prior to sampling is about 4 percent of the sample volume, and samples collected intermittently may be erroneous. Therefore, velocities less than 7 fps and surges less than 8 in. are better general limits.



There is no general purpose single-stage sampler. However, of the approved samplers the U. S. U-59D will sample satisfactorily over the widest range of conditions.

Figs. 23 to 25 are guides for selecting the appropriate sampler model. They show the type of sampling (continuous, intermittent, or from tops of surges) and the probable error in concentration in the primary sample for given stream velocities, water-surface surges, sediment sizes, and water temperatures.

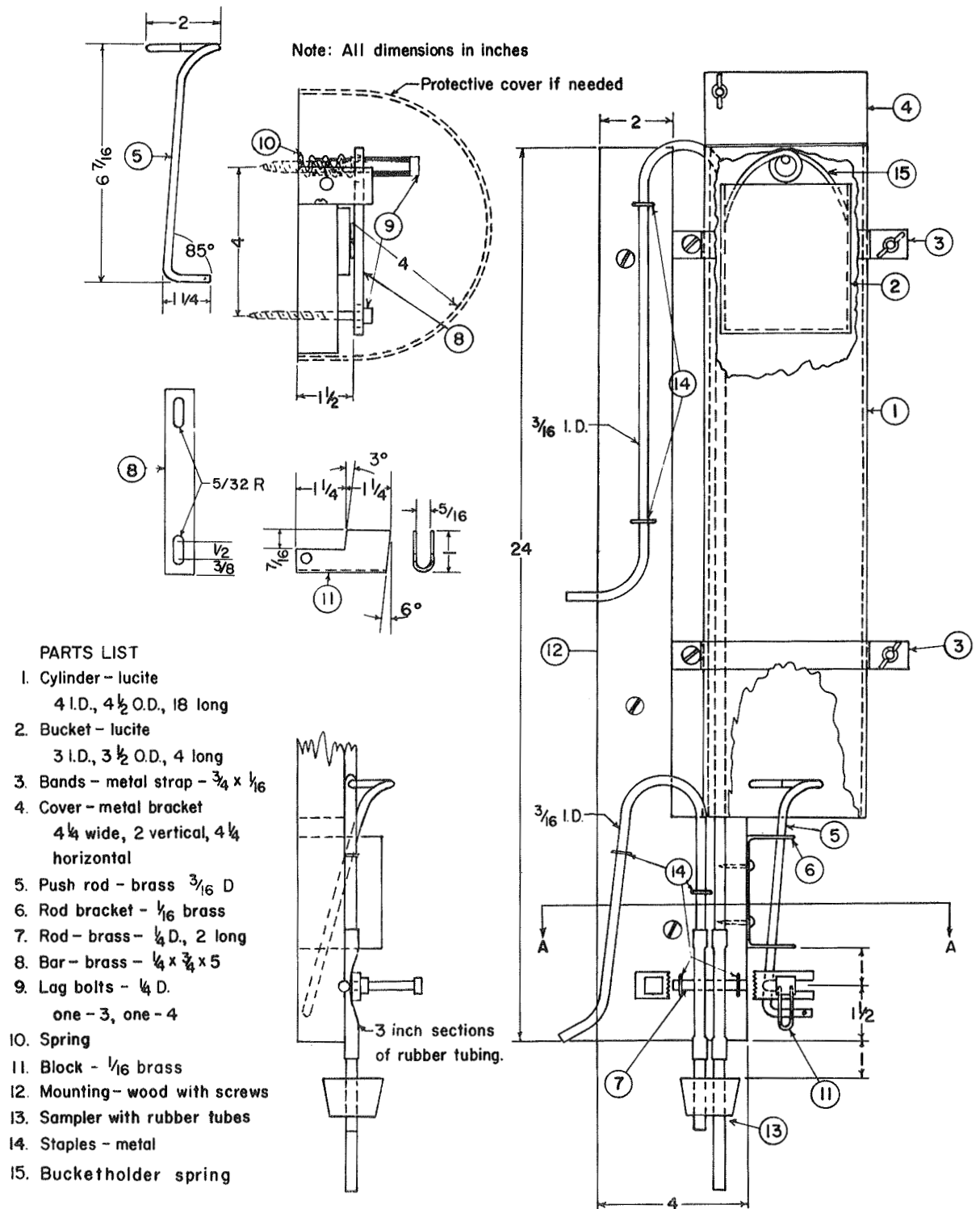
35. Sampler for falling stage or secondary rise--Sampling is usually more critical on the rising than on the falling stage of a flood event. However, single-stage samplers can be adapted to sample on falling stages. One type of adaptation is shown in Fig. 43. When the sampler is set, the rubber tubes are pinched shut. The bucket fills with water when the first rise in stage overtops its rim. When the stage falls below the bucket, the bucket will settle until its weight on the push rod trips the opening mechanism. The mechanism should be adjusted to trip at less than the full weight of the bucket. The exhaust port should be at or above the stage at which the sampler will be tripped open so that sampling will begin immediately.

A modification of the falling-stage sampler so that the intake is a few inches above the tripping stage allows sampling on a secondary rise.

36. Sampler modifications for specific conditions--Because the four models of the single-stage sampler described in Section 34 are not adequate to cover all sampling conditions, modification may be necessary for a particular installation or type of service. Adjustment for a high velocity at the time of sampling may be made by increasing the heights of the exhaust invert and the outer leg of the intake. (A high velocity subsequent to sampling may be disregarded if it does not occur at the stage at which the sampler is mounted.) The outer leg of the intake may be lengthened to provide for a large water-surface surge, but the outer leg of the exhaust should always be taller than the outer leg of the intake (unless the excess intake is below the level of the inner end of the air exhaust) to prevent accretion through the air exhaust. Lengthening the inner leg of the intake would sometimes increase the intake velocity, but lengthening the outer leg of the intake would always reduce the intake velocity. (See Sec. 37.)

The tall exhaust tube on some of the samplers makes them awkward to handle, especially if the sampler is to be taken to the laboratory as a unit after the sample is obtained. If a slip joint of rubber tubing is used in the exhaust just above the stopper, the top part of the exhaust tube can be left in place in the field. The rubber-tube section can be closed with a clamp and then disconnected above the clamp. The same device can be used in the intake line if the inside of the connection is kept fairly smooth.





Single-stage samplers can be designed for permanent or semipermanent mounting in the field. (See Fig. 44.) The container may be removed as from other sediment samplers. A tight seal must be maintained at the top of the container and around the intake and exhaust. Care is required to avoid contamination when a container is removed or installed.

Several types of valves for the air exhaust or intake have been studied, and one type that allows passage of air but not of water has been tested. The tall air-exhaust invert seems more dependable than a valve for prevention of circulation through the sampler. At times, the sample probably should be sealed soon after it is taken. A way of clamping the intake and exhaust is shown in Fig. 45.

37. Some details of sampler design--Usually, problems of single-stage sampler design have simple and obvious answers that can be obtained readily from data already presented. Some of the minor problems are too complicated to discuss in detail, but they may be partly clarified by comment and illustration.

If vertical-intake samplers are used only for sediments finer than 62 microns, few design problems are involved. If used for sands, the height of each leg of the intake invert should exceed the water-surface surge height by at least 2 in. so that an adequate sampling velocity is maintained at the low point of the water-surface surges.

Three heights of horizontal sampler intakes are shown in Figs. 40 to 42. The total heads at the time sampling starts are approximately 4, 8 1/2, and 20 in.; and the total, or unfolded, lengths of the intakes are 9, 18, and 40 in., respectively. Average calibration data for intakes of these dimensions were used to define Fig. 46. (See Figs. 17 to 19 and Table 3.) Data for several combinations of static head and flume velocity are shown both for intakes 3/16 in. in diameter throughout and for intakes 1/4 in. in diameter with a 3/16-in. nozzle.

The normal sampling velocity curves of Fig. 46 are based on the sampler design of the recommended U.S. U-59B, C, and D series. Normal sampling velocities above these curves can be obtained from special designs, but for the recommended samplers the curves are limiting unless intermittent sampling is allowed.

A method for increasing the sampling velocity together with some of the limitations involved will be illustrated. Assume a stream velocity of 6 fps and a water-surface surge of 4 in. Sampler U.S. U-59C would sample intermittently because the outer leg of the intake is only 7 in. high. Select the U.S. U-59D as the basic sampler. The normal sampling velocity is 5.4 fps. Could this be raised to 6 fps to give an intake ratio of unity?

Because the total of surge and velocity head is 11 in. (7-in. velocity head for 6 fps plus 4-in. surge), about 6 or 7 in. can be removed from the 18-in.

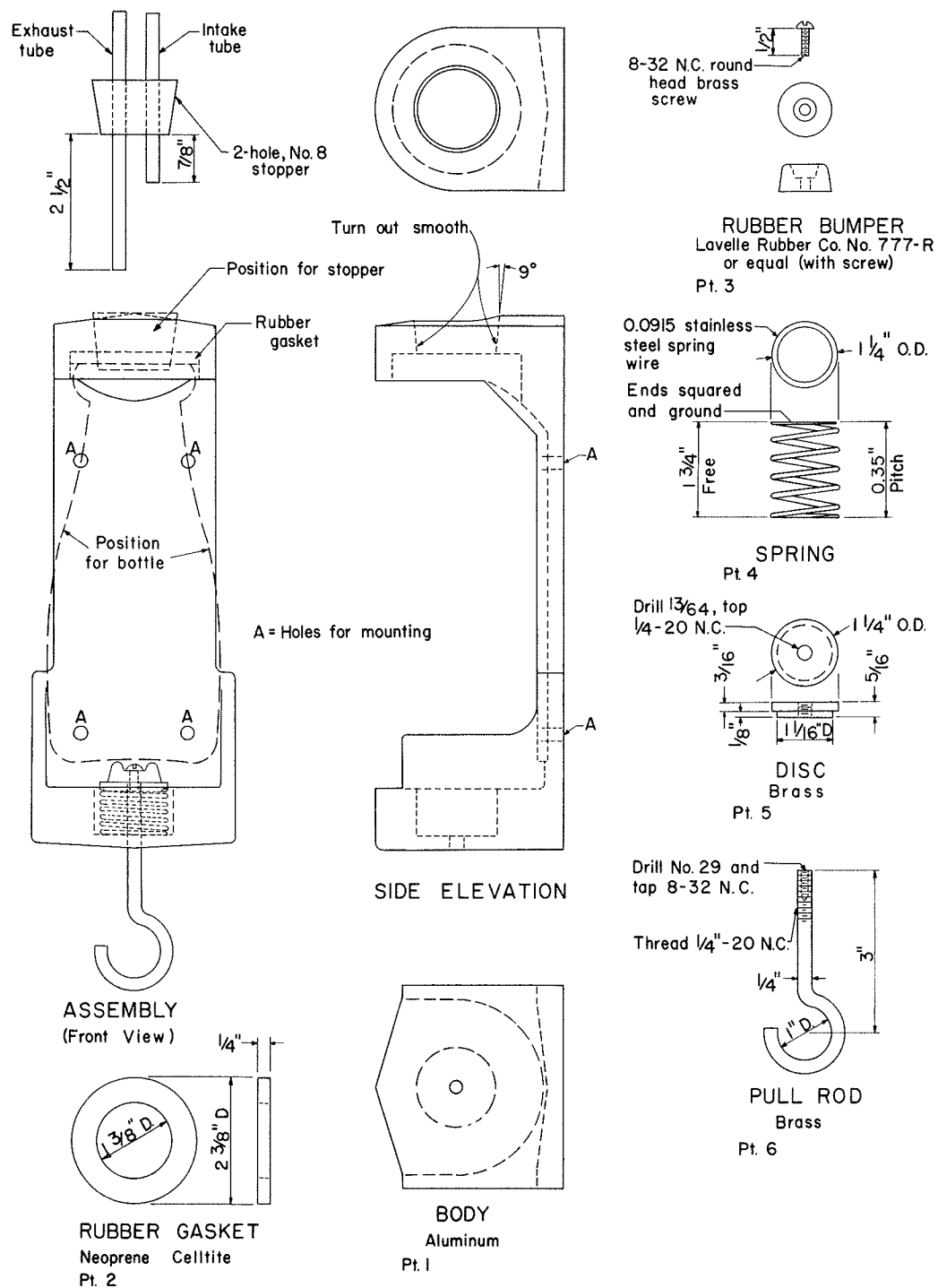


FIG. 44 - SAMPLER FRAME FOR PERMANENT MOUNTING

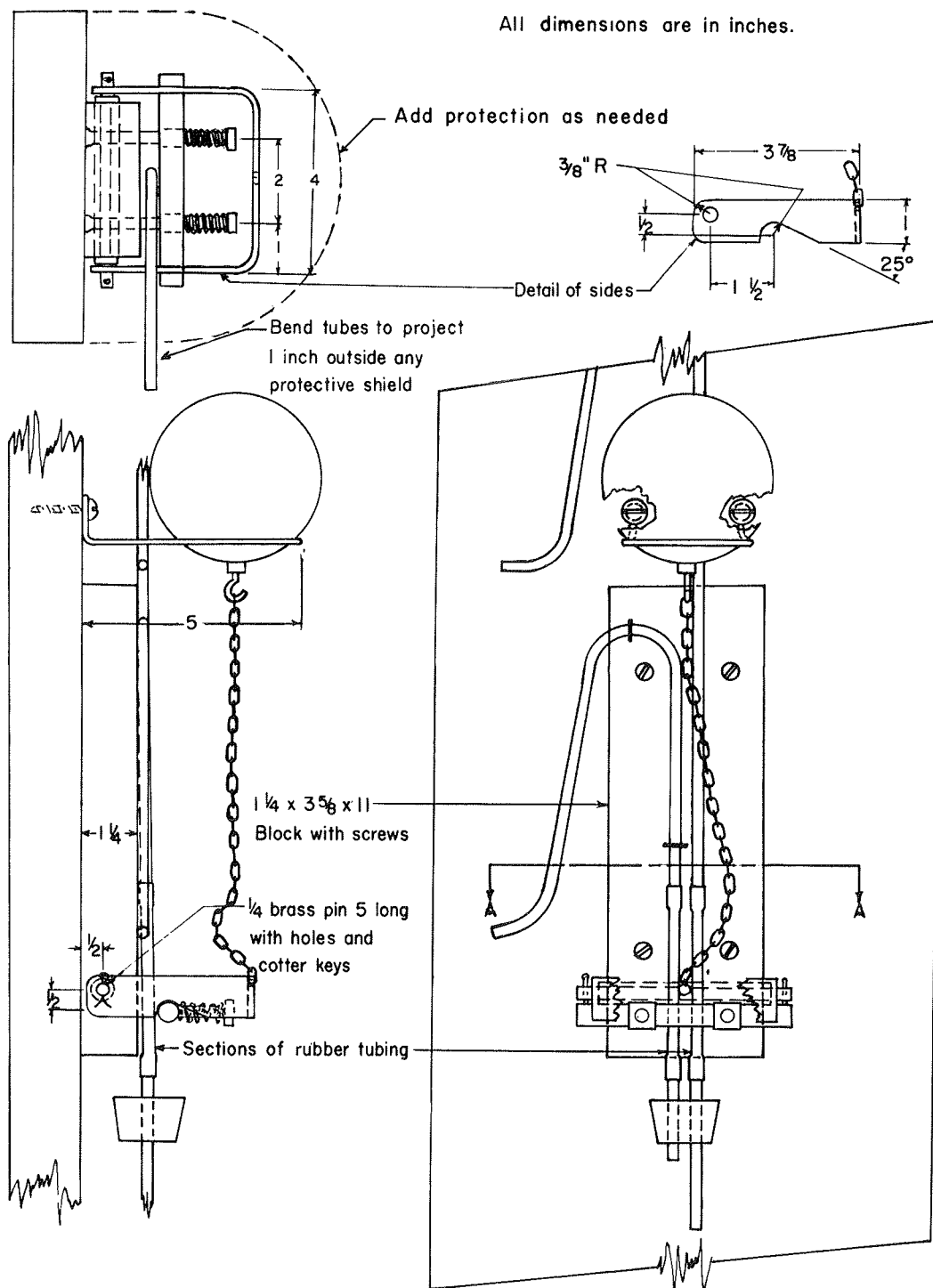


FIG. 45 - SELF-SEALING SINGLE-STAGE SAMPLER

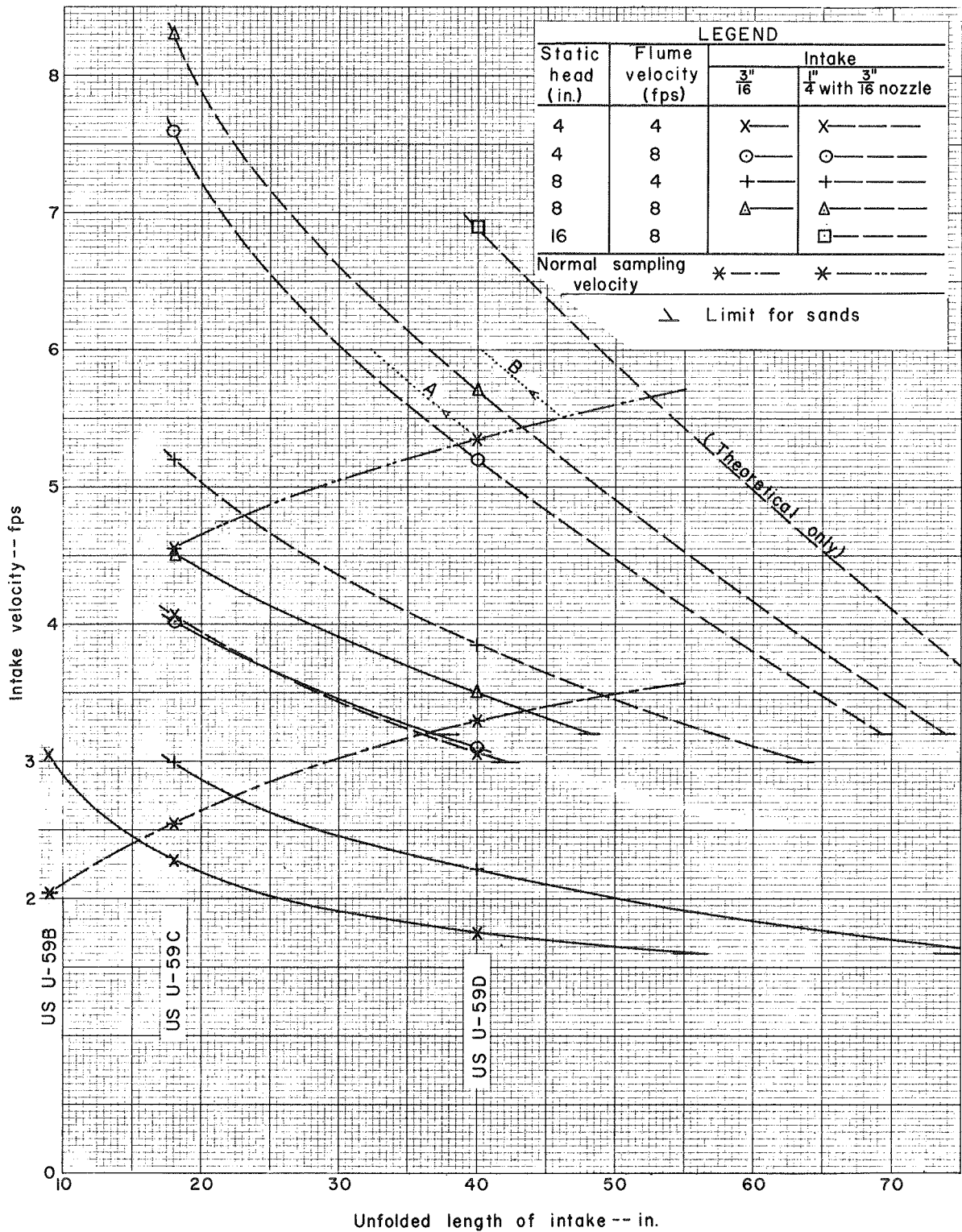


FIG. 46- RELATION OF INTAKE VELOCITY AND INTAKE LENGTH  
 (TEMPERATURE 37°F)

outer leg of the U. S. U-59D intake. Follow the slope of the curve for velocity vs intake length back 6 or 7 in. of intake length (dotted line A of Fig. 46). A velocity of nearly 6 fps could be obtained by eliminating all the excess intake height, but no factor of safety would remain. The line of normal sampling velocity for the 1/4-in. intake with 3/16-in. nozzle shows that increasing the height of the intake invert will slowly increase the intake velocity. The intake crown could be raised 3 in. to give a normal sampling velocity of about 5.5 fps at a total intake length of 46 in. The outer leg would be 21 in. high, and 6 in. can be removed from the 21 in. to give a sampling velocity of 6 fps at a total intake length of 40 in. (dotted line B of Fig. 46).

For the high-velocity sampler (40-in. intake) a plotted intake velocity of 5.75 fps is shown with an 8-in. static head and an 8-fps flume velocity. This is above the normal sampling velocity curve. Two factors that are minor in stream sampling have been ignored to simplify this presentation: In a flume where water-surface surges are very small, a high-velocity head (based on the square of the average velocity) is slightly more effective than an equal static head in producing a high intake velocity. However, the water-surface surges in a stream reduce the average intake velocity, and the surges tend to increase as stream velocity increases.

Could the intake nozzles of one or more of a series of samplers, mounted at a given elevation, be lowered to take samples at different depths below the stream surface? That is, could dimension AC in Fig. 3 be held, but BC be increased? If the object of lowering the nozzle is to define a vertical distribution of sediment by a series of simultaneous samples, the first difficulty is that the samplers would not sample simultaneously without some special control. If B is not above A, combinations of velocity and water-surface surge permit sampling in dribbles over the intake crown, and results of such sampling are meaningless.

Fine sediments are so uniformly distributed that there is no point in special adaptations to determine the distribution. Generally, the intake velocities of single-stage samplers are too low for accurate sampling of coarse sediments. Fig. 46 shows that the intake velocities decrease as the total length of the intake is increased. Lowering the sampler intake nozzle would almost always give intake velocities so low that the samples would be inaccurate unless corrections were applied.

When the intake velocity drops below certain limits, concentrations of sands in samples have no definite relation to stream concentrations. If the velocity in the intake falls below about 1.5 fps, sands may not rise in the outer leg of the intake. A nozzle velocity of nearly 3.0 fps in the 3/16-in. tip of the 1/4-in. intake is required for a velocity of 1.5 fps in the vertical part of the intake. Sampling corrections for sands are large but undefined for intake ratios below 0.4. An inspection of Fig. 46 shows that the maximum possible lowering of the intake would be 3 or 4 ft and could be obtained only with certain samplers under special

conditions. Sampling would be at very unfavorable intake velocities. Also, the volume of the intake would be so large that a high presampling error could be expected.

38. Availability of single-stage samplers--The tubing and stopper components of the approved models of the single-stage samplers can be made on order from Federal agencies. Orders should be addressed to the District Engineer, U. S. Army Engineer District, Post Office and Custom House, St. Paul 1, Minn.

39. Selection of sampling site--Although the location of the sampling point on a stream is fixed within certain limits, some choice of site is generally available. A straight representative reach of stream having good hydraulic characteristics should be selected. There must be a support for the samplers or a place where a support may be installed. If possible, the samplers should be installed at a recording, staff-gage, or wire-weight-gage station so that the samples can be referenced to a stream-discharge record or at least to a water stage. Accessibility, especially during storm periods, is important.

The installation must be located and constructed to withstand floods and must provide protection from drift and debris over the full range of stage. It should be at a point where the sediment concentration will be as representative of that in the stream cross section as possible.

40. Installation of the sampler--The ideal sampler support would be a vertical timber standing near the middle of the stream. Stability, accessibility, and economy will dictate many compromises. A pier or abutment can be used; but if the support is concrete, special bolt or screw anchors may be required for attachment of samplers and sampler protection. (A wooden plank, on which the samplers can be mounted, may be fastened to the concrete.) Special mounting may be required at some sites.

A sufficient number of samplers should be mounted to sample the range of stage. More than one sampler may be mounted at a given elevation, or samplers may be mounted at closely spaced elevations so that one sample can be checked against another. Because of velocity head and water-surface surge, the primary sample is usually taken before the average water surface reaches the elevation of the crown of the intake.

Several bottle and tube holding devices are shown in Fig. 47. Field engineers will develop their own modifications as experience with the single-stage samplers develops.

A sampler mounting designed by P. B. Allen and R. F. Piest is on the upstream pile of the right-bank pile bent at gaging station no. 34 on Pigeon Roost Creek near Holly Springs, Miss. The maximum velocity is about 7 fps at this site.

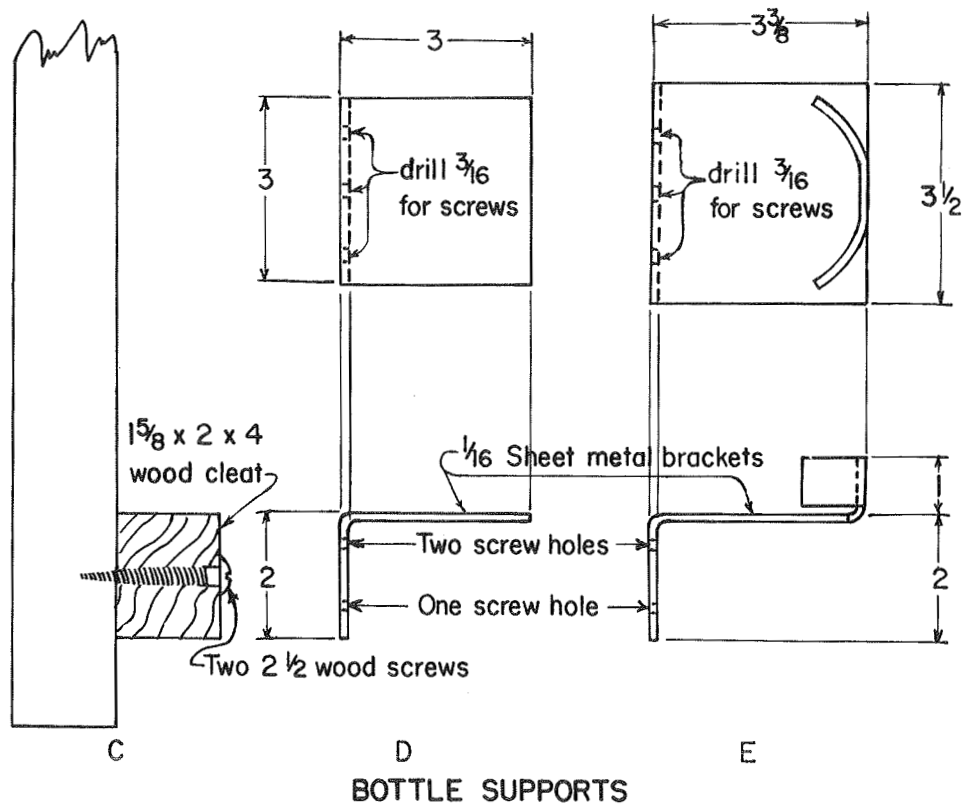
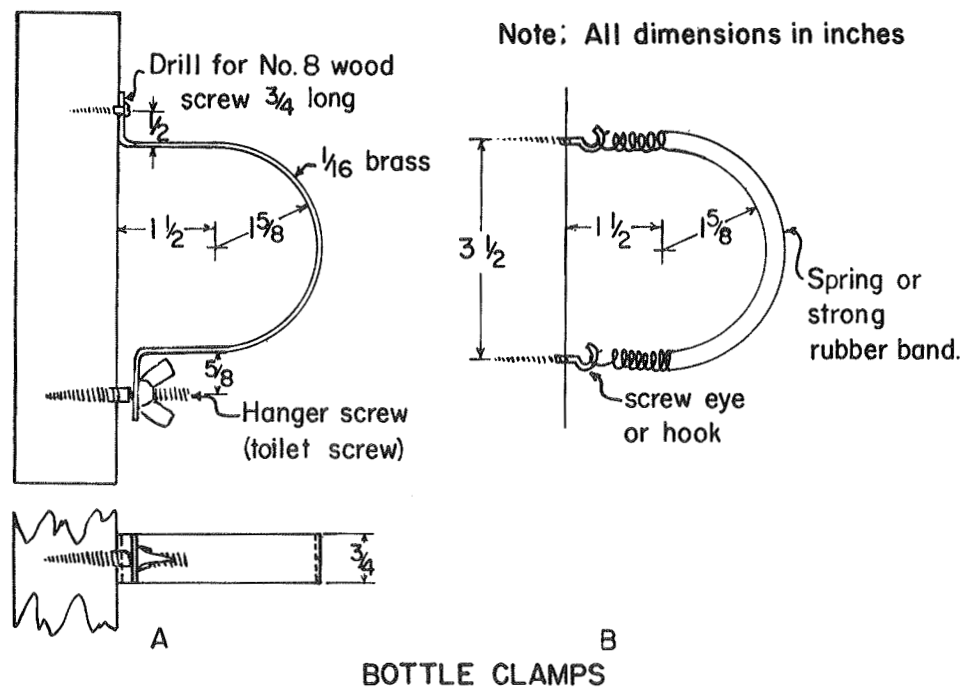


FIG. 47 - AUXILIARY EQUIPMENT FOR SINGLE-STAGE SAMPLERS



The sample bottles and the intake and exhaust tubes are mounted on wooden planking. Angle irons are used for attachment to the wooden pile, and an angle iron with the "V" pointed upstream reinforces and protects the planking. The planking is notched to permit the tubes to pass through holes in the point of the angle. Bottles are inclined at an angle to permit mounting at about 6-in. vertical intervals over the range of stage corresponding to medium and high discharges.

Fig. 48A shows the intake-tube side of the installation. Streamflow is from left to right in this picture. The parts of the intake and exhaust tubes that extend upstream from the angle iron are wrapped in absorbent cotton saturated with insect repellent, and moth balls are placed in each bottle to discourage insects from plugging the tube. Fig. 48B shows the exhaust-tube side of the installation and Mr. Allen placing a bottle in the sampler rack. Each bottle is mounted in a strap metal holder that has a hinged bottom held in place by a spring.

41. Protection of the sampler--In most streams the samplers will require protection from drift, livestock, and vandals. At some sites access to the installation should be restricted by fencing. Protection from freezing may be needed.

Protection can be provided by an enclosure of the sampler. (See Fig. 49.) A section of pipe cut in half lengthwise or a cover of sheet metal or heavy metal mesh rolled to a semicircular or U-shaped section is suggested. Either type may be hinged along one edge and fastened with hasp and staple on the other edge. Such a cover should not be in a long section except for a flashy stream. Housing for vertical-intake samplers must permit ample water circulation around the intake. Horizontal intakes should protrude at least an inch through the cover and should point into the approaching streamflow.

Fig. 50 shows a series of bars that provide partial protection, that facilitate inspection and servicing, and that minimize obstruction to flow at the intake nozzle. Longer and heavier bars than those of Fig. 50 may be used. Some types of steel steps provide satisfactory protection, and they may improve the accessibility to the sampler.

42. Servicing the sampler--A sampler is exposed to the atmosphere both before and after a sample is taken. Water may condense in the sample container prior to sampling. Dust may collect in the intake and air exhaust, but much of the dust will wash out because of surges in the intake prior to sampling and in the air exhaust subsequent to sampling. Mud, nesting material, and other obstructions may be deposited by birds or insects so that sampling is hindered or so that samples are contaminated. (Use of creosote or other insect repellents is helpful.) If samplers are serviced regularly and adequately, errors due to sample exposure will be minimized. Frequent servicing and the pickup of samples soon after a flood will reduce the loss from vandalism.



FIG. 48 B

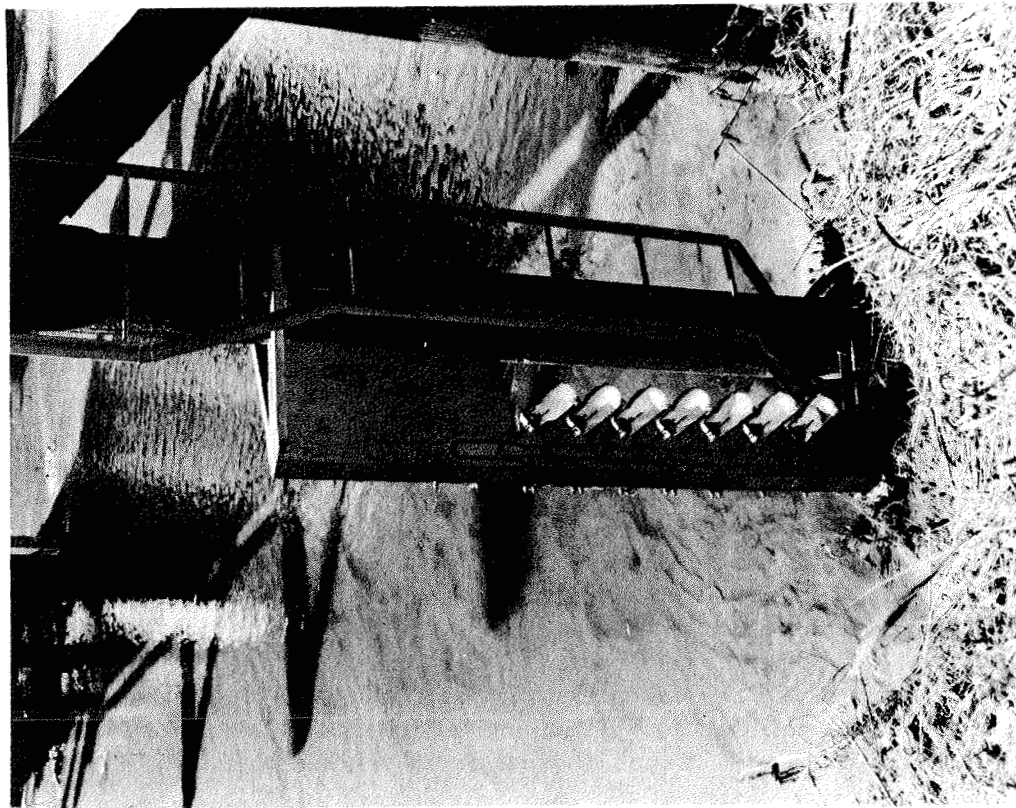
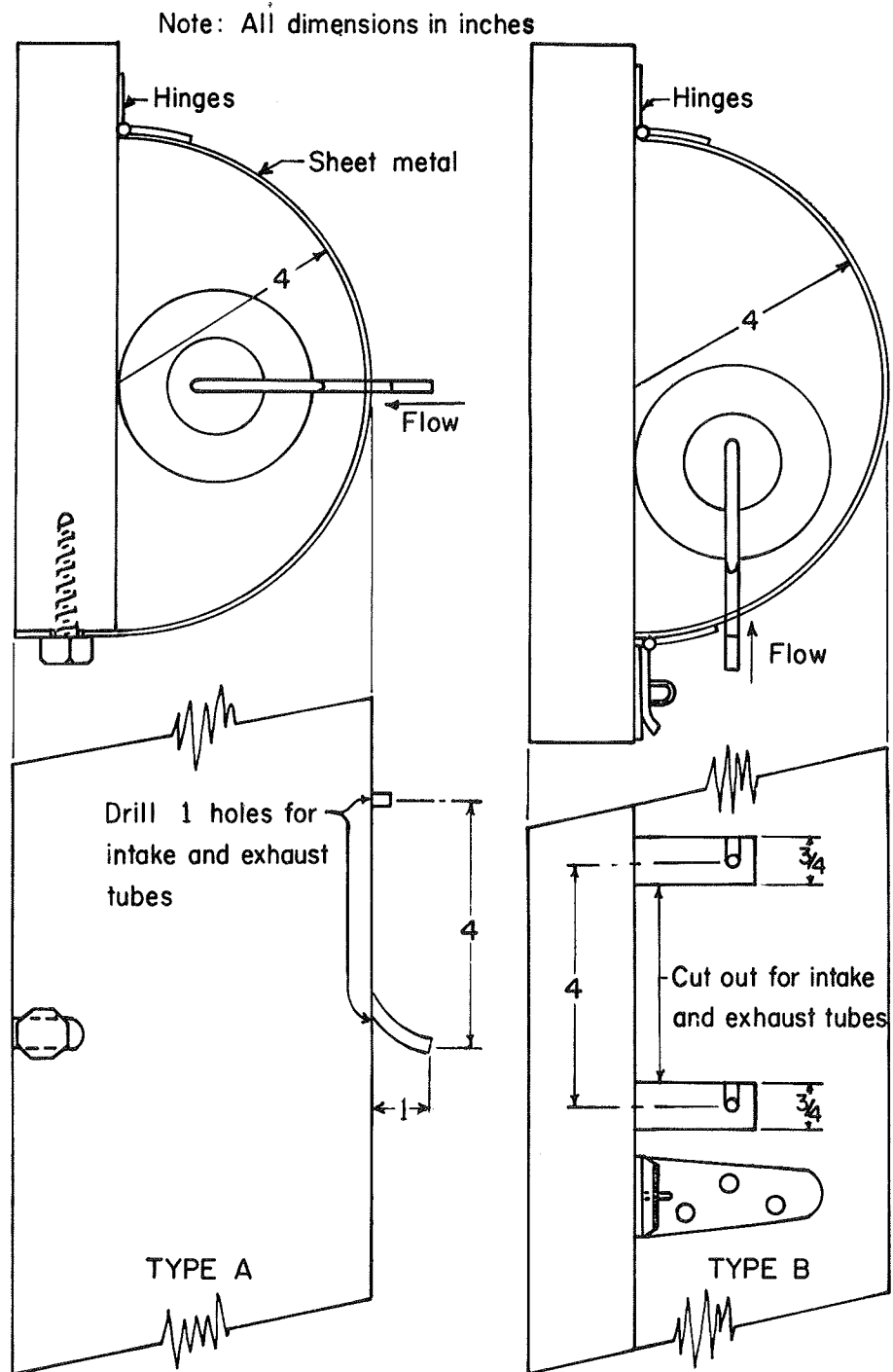


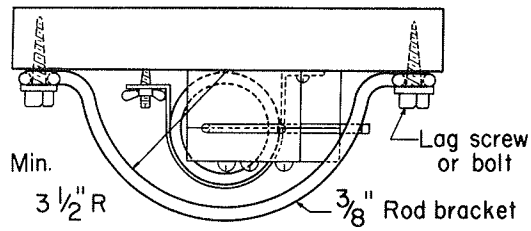
FIG. 48 A

FIG. 48 — SINGLE-STAGE SAMPLER INSTALLATION

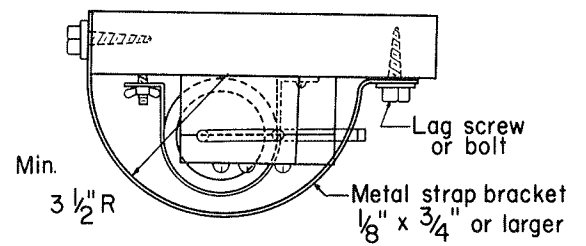


Note: Adjust total length and number of units as required.  
For vertical intake samplers use same type made with strong open mesh or plate with many holes.

FIG. 49 – SAMPLER PROTECTION—COVER TYPE

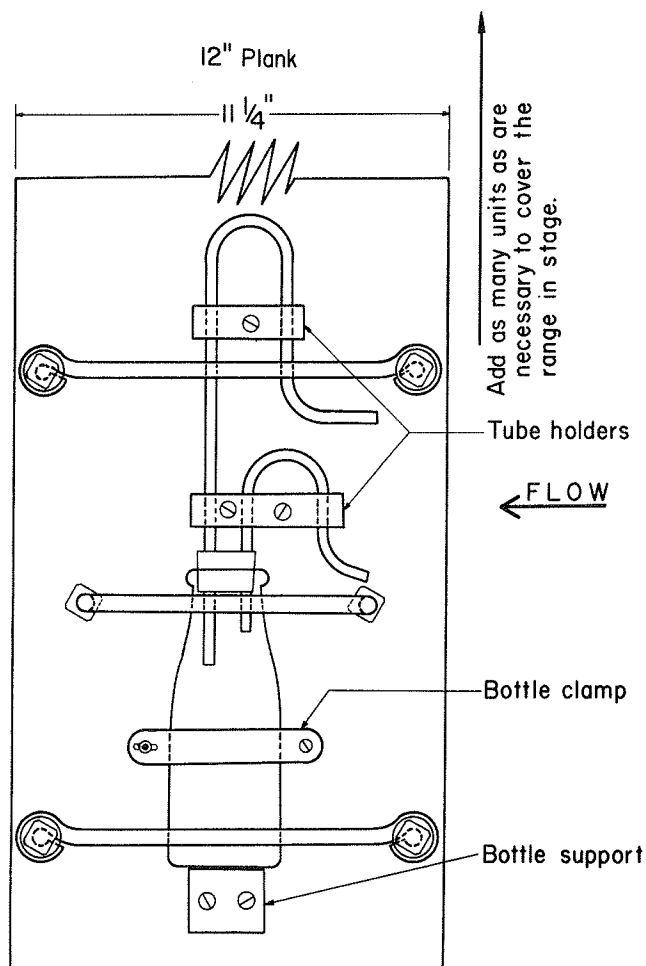


TOP VIEW

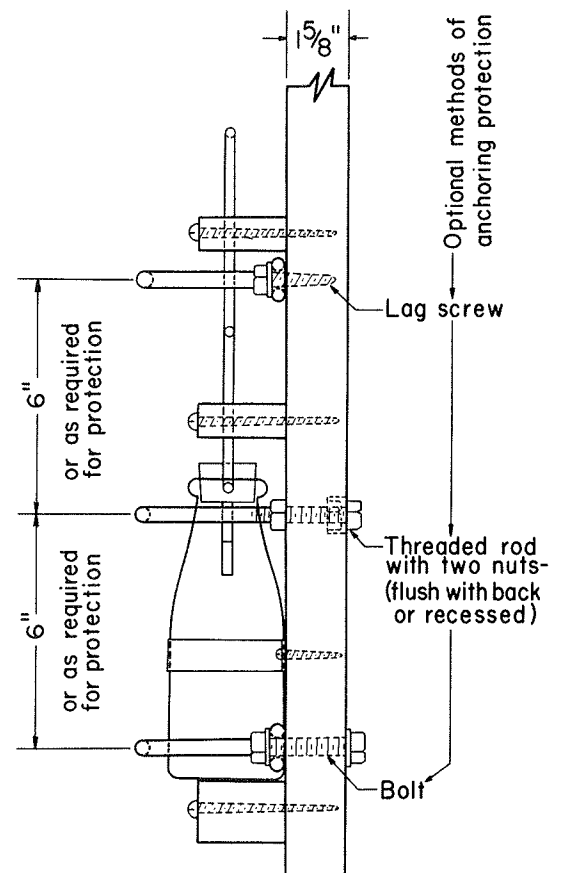


TOP VIEW

ALTERNATE PROTECTION USING STRAP IRON



ELEVATION



SIDE VIEW

FIG. 50 — SAMPLER PROTECTION-- RODS OR BARS

After a flood the samplers are generally covered with mud and debris, which make removal of the sample container difficult without contaminating the sample. Washing and rinsing the samplers with stream water and clean water are helpful but not always adequate. Often the best procedure is to clean the sampler in the laboratory. If containers must be changed in the field, some type of capping is desirable to keep the stopper and top of the bottle clean from deposition. Rubber tape may be wrapped around the joint between bottle and stopper. Three partially successful types of caps are shown in Fig. 51. Type A is a heavy-rubber cover that has been very successful in the laboratory but is somewhat hard to use in the field; type B is a snap-over cap of flexible rubber that is easy to use but does not withstand weathering; and type C is a plastic cap that is cheap and easy to use but often fails to seal satisfactorily.

Breakage, freezing, and confused identification of samples can be avoided if the single-stage samples are handled and stored with the same care as other sediment samples. The transportation of samples inside the assembled sampler creates problems because of the awkward size and shape of the sampler.

The substitution of collapsible or rigid plastic containers for glass milk bottles has been considered. The high initial cost of such a change does not appear justified at this time (1961).

## V. USE OF SINGLE-STAGE SAMPLE DATA

43. Sources of errors in sampling--Familiarity with the single-stage samplers should not be allowed to obscure their limitations and probable errors.

Four sources of sampling error can be avoided or eliminated; however, their effect is not quantitatively predictable:

(1) Presampling deposits in the intake nozzle can be eliminated by inclining the intake nozzle downward from the horizontal.

(2) Circulation can be eliminated by making the exhaust invert sufficiently high.

(3) Surge enrichment can be avoided by extending the inner end of the exhaust tube farther into the bottle.

(4) Contamination can be avoided by careful handling.

Some sampling errors can be minimized but not eliminated; however, for known sampling conditions their effect is predictable:

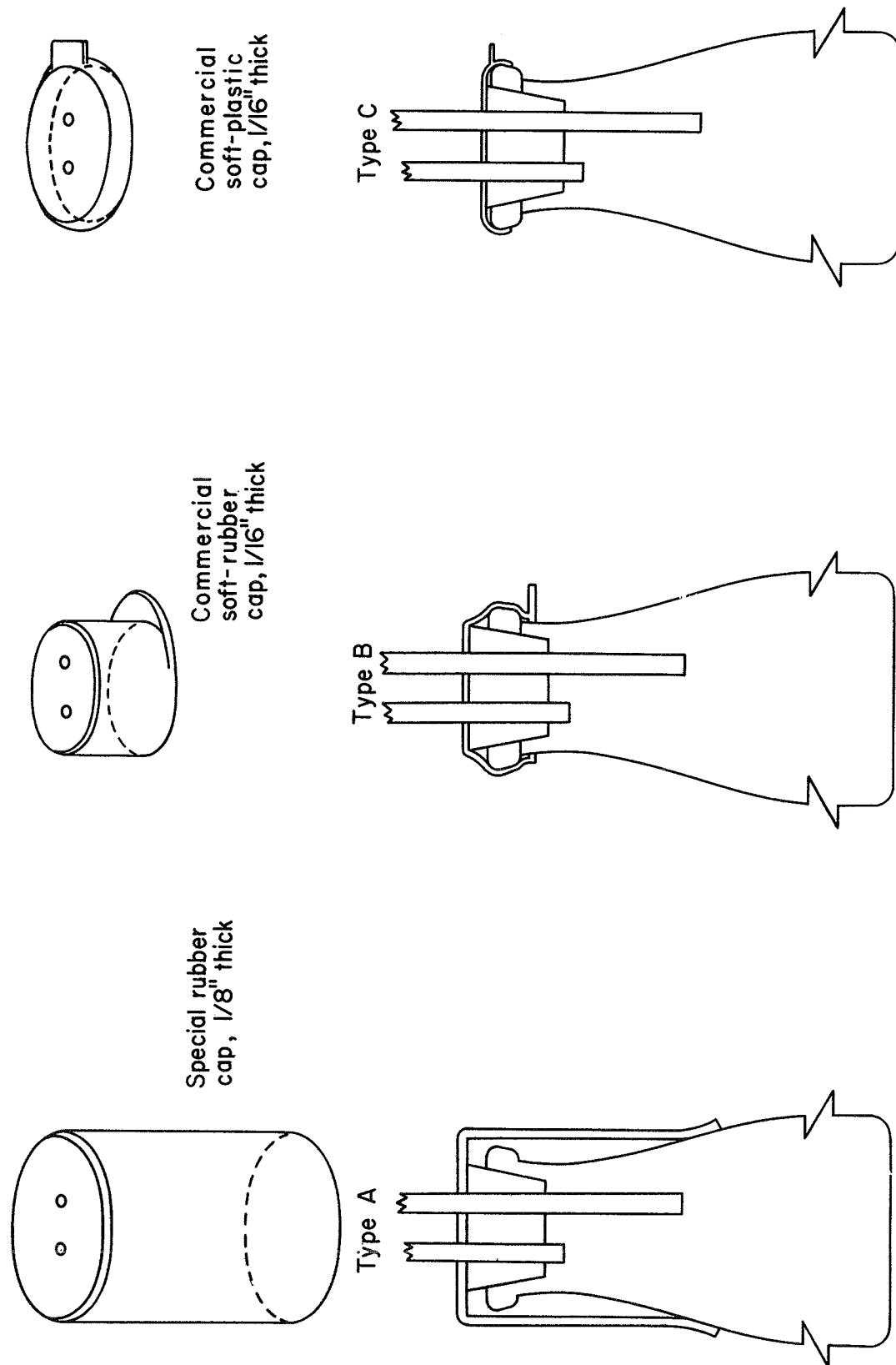


FIG. 51 - AUXILIARY BOTTLE CAPS

(1) Unfavorable intake orientation and unsatisfactory intake ratios during primary sampling cause the largest errors in sediment concentration in the sample.

(2) The accretion to sample volume because of submergence subsequent to sampling will be small, and the accretion can be measured or computed as a basis for correcting the sample concentration.

(3) The sample may be diluted by condensation in the sample container prior to sampling and by low concentrations of coarse sediments in suspension in the outer leg of the intake at the time sampling starts. Dilution due to unrepresentative concentration in the intake when sampling starts is limited by the volume of the outer leg of the intake, which is about 1 percent of the volume of a normal sample for recommended samplers U.S. U-59A and U.S. U-59B and 2 and 4 percent of the normal sample volume for samplers U.S. U-59C and U.S. U-59D, respectively.

Sample volume is an indication of sampling error. At the end of primary sampling, the sample surface in the container should be just above the inner end of the exhaust tube. A smaller sample usually indicates an obstruction of the exhaust tube or perhaps an obstruction of both intake and exhaust. A larger sample indicates a circulation or accretion backward through the air exhaust. A sample that fills the bottle indicates leakage at the stopper. Subsequent submergence can add to the volume, but generally the accretion will be minor and consistent throughout a group of samples from a single site and storm.

44. Corrections for sampling errors--Sampling errors vary with the size of sediment sampled. The errors depend on the sampler, the stream velocity, the water temperature, and the water-surface surge. Careful selection of samplers and, if necessary, the use of specially designed samplers should yield samples that are accurate to within 10 percent of the concentration of suspended sediment at the sampling point at the time of sampling. If the available sources of sampling error have been eliminated, any samples taken under conditions that give undesirable intake velocities may be corrected by using Figs. 23 to 25, which show errors in sediment concentration in the primary sample. The corrections may not be reliable for highly intermittent sampling. All other corrections, such as those for dilution and accretion, are generally small enough to disregard. One should be aware of the conditions that produce sampling errors and be alert to make corrections when needed.

45. Determination of sediment concentration at a sampling section--Even an accurate sample of the sediment in the stream at a sampling point may not be representative of the average sediment content at the sampling point because of rapid fluctuations in sediment content with time. Ten samples of equal sampling accuracy might show wide variations in concentration because of flow conditions. In the same set of samples the concentration of sediment finer than 62 microns might be uniform although the concentration of sands varies greatly.

Frequently, single-stage sampling will be close to one streambank. The velocity distribution may indicate the approximate distribution of sediment across the stream, but there is no satisfactory way to relate the sediment concentration at the sampling point to the average concentration for the entire width of the stream.

The sampling point for the single-stage sampler is near the water surface even when a stream is very deep. Various theories have been advanced to explain the distribution of sediment in a stream vertical, but none of them are sufficiently simple and dependable to relate sample concentration to concentration in the stream vertical without obtaining additional data.

Suppose the sediment concentration in a single-stage sample is accurate within 10 percent. Even if the variation of a single sample from the average is ignored, the single-stage sample may not determine the average concentration with an accuracy approaching 10 percent. The single-stage sample must be related to the concentration in the cross section of the stream. For silts and clays the relation of concentration at one point to that of the entire cross section may not be known accurately. For sands the lateral and vertical distributions of concentration may be so uncertain that the single-stage sample does not determine the concentration in the cross section within 50 percent although corrections for distribution are made.

When single-stage sediment samples are used to compute sediment concentration in a stream, the accuracy of the samples and the need for corrections should be evaluated by considering the probable velocity at the time of sampling, the water temperature, and the water-surface surge in relation to the sampler and to size of sediment. Then the concentration at the sampling point should be related to that in the entire stream, whenever possible, by measuring the concentrations for both. A measurement of the sediment concentration in the stream cross section can be made with manual sampling equipment. At the same time, one or more single-stage samples may be obtained by lowering a single-stage sampler to the elevation at which it starts to fill and then removing the sample after filling. (Reports No. 1, 3, and 8 contain information on sediment distribution in streams and on methods of measuring suspended sediment in streams. Report No. 6 shows modern types of suspended-sediment samplers.)

Even after the concentration of sediment in the cross section has been determined, relating the concentration to stream discharge or to time may be difficult. Because of velocity and surge effects the sampling stage is seldom known precisely, and at times it may be known only approximately. Also, the stage of the sampler may not be the same as that at the reference gage used for stream stage or discharge. When the stream stage changes slowly, a small uncertainty in the sampling stage may make a large uncertainty in the time at which the sample is taken.



## VI. CONCLUSIONS

### 46. Conclusions--

(1) Single-stage sediment samplers can be designed to obtain streamflow samples at or near the water surface (usually as the stream rises).

(2) An all-purpose single-stage sampler has not been developed because inherent limitations on the velocity in the intake nozzle restrict each model to a narrow range of conditions when sands are to be sampled.

(3) Four sampler models have been designed on the basis of development work. Briefly their limitations\* are as follows:

	<u>Sediment</u>	<u>Stream velocity</u> (fps)	<u>Water-surface surge</u> (in.)
U.S. U-59A	finer than 62 microns	reasonably low	less than 4
U.S. U-59B	sands and finer	less than 3	less than 2
U.S. U-59C	sands and finer	less than 5	less than 5
U.S. U-59D	sands and finer	less than 7	less than 8

For a detailed presentation of sampling characteristics see Figs. 23 to 25.

(4) Each of samplers U.S. U-59 B, C, and D samples accurately for a narrow range of stream velocity, water-surface surge, and water temperature; for certain sizes of sediment, each sampler will sample with reasonable accuracy for a somewhat wider range of hydraulic conditions and may sample with acceptable accuracy for a still wider range.

(5) The single-stage samplers will be useful when:

- a. Data on concentration of sediment from a point near the water surface are of value.
- b. Sampling by more accurate methods is not practical or feasible.

(6) To a far greater extent than with other approved sediment samplers, the accuracy of the single-stage sediment data depends on the competence of those who install and service the samplers and process the data. The designer of an installation and the user of the data should be thoroughly aware of the sources of errors in sampling, the possible ways of correcting these errors, and the methods

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\* If the approved samplers are not satisfactory for a certain stream, the basic design can be modified by using information in this report.

for determining the concentration at a sampling section as given in Sections 43, 44, and 45 of this report.

## VII. APPENDIX

47. Data tables--Some illustrations in the text have shown only part of the data available from the sampler tests.

The following tables are presented to preserve the data for the benefit of those who may wish to study sampler action further:

Table 1 - Sediment deposited in sampler intake .....	Page 92
(Discussion in Sec. 14, p. 23)	
Table 2 - Enrichment from presampling sediment deposits in sampler intakes of different slopes .....	Page 93
(Discussion in Sec. 14, p. 23)	
Table 3 - Intake calibration data, water temperature 35° - 39° F	Page 94
(Discussion in Sec. 19, p. 31)	
Table 4 - Intake calibration data, water temperature 70° - 76° F	Page 98
(Discussion in Sec. 19, p. 31)	
Table 5 - Experimental accretion .....	Page 102
(Discussion in Sec. 27, p. 53)	
Table 6 - Sample enrichment by surges .....	Page 103
(Discussion in Sec. 31, p. 60)	

TABLE 1  
SEDIMENT DEPOSITED IN SAMPLER INTAKE  
[In grams]

(For intakes see Fig. 5)										
Downward angle (degrees)	Submerged time (min) Surge (in.)	LONG INTAKES 1A, 1B, 1C					SHORT INTAKES 1D, 1E, 1F			
		1	3	5	10	30	1	3	5	10
		Sediment concentration 10,000 ppm					Sediment size 125 - 250 microns			
0	1/2	0.2271	0.5158	0.6774	0.6527		0.0841	0.1708	0.1712	0.2543
		.2059	.3618	.6618	.6252		.0871	.1257	.2215	.2205
		Avg .2165	.4388	.6696	.6390		.0856	.1482	.1964	.2374
	1	.3644	.4628	.5198	.4348		.1112	.2212	.1491	.1733
		.3974	.3847	.4655	.4106		.1422	.1718	.1158	.1436
		Avg .3809	.4238	.4926	.4227		.1267	.1965	.1324	.1584
10	1/2	.3208	.3058	.1177	.3566		.0106	.0071	.0211	.0244
		.1075	.2867	.2984	.2981		.0091	.0116	.0087	.0372
		Avg .2142	.2962	.2080	.3274		.0098	.0094	.0149	.0308
	1	.0270	.1498	.2615	.1381		.0128	.0132	.0141	.0069
		.1424	.1129	.1006	.0978		.0119	.0180	.0110	.0054
		Avg .0847	.1314	.1810	.1180		.0124	.0156	.0126	.0062
20	1/2	.0609	.2441	.1450	.2188		.0115	.0110	.0108	.0100
		.1080	.3270	.3411	.5226		.0080	.0090	.0109	.0098
		Avg .0844	.2856	.2430	.3707		.0098	.0100	.0108	.0099
	1	.0558	.1979	.0444	.0692		.0067	.0058	.0047	.0057
		.1108	.2228	.0547	.1493		.0074	.0048	.0071	.0060
		Avg .0833	.2104	.0496	.1092		.0070	.0053	.0059	.0058
Sediment concentration 1,000 ppm	1/2	.0134	.0047	.0057	.0038		.0020	.0022	.0019	.0014
		.0081	.0195	.0092	.0106		.0018	.0017	.0016	.0018
		Avg .0108	.0121	.0074	.0072		.0019	.0020	.0018	.0016
	1	.0414	.0240	.0080	.0067		.0007	.0009	.0007	.0008
		.0280	.0209	.0341	.0133		.0005	.0005	.0010	.0006
		Avg .0347	.0224	.0210	.0100		.0006	.0007	.0008	.0007
Sediment size 62 - 125 microns	1/2	.0406	.0156	.0352	.0237		.0010	.0013	.0012	.0006
		.0350	.0235	.0288	.0111		.0008	.0010	.0008	.0010
		Avg .0378	.0196	.0320	.0174		.0009	.0012	.0010	.0008
	1	0.0097	0.0204		0.0602	0.1982	0.0138	0.0364		0.0324
		.0092	.0240		.0593		.0138	.0224		.0353
		Avg .0094	.0222		.0598	.1982	.0138	.0294		.0338
0	1	.0164	.0357		.1473	.2121	.0044	.0051		.0026
		.0210	.0518		.0691		.0042	.0026		.0024
		Avg .0187	.0438		.1082	.2121	.0043	.0038		.0025
	2	.0178	.0080		.0470	.0628	.0004	.0013		.0009
		.0257	.0448		.0509	.0887	.0008	.0013		.0008
		Avg .0218	.0264		.0490	.0758	.0006	.0013		.0008
10	1/2	.0084	.0214		.0333		.0012	.0020		.0009
		.0079	.0124		.0208		.0006	.0008		.0021
		Avg .0082	.0169		.0270		.0009	.0014		.0015
	1	.0144	.0092		.0295		.0007	.0007		.0023
		.0022	.0067		.0107		.0007	.0009		.0027
		Avg .0083	.0080		.0201		.0007	.0008		.0025
20	1/2	.0208	.0271		.0255		.0011	.0008		.0003
		.0179	.0360		.0218		.0012	.0003		.0011
		Avg .0194	.0316		.0236		.0012	.0006		.0007
	1	.0035	.0114		.0031		Too small to be measurable			
		.0099	.0012		.0029					
		Avg .0067	.0063		.0030					
Sediment size 125 - 250 microns	1	.0084	.0040		.0019		Too small to be measurable			
		.0114	.0026		.0020					
		Avg .0099	.0033		.0020					
	2	.0035	.0021		.0013		Too small to be measurable			
		.0019	.0020		.0025					
		Avg .0027	.0020		.0019					

TABLE 2

ENRICHMENT FROM PRESAMPLING SEDIMENT DEPOSITS  
 IN SAMPLER INTAKES OF DIFFERENT SLOPES  
 [In parts per million]  
 [Sediment size 62-125 microns]

Surge (in.)	Delay time (min)	Intake slope Intake (Fig. 5)	LONG INTAKE			SHORT INTAKE		
			0°	-10°	-20°	0°	-10°	-20°
	0		1A	1B	1C	1D	1E	1F
	0		820	840	940	935	918	892
1/2	10		902	887	947	954	917	902
		Algebraic diff.	+82	+47	+7	+19	-1	+10
1	10		1,035	876	941	946	925	902
		Algebraic diff.	+215	+36	+1	+11	+7	+10
2	10		923	846	940	944	916	901
		Algebraic diff.	+103	+6	0	+9	-2	+9
		Averages:						
		Algebraic diff.	+133	+30	+3	+13	+1	+10
		Percentage diff.	+16	+4	0	+1	0	+1

TABLE 3

INTAKE CALIBRATION DATA,\*  
 WATER TEMPERATURE 35° to 39° F  
 [In feet per second]

Head	Sampler A		Sampler B		Sampler C		Sampler D		Sampler E		Head
(in.)	Flume velocity	Intake velocity	Flume velocity	Intake velocity	Flume velocity	Intake velocity	Flume velocity	Intake velocity	Flume velocity	Intake velocity	(in.)
4 1/2	0	2.16	0	2.17	0	2.03	0	2.15	0	2.08	4 1/2
4	0	2.03	0	2.06	0	2.03	0	2.03	0	1.98	4
3 1/2	0	1.81	0	1.86	0	1.82	0	1.85	0	1.78	3 1/2
3	0	1.67	0	1.70	0	1.68	0	1.67	0	1.62	3
2	0	1.26	0	1.29	0	1.18	0	1.26	0	1.24	2
4	1.00	2.17	1.00	2.16	1.00	2.08	.99	2.12	.99	2.09	4
3	1.00	2.00	1.00	1.94	1.00	1.84	.99	1.90	.99	1.85	3
2	1.00	1.40	1.00	1.45	1.00	1.43	.99	1.40	.99	1.42	2
4	2.04	2.30	2.04	2.33	2.04	2.18	2.04	2.29	2.04	2.19	4
3	2.04	1.95	2.04	1.92	2.04	1.85	2.04	1.87	2.04	1.90	3
2	2.04	1.61	2.04	1.68	2.04	1.59	2.04	1.58	2.04	1.61	2
4	3.02	2.41	3.02	2.37	3.02	2.11	3.02	2.47	3.02	2.26	4
3	3.02	1.99	3.02	2.07	3.02	1.93	3.02	2.15	3.02	1.97	3
2	3.02	1.67	3.02	1.80	3.02	1.73	3.02	1.68	3.02	1.73	2
4	4.00	2.96	3.96	2.93	4.00	2.86	4.00	3.04	4.00	2.72	4
3	4.00	2.71	3.96	2.54	4.00	2.73	4.00	2.76	4.00	2.50	3
2	4.00	2.34	3.96	2.40	4.00	2.20	4.00	2.35	4.00	2.33	2
3	5.13	3.42	5.13	3.32	5.13	2.97	5.13	3.37	5.13	3.20	3
2	5.13	3.08	5.13	3.24	5.13	3.02	5.13	3.14	5.13	3.01	2
3	7.12	4.64	7.12	4.73	7.12	4.45	7.12	4.59	7.12	4.60	3
2	7.12	4.60	7.12	4.47	7.12	4.31	7.12	4.63	7.12	4.36	2
2	8.7	5.53	8.5	5.42	8.6	5.25	8.8	5.34	8.8	5.29	2

\* Samplers 3A to 3E of Fig. 15

TABLE 3 - CONTINUED

INTAKE CALIBRATION DATA,\*  
 WATER TEMPERATURE 35° to 39° F  
 [In feet per second]

Head	Sampler F		Sampler G		Sampler H		Sampler I		Sampler J		Head
(in.)	Flume velocity	Intake velocity	Flume velocity	Intake velocity	Flume velocity	Intake velocity	Flume velocity	Intake velocity	Flume velocity	Intake velocity	(in.)
16	0	2.82									16
14	0	2.82									14
12	0	2.81									12
10	0	2.78	0	4.93	0	4.96	0	4.82	0	5.58	10
9	0	2.60	0	4.57	0	4.60	0	4.31	0	5.20	9
8	0	2.37	0	4.46	0	4.40			0		8
7					0	4.22	0	3.98			7
6	0	2.02	0	3.84							6
4	0	1.56	0	3.09							4
2	0	1.02	0	2.11	0	3.21					2
10	1.02	2.63	1.00	5.28	1.00	4.68	1.02	5.22	1.00	5.70	10
9	1.02	2.52	1.00	4.87	1.00	4.90	1.02	4.71	1.00	5.00	9
8	1.01	2.40	1.00	4.57	1.00	4.27					8
6	1.00	2.03	1.00	3.84	1.00	4.12	1.00	4.06	1.00	4.32	6
4	1.00	1.71	1.00	3.12	1.00	3.42	1.00	3.19	1.00	2.38	4
2	1.00	1.18	1.00	2.27	1.00	2.30					2
9	2.07	2.77	2.04	4.99	2.07	5.34	2.07	4.95	2.05	5.19	9
8	2.07	2.54	2.03	4.73	2.07	4.45	2.07	4.88	2.05	5.12	8
7	2.07	2.43			2.05	4.30					7
6	2.06	2.16	2.02	3.70	2.05	4.20	2.06	4.05	2.05	4.50	6
4	2.06	1.73	2.02	3.00	2.05	3.14	2.06	3.79	2.05	3.67	4
2	2.06	1.48					2.06	3.21			2
8	3.10	3.02	3.15	4.64	3.55	4.96	3.10	4.90	3.15	4.36	8
7	3.07	2.59	3.14	4.50	3.14	4.93					7
6	3.05	2.42	3.12	4.30	3.12	4.54	3.05	4.64	3.12	4.07	6
5	3.05	2.13			3.12	4.18	3.05	3.95	3.12	4.30	5
4	3.05	1.95	3.12	3.70	3.12	3.82	3.05	3.98	3.12	4.10	4
2	3.05	1.52	3.12	3.04	3.12	3.19	3.05	3.30	3.12	1.95	2
8	4.00	3.03	4.00	5.15	4.00	5.71	4.00	5.71	4.00	5.95	8
6	3.98	2.71	3.98	4.72	3.98	4.87	3.98	4.67	3.98	4.50	6
5			3.98	4.36	3.98	4.47			3.98	4.83	5
4	3.98	2.30	3.98	4.01	3.98	4.47	3.98	4.22			4
3	3.98	2.15	3.98	3.63	3.98	3.98	3.98	4.13	3.98	4.02	3
8	5.03	3.56	4.95	5.99	5.03	6.33	5.03	6.29	5.03	6.63	8
6	5.03	3.08	5.00	5.69	5.03	5.80	5.03	5.55	5.03	5.07	6
5	5.03	2.89									5
4	5.03	2.84	5.00	5.05	5.03	4.94	5.03	4.89	5.03	5.13	4
3	5.03	2.40	5.00	4.66	5.03	4.61	5.03	4.65			3
2	5.03	2.00	5.00	3.66	5.03	4.50			5.03	3.59	2
8	7.36	4.27	7.42	7.70	7.36	8.49	7.36	8.19	7.40	8.84	8
6	7.36	3.99	7.45	7.66	7.38	7.79	7.38	7.72	7.42	7.90	6
4	7.36	3.78	7.45	7.16	7.38	7.16	7.38	7.38	7.42	7.50	4
2	7.36	3.58	7.45	6.81	7.38	6.82	7.38	6.96	7.42	7.09	2
8	8.8	4.46	8.9	9.18	8.4	9.68	8.7	9.58	8.8	9.24	8
6	8.9	4.23	8.9	8.87	8.5	8.57	8.8	9.12	8.8	8.59	6
4	8.9	4.09	8.9	8.66	8.5	7.94	8.8	8.44	8.8	8.29	4
2			8.9	8.05	8.5	7.73	8.8	8.24	8.8	8.12	2

\* Samplers 3F to 3J of Fig. 15

TABLE 3 - CONTINUED

INTAKE CALIBRATION DATA,\*  
WATER TEMPERATURE 35° to 39° F  
[In feet per second]

Head	Sampler K		Sampler L		Sampler M		Sampler N		Sampler O		Head
(in.)	Flume velocity	Intake velocity	Flume velocity	Intake velocity	Flume velocity	Intake velocity	Flume velocity	Intake velocity	Flume velocity	Intake velocity	(in.)
12					0	2.78					12
10	0	4.65			0	2.75					10
9	0	4.70			0	2.74					9
8	0	4.31	0	1.92	0	2.50					8
6			0	1.93	0	2.10					6
5			0	1.92			0	2.21	0	2.26	5
4			0	1.90	0	1.74	0	1.91	0	1.97	4
3			0	1.69			0	1.60	0	1.62	3
2			0	1.32	0	1.07	0	1.31	0	1.29	2
12					.99	2.79					12
10	1.00	5.12			.99	2.72					10
8	1.00	4.64	.99	1.88	.99	2.37					8
6	1.00	3.67	.99	1.89	.99	1.95					6
5			.99	1.92			.99	2.37	.99	2.39	5
4	1.00	2.81	.99	1.89	.99	1.47	.99	2.13	.99	2.04	4
3			.99	1.60			.99	1.84	.99	1.57	3
2			.99	1.12			.99	1.46	.99	1.43	2
12					2.09	2.68					12
10					2.08	2.56					10
8	2.05	4.60			2.07	2.37					8
6	2.05	3.76			2.06	1.89					6
5			2.04	2.00			2.04	2.52	2.04	2.52	5
4	2.05	3.12	2.04	1.87	2.06	1.49	2.04	2.19	2.04	2.27	4
3			2.04	1.65			2.04	1.93	2.04	1.92	3
2			2.04	1.23			2.04	1.63	2.04	1.61	2
10					3.20	2.54					10
8	3.12	4.68			3.10	2.40					8
6	3.12	4.40			3.05	1.85					6
5							3.02	2.54	3.02	2.64	5
4	3.12	3.42			3.05	1.41	3.02	2.39	3.02	2.02	4
3			3.00	1.56			3.02	2.13	3.02	1.87	3
2	3.12	3.22	3.00	1.13	3.05	1.04	3.02	1.65			2
8	4.00	4.83			4.00	2.47					8
6	3.98	4.18			3.98	2.11					6
4			4.00	2.04	3.98	1.58	4.00	No Sample	4.00	2.98	4
3	3.98	3.80	4.00	1.64			4.00		4.00	2.70	3
2			4.00	1.25	3.98	1.01			4.00	2.63	2
8	4.95	5.88			5.03	2.80					8
6	5.00	4.61			5.03	2.40					6
4	5.00	4.43	5.03	2.81							4
3			5.03	2.00			5.13	2.14	5.13	3.09	3
2	5.00	3.91	5.03	1.36			5.13	1.06	5.13	3.04	2
8	7.40	8.19			7.3	3.25					8
6	7.42	7.66			7.3	3.06					6
4	7.42	7.08	7.08	2.39	7.3	2.78					4
3							7.12	4.44	7.08	4.46	3
2	7.42	6.50	7.08	2.24	7.3	2.14	7.12	3.50	7.08	4.15	2
8	8.8	8.78			8.8	3.23					8
6	8.9	8.23			8.9	2.40					6
4	8.9	8.10	8.9	3.10	8.9	2.45					4
2	8.9	7.48	8.9	2.62	8.9	2.38	8.8	5.28	8.9	5.52	2

\* Samplers 3K of Fig. 15 and 3L to 3O of Fig. 16



TABLE 3 - CONTINUED

INTAKE CALIBRATION DATA,\*  
 WATER TEMPERATURE 35° to 39° F  
 [In feet per second]

Head	Sampler P		Sampler Q		Sampler R		Sampler S		Sampler T		Head
(in.)	Flume velocity	Intake velocity	Flume velocity	Intake velocity	Flume velocity	Intake velocity	Flume velocity	Intake velocity	Flume velocity	Intake velocity	(in.)
22	0	3.23	0	5.60	0	5.70	0	5.71	0	5.54	22
21			0	5.28	0	5.50	0	5.42	0	5.50	21
20	0	3.23	0	4.73	0	5.42	0	5.49	0	5.32	20
18	0	3.09	0	5.09	0	5.11	0	5.24	0	5.07	18
16	0	3.10	0	4.52	0	4.68	0	4.76	0	4.63	16
14	0	2.71	0	4.40	0	4.26	0	4.46	0	4.65	14
12	0	2.40	0	3.69	0	4.06	0	3.98	0	4.11	12
10	0	2.11	0	3.69	0	4.01	0	3.14	0	3.62	10
8	0	1.74			0	3.27	0	3.33	0	3.78	8
20	1.05	3.33			1.05	5.41					20
18	1.04	2.96			1.04	4.98					18
14	1.03	2.77			1.04	4.50					14
10	1.02	2.11			1.02	3.81					10
6	1.00	1.52			1.00	2.95					6
20			2.06	5.69	2.06	5.34	2.06	5.54	2.06	5.95	20
19	2.08	3.22	2.06	5.46	2.06	5.15	2.06	5.51	2.06	5.28	19
18	2.08	3.56	2.06	5.16	2.06	5.13	2.06	5.14	2.06	5.31	18
16	2.08	3.11									16
14	2.07	2.98	2.06	4.62	2.06	4.62	2.06	4.49	2.06	4.56	14
10	2.07	2.23	2.06	4.15	2.06	3.90	2.06	3.87	2.06	3.74	10
6	2.06	1.66	2.06	3.13	2.06	2.90	2.06	2.59	2.06	2.81	6
19	3.20	3.31	3.20	5.37	3.20	5.19	3.20	5.47	3.20	5.30	19
18	3.20	3.04	3.20	5.00	3.20	4.97	3.20	5.14	3.20	4.91	18
16	3.20	3.06	3.20	5.07	3.20	5.02	3.20	5.00	3.20	4.93	16
14	3.20	2.87	3.20	4.56	3.20	4.85	3.20	4.72	3.20	4.71	14
10	3.18	2.47	3.18	3.77	3.18	3.86	3.18	4.03	3.18	3.63	10
6	3.12	1.84	3.12	3.30	3.12	3.13	3.11	3.12	3.11	2.84	6
18	4.16	3.22	4.18	5.54	4.18	5.66	4.20	5.67	4.20	5.48	18
16	4.15	2.90	4.17	5.33	4.18	5.07	4.20	4.95	4.20	5.25	16
14	4.14	3.22	4.14	5.12	4.15	4.80	4.14	4.93	4.12	4.84	14
12	4.13	2.79	4.12	4.93	4.12	4.44	4.12	4.39	4.11	4.54	12
8	4.05	2.25	4.05	4.36	4.05	3.96	4.06	3.80	4.06	3.98	8
4	3.97	1.74	3.98	3.23	3.98	2.78	3.99	3.06	4.00	2.63	4
18	4.86	3.48	4.86	5.97	4.82	5.91	4.80	5.76	4.70	5.84	18
16	4.90	3.37	4.90	5.63	4.84	5.46	4.82	5.67	4.72	5.63	16
14	4.90	3.17	4.90	5.31	4.86	5.08	4.84	5.04	4.74	4.80	14
12	4.92	3.09	4.92	4.70	4.88	5.06	4.86	4.78	4.78	5.01	12
8	4.95	2.59	4.92	4.23	4.95	4.05	4.92	4.41	4.88	4.31	8
4	4.98	2.14	4.92	3.46	4.98	3.45	4.95	3.70	4.90	3.67	4
18	6.8	4.22	6.8	7.31	6.8	6.84	6.8	6.71	6.8	6.72	18
16	6.9	4.08	6.9	6.99	6.9	6.49	6.9	6.70	6.9	6.43	16
12	7.1	3.73	7.1	6.33	7.1	6.17	7.1	5.90	7.1	5.97	12
8	7.3	3.37	7.3	5.40	7.2	5.41	7.3	5.37	7.2	4.90	8
7	7.4	3.24	7.4	4.54	7.3	4.93	7.2	4.98	7.2	4.47	7
18	8.3	4.52	8.6	8.22	8.6	7.77	8.6	7.44	8.6	7.27	18
16	8.4	4.41	8.7	8.03	8.7	7.41	8.6	7.16	8.6	6.75	16
12	8.5	4.20	8.8	7.88	8.7	7.16	8.7	6.66	8.7	6.29	12
8	8.7	3.74	8.8	6.88	8.8	6.58	8.8	6.82	8.8	5.94	8
4	8.8	3.29	9.0	6.05	8.9	5.65	8.9	5.50	8.9	5.25	4
2	8.8	3.04	9.0	6.25							2

\* Samplers 3P to 3T of Fig. 16

TABLE 4

INTAKE CALIBRATION DATA,\*  
 WATER TEMPERATURE 70° to 76° F  
 [In feet per second]

Head	Sampler A		Sampler B		Sampler C		Sampler D		Sampler E		Head
(in.)	Flume velocity	Intake velocity	Flume velocity	Intake velocity	Flume velocity	Intake velocity	Flume velocity	Intake velocity	Flume velocity	Intake velocity	(in.)
4 1/2	0	2.56	0	2.58	0	2.44	0	2.54	0	2.48	4 1/2
3 1/2	0	2.31	0	2.30	0	2.23	0	2.34	0	2.21	3 1/2
3	0	2.12	0	2.06	0	2.07	0	2.11	0	2.00	3
2	0	1.50	0	1.56	0	1.51	0	1.47	0	1.54	2
3	1.54	2.60	1.56	2.62	1.53	2.52	1.57	2.65	1.58	2.54	3
2	1.54	2.21	1.56	2.14	1.53	1.82	1.57	2.38			2
4	2.62	2.98	2.66	2.94	2.56	3.09	2.68	2.94	2.58	2.94	4
3	2.62	2.56	2.66	2.32	2.56	2.82	2.68	2.63	2.58	2.48	3
2					2.56	2.18					2
3	4.02	3.45	4.04	3.42	4.00	3.15	4.04	3.30	4.06	3.19	3
2	4.02	2.94	4.04	3.09	4.00	2.89	4.04	2.96	4.06	2.97	2
3	5.72	4.67	5.66	4.60	5.62	4.40	5.68	4.33	5.70	4.20	3
2	5.72	4.40	5.66	4.30	5.62	4.10	5.68	4.11	5.70	3.99	2
3	7.65	6.39	7.40	5.97	7.70	6.05	7.45	5.72	7.50	5.54	3
2	7.65	5.97	7.40	5.56	7.70	5.74	7.45	5.32	7.50	5.25	2
3	9.86	7.44	9.88	7.34	9.84	8.24	9.90	6.82	9.94	6.63	3
2	9.86	7.12	9.88	6.92	9.84	7.09	9.90	6.94	9.94	6.42	2

\* Samplers 3A to 3E of Fig. 15

TABLE 4 - CONTINUED

INTAKE CALIBRATION DATA,\*  
 WATER TEMPERATURE 70° to 76° F  
 [In feet per second]

Head	Sampler F		Sampler G		Sampler H		Sampler I		Sampler J		Head
(in.)	Flume velocity	Intake velocity	Flume velocity	Intake velocity	Flume velocity	Intake velocity	Flume velocity	Intake velocity	Flume velocity	Intake velocity	(in.)
10	0	3.16	0	5.59	0	5.52	0	5.24			10
9	0	2.96	0	5.22	0	5.00	0	5.33	0	5.68	9
8	0	2.80	0	4.92	0	4.70	0	4.93	0	5.10	8
7	0	2.44	0	4.53	0	4.03	0	4.36			7
6	0	2.33	0	4.34	0	4.20					6
4	0	1.94	0	3.28	0	3.44					4
8	1.53	2.82	1.56	5.77	1.55	5.23	1.54	5.35	1.56	5.62	8
7	1.53	2.76	1.57	5.71	1.55	5.08	1.54	4.92			7
6	1.54	2.70	1.57	5.14	1.55	4.81					6
5	1.54	2.42	1.58	4.69	1.55	4.70					5
4	1.54	2.20	1.58	4.49	1.55	3.91					4
8	2.65	3.10	2.56	5.04	2.65	5.79	2.65	5.76	2.56	5.90	8
7	2.65	2.71	2.56	4.51	2.65	5.31	2.65	5.57			7
6	2.65	2.60	2.56	4.45	2.65	4.97					6
4	2.65	2.21	2.56	3.62	2.65	4.27					4
8	4.06	3.30	4.14	6.28	4.10	6.63	4.08	6.58	4.12	6.71	8
7	4.06	3.26	4.14	5.77	4.10	6.25					7
6	4.06	3.06	4.14	5.39	4.10	5.90	4.08	5.85	4.12	5.39	6
5			4.14	4.86	4.10	5.21					5
4	4.06	2.70	4.14	4.71	4.10	5.12					4
8	5.48	3.85	5.48	8.09	5.48	7.92	5.48	7.77	5.48	7.36	8
7	5.48	3.72	5.48	7.10	5.48	7.59					7
6	5.48	3.55	5.48	6.71	5.48	6.86	5.48	7.18	5.48	6.13	6
4	5.48	3.21	5.48	5.95	5.48	5.81					4
8	7.70	4.81	7.55	9.42	7.70	10.58	7.70	9.98	7.50	9.49	8
7	7.70	4.61	7.55	9.09	7.70	10.08					7
6	7.70	4.53	7.55	9.02	7.70	9.90	7.70	9.07	7.50	8.66	6
4	7.70	4.34	7.55	8.50	7.70	9.05					4
3	7.70	4.11			7.70	8.80					3
8	9.96	6.06	9.90	11.62	9.94	12.41	9.96	11.80	9.92	10.47	8
7	9.96	5.98	9.90	11.55	9.94	12.20					7
6	9.96	5.82	9.90	11.26	9.94	11.98	9.96	10.22	9.92	10.14	6
4	9.96	5.64	9.90	10.80	9.94	11.23					4
2	9.96	5.45	9.90	10.10	9.94	10.59					2

\* Samplers 3F to 3J of Fig. 15

TABLE 4 - CONTINUED  
 INTAKE CALIBRATION DATA,\*  
 WATER TEMPERATURE 70° to 76° F  
 [In feet per second]

Head	Sampler K		Sampler L		Sampler M		Sampler N		Sampler O		Head
(in.)	Flume velocity	Intake velocity	Flume velocity	Intake velocity	Flume velocity	Intake velocity	Flume velocity	Intake velocity	Flume velocity	Intake velocity	(in.)
10					0	2.99					10
8					0	2.75					8
6					0	2.40					6
5			0	2.22			0	2.68	0	2.62	5
4			0	2.15	0	1.90					4
3			0	1.82							3
2			0	1.53							2
9					1.56	2.98					9
8					1.56	2.75					8
6					1.56	2.46					6
5			1.60	2.26	1.56	2.23	No sample		1.59	2.88	5
4			1.60	2.26	1.56	2.02			1.59	2.78	4
3			1.60	2.15							3
2			1.60	1.67							2
8	2.56	5.54			2.65	2.80					8
7	2.56	5.07			2.65	2.59					7
6					2.65	2.45					6
5			2.62	2.19	2.65	2.22					5
4			2.62	1.94			2.58	2.80	No sample		4
3			2.62	1.64							3
8	4.12	6.10			4.14	2.67					8
7					4.14	2.52					7
6	4.12	5.12			4.14	2.40					6
5			4.10	2.59			No sample		4.08	3.84	5
4			4.10	2.36	4.14	1.96			4.08	3.63	4
3			4.10	1.92							3
2			4.10	1.65							2
8	5.48	7.12			5.52	3.33					8
7					5.52	3.05					7
6	5.48	6.72			5.52	2.76					6
5			5.50	3.02	5.52	2.43	5.74	5.10	5.78	5.07	5
4			5.50	2.55					5.78	4.65	4
3			5.50	2.48							3
2			5.50	1.85							2
8	7.50	8.89			7.65	3.25					8
7					7.65	2.89					7
6	7.50	8.15			7.65	2.86					6
5			7.60	2.85			7.70	5.77	No sample		5
4			7.60	2.08							4
3			7.60	2.28							3
8	9.92	10.10			9.94	3.13					8
7					9.94	2.66					7
6	9.92	8.78									6
5			9.84	3.72			No sample		9.96	7.02	5
4			9.84	3.28							4
3			9.84	2.93							3

\* Samplers 3K of Fig. 15 and 3L to 3O of Fig. 16

TABLE 4 - CONTINUED

INTAKE CALIBRATION DATA,\*  
 WATER TEMPERATURE 70° to 76° F  
 [In feet per second]

Head	Sampler Q		Sampler R		Sampler S		Sampler T		Sampler U		Head
(in.)	Flume velocity	Intake velocity	Flume velocity	Intake velocity	Flume velocity	Intake velocity	Flume velocity	Intake velocity	Flume velocity	Intake velocity	(in.)
22	0	6.14	0	5.97	0	6.17	0	6.11	0	6.96	22
20	0	5.67	0	5.71	0	5.83	0	5.46	0	6.04	20
18			0	5.23					0	6.54	18
16			0	4.70					0	5.90	16
14			0	4.54					0	5.82	14
12			0	4.21							12
8			0	3.67							8
22	1.54	5.96	1.54	6.14	1.55	6.40	1.55	5.96	1.55	8.26	22
20	1.54	5.56	1.54	5.69	1.55	5.56	1.55	5.92	1.55	8.08	20
18			1.54	5.83					1.56	6.94	18
16			1.54	5.15					1.56	6.44	16
14									1.56	6.00	14
12			1.55	4.36							12
22			2.46	6.13					2.51	8.54	22
20	2.49	6.13	2.47	5.98	2.50	6.11	2.50	5.90	2.53	7.90	20
18	2.50	5.85	2.47	5.73	2.51	5.89	2.51	5.68	2.53	7.51	18
16			2.49	5.71					2.54	6.74	16
12			2.51	4.99					2.55	6.41	12
8			2.54	3.93							8
22			4.12	6.08					4.06	8.68	22
20	4.14	6.63	4.12	6.37	4.14	6.44	4.14	6.70	4.08	9.08	20
18	4.14	6.16	4.14	5.89	4.14	5.94	4.14	6.07	4.10	7.88	18
16			4.15	5.46					4.12	6.28	16
14			4.16	4.88							14
12			4.17	4.59							12
10			4.18	4.01							10
20	5.36	7.34	5.36	7.03	5.38	7.11	5.38	7.21	5.40	10.26	20
18	5.38	7.11	5.38	6.94	5.40	6.68	5.40	6.70	5.40	9.86	18
16			5.40	6.66					5.44	7.49	16
14			5.44	6.07					5.46	7.39	14
12			5.46	5.60							12
10			5.48	5.38							10
20			7.40	7.91					7.30	10.99	20
18	7.50	7.75	7.42	7.65	7.38	7.83	7.32	7.19	7.32	10.45	18
16	7.54	7.58	7.46	7.38	7.40	7.64	7.34	7.10	7.32	10.26	16
14			7.48	6.94					7.32	9.86	14
12			7.50	6.42					7.34	8.82	12
10			7.55	6.03					7.38	7.90	10
8			7.60	5.92					7.40	7.89	8
14	9.84	7.82	9.84	7.89	9.84	7.83	9.84	7.11	9.84	12.74	14
12	9.84	7.45	9.84	7.77	9.84	7.70	9.84	6.98	9.84	11.64	12
10			9.84	7.49					9.84	11.58	10
8			9.84	7.57					9.84	9.98	8
4			9.84	6.31					9.84	9.04	4
2			9.84	6.03					9.84	8.68	2

\* Samplers 3Q to 3U of Fig. 16

TABLE 5  
EXPERIMENTAL ACCRETION  
[Milliliters]

Velocity fps	First cycle Submergence (ft)					Second cycle Submergence (ft)					Third cycle Submergence (ft)					
	0	5	10	15	19	0	5	10	15	19	0	5	10	15	19	0
SAMPLER L (3L of Fig. 15)																
1	0	7				7	11				11	15				15
1	0	7	15			15	18	22			22	24	27			27
1	0	4	10	15	20	20	20	23	28	31	31	31	35	37	39	39
1	0	7	15	20	23	23	24	27	31	33	33	33	37	39	41	41
3	1	7				7	11				11	13				
3	1	7	13			13	15	23			23	26	30			
3	1	7	13	18	22	22	23	27	31	35	35	35	38	42	43	43
6	2	8				8	11				11	13				13
6	2	8	13			13	18	21			21	23	27			27
6	2	8	13	19	23	23	23	27	31	35	35	35	38	40	42	42
SAMPLER F (3F of Fig. 15)																
1	3	12				12	14				14	15				15
1	3	9	12			12	12	19			19	19	24			24
1	3	12	18	22	26	26	27	30	34	36	36	37	39	41	43	42
3	1	9				9	12				12	15				15
3	1	8	16			16	16	23			23	23	29			29
3	-1	8	16	21	23	23	23	29	33	37	37	37	39	41	43	43
6	1	9				9	13				13	15				15
6	1	8	17			17	19	24			24	26	31			31
6	-1	8	15	20	24	24	27	31	34	37	37	37	40	43	45	45
SPECIAL SAMPLER *																
1	1	6				6	8				8	11				11
1	1	6	11			11	11	17			17	17	21			21
1	1	6	11	15		15	15	19	23		23	23	27	30		25
1	1	6	11	15	19	19	19	23	26	27	25	25	29	30	32	
3	1	7				7	10				10	13				13
3	1	6	11			11	13	17			17	19	24			24
3	0	6	11	16		16	19	23	25		25	25	29	31		25
3	1	8	13	16	18	18	21	25	28	29	25	25	29	31	32	25
6	0	8				8	12				12	15				15
6	1	6	13			13	16	21			21	24	27			23
6	1	6	12	16		16	19	23	27		23	25	28	30		23
6	0	6	11	15	18	18	21	24	27	28	23	25	28	30	32	23

Note: Data for 19 ft cycles at a velocity of 6 fps were plotted on Fig. 30.

\* Special sampler of Sec. 27 (similar to 3A of Fig. 15 except for length of extensions into sample container)

TABLE 6  
SAMPLE ENRICHMENT BY SURGES  
[In parts per million]

Sediment		Air exhaust (in.)	Time (min)	Surge in air exhaust (in.)					
Concentration in jar (ppm)	Sieve size (microns)			1/2	1	1-1/2	2	4	6
HORIZONTAL INTAKE SAMPLER (3C of Fig. 15)									
1,000	< 62	3/16	5	1	7	9	11	16	51
1,000	do	do	30	8	10	24	38	113	386
5,000	do	do	5	0	6	11	30	90	327
5,000	do	do	30	6	10	70	160	554	1,690
10,000	do	do	5	4	6	33	61	194	737
10,000	do	do	30	6	13	73	331	1,140	3,690
1,000	62-125	do	5	4	9	21	32	54	118
1,000	do	do	30	14	28	40	64	137	406
5,000	do	do	5	6	17	27	37	139	326
5,000	do	do	30	14	40	59	200	447	1,980
10,000	do	do	5	8	20	30	90	256	599
10,000	do	do	30	18	40	78	262	1,810	3,490
1,000	125-250	do	5	7	9	13	60	21	251
1,000	do	do	30	7	9	28	1,200	456	1,160
10,000	do	do	5	4	9	36	213	58	336
10,000	do	do	30	7	9	125	5,330	850	1,700
10,000	250-500	do	5	3	4	13	68	129	506
10,000	do	do	30	2	5	31	967	2,350	3,530
1,000	< 62	1/8	5	0	2	8	8	20	18
1,000	do	do	30	5	8	11	15	31	53
5,000	do	do	5	0	2	7	20	31	56
5,000	do	do	30	3	8	20	41	214	439
10,000	do	do	5	1	4	18	56	110	185
10,000	do	do	30	5	8	31	155	294	536
1,000	62-125	do	5	3	9	22	31	49	63
1,000	do	do	30	10	20	29	41	82	125
5,000	do	do	5	5	9	21	30	90	125
5,000	do	do	30	11	25	39	58	185	598
10,000	do	do	5	6	10	20	45	164	239
10,000	do	do	30	14	27	65	148	580	693
VERTICAL INTAKE SAMPLER (3" invert)									
10,000	< 62	3/16	5	0	1	1	4	326	1,050
10,000	do	do	30	1	1	2	5	1,540	5,560
10,000	62-125	do	5	10	23	35	46	495	1,560
10,000	do	do	30	15	34	42	67	2,830	8,170
10,000	125-250	do	5	3	7	18	40	1,110	3,860
10,000	do	do	30	8	17	28	244	12,400	27,000
10,000	250-500	do	5	2	3	8	100	1,550	4,630
10,000	do	do	30	5	6	20	1,570	5,170	16,800
SPECIAL INTAKE SAMPLER (Fig. 38)									
10,000	< 62	do	5	6	60	95	117	347	725
10,000	do	do	30	125	286	603	1,080	1,870	3,380
10,000	62-125	do	5	11	14	321	357	396	556
10,000	do	do	30	12	38	1,660	2,310	3,180	3,930
10,000	125-250	do	5	5	19	58	363	506	-
10,000	do	do	30	8	35	247	4,260	9,750	-

#### 48. Annotations of numbered reports--

Report No. 1--"Field Practice and Equipment Used in Sampling Suspended Sediment" reviews in detail the equipment and methods used in suspended-sediment sampling from the time of the earliest known investigations to 1940 and includes discussions of the advantages and disadvantages of different methods and instruments. The requirements of a sampler that would satisfy all field conditions are set forth.

Report No. 2--"Equipment Used for Sampling Bed Load and Bed Material" reviews the equipment and methods used in bed-load and bed-material sampling and is similar in presentation to Report No. 1.

Report No. 3--"Analytical Study of Methods of Sampling Suspended Sediment" covers an investigation of the accuracy of various methods of sampling suspended sediment in a vertical section of a stream. This analytical study is based on the application of turbulence theories to sediment transportation.

Report No. 4--"Methods of Analyzing Sediment Samples" describes many methods for determining the size of small particles and for establishing the particle-size gradation and total concentration of sediment in samples. Detailed instructions are given for many of the common methods that have been developed and used by agencies doing extensive work in sedimentation.

Report No. 5--"Laboratory Investigations of Suspended-Sediment Samplers" reports the effects of intake conditions on the representativeness of sediment samples and on the filling characteristics of slow-filling samplers.

Report No. 6--"The Design of Improved Types of Suspended-Sediment Samplers" describes the development of several integrating samplers suitable for taking vertically depth-integrated samples in flowing streams and others suitable for taking time-integrated samples at a fixed point. Details of the recommended types are given.

Report No. 7--"A Study of New Methods for Size Analysis of Suspended-Sediment Samples" reports on research to develop methods of size analysis suitable for most suspended-sediment investigations and describes the apparatus and technique of the bottom-withdrawal-tube method.

Report No. 8--"Measurement of the Sediment Discharge of Streams" describes methods and equipment for making sediment measurements under the diverse conditions in streams.

Report No. 9--"Density of Sediments Deposited in Reservoirs" presents data on the apparent density of sediment deposited in reservoirs. The results are summarized, and certain conclusions useful in engineering studies are given.



Report No. 10--"Accuracy of Sediment Size Analyses Made by the Bottom-Withdrawal-Tube Method" recounts extensive tests made to evaluate the accuracy of the bottom-withdrawal-tube method. Glass spheres of sand sizes were used as the sediments.

Report No. 11--"The Development and Calibration of the Visual-Accumulation Tube" describes the design of equipment and methodology useful for a simple and accurate analysis of size gradation of sands.

Report No. 12--"Some Fundamentals of Particle-Size Analysis" presents some of the basic concepts, definitions, and data on relationships involved in particle-size analysis. The relation of fall velocity to physical size is examined in detail.