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Techniques of Water-Resources Investigations of the United States Geological Survey

Chapter A8

DISCHARGE MEASUREMENTS AT GAGING STATIONS

By Thomas J. Buchanan and William P. Somers

Book 3

APPLICATIONS OF HYDRAULICS

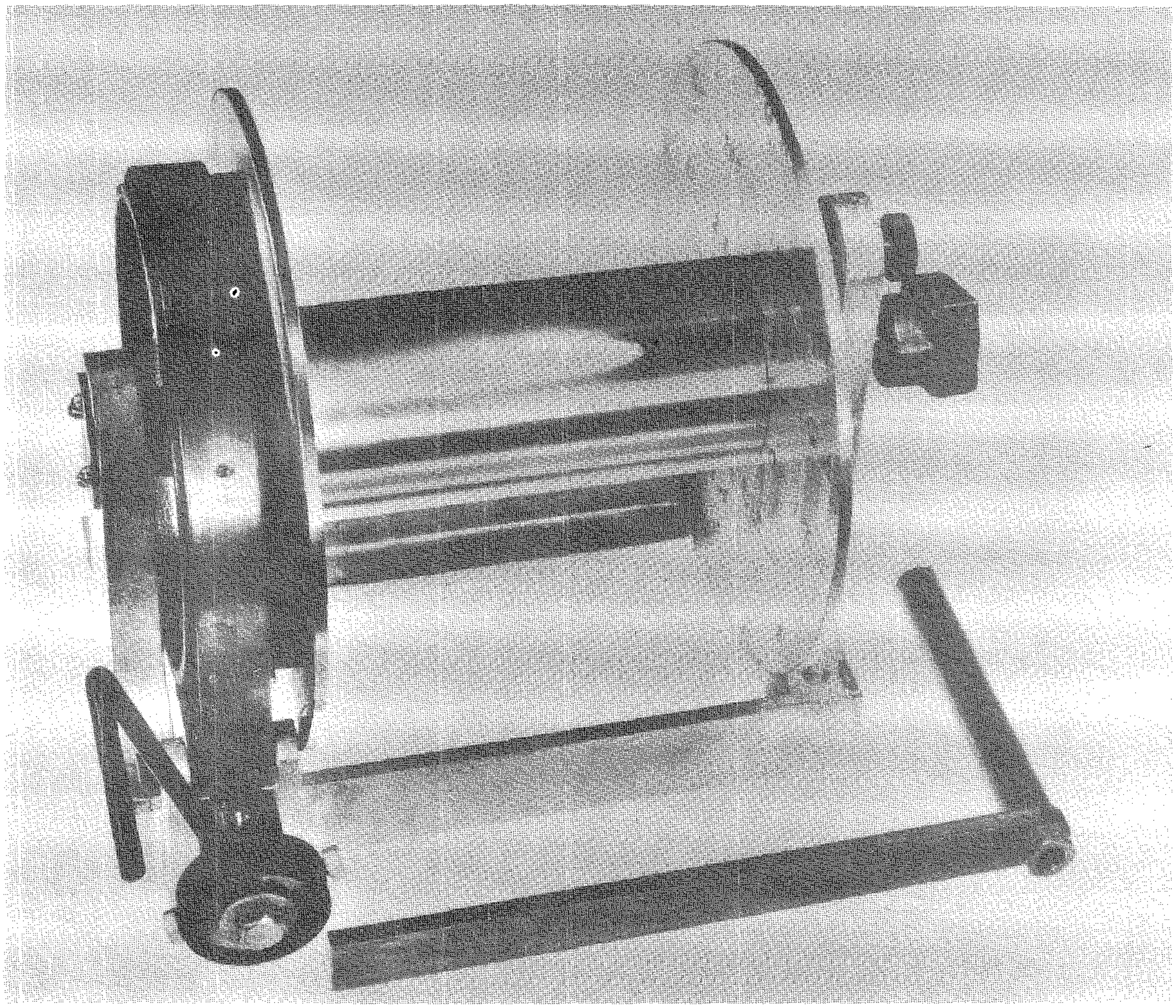

Figure 46.—Horizontal-axis boat tag-line reel with a brake.

is the battery for the current-meter circuit, the headphone jacks, and the two-conductor jack for the sonic sounder. A switch allows the remote-indicating unit to be used separately or in conjunction with the sonic sounder. The sonic sounder is mentioned on page 16. This assembly is useful in tidal investigations and other special studies as well as at regular gaging stations, where it is desirable to determine the direction of flow beneath the surface when it may differ from that at the surface.

Miscellaneous equipment

Several miscellaneous items which have not been described are necessary when current-meter measurements are made. Three classifications of this equipment are timers, counting equipment, and waders and boots.

In order to determine the velocity at a point with a current meter, it is necessary to count the revolutions of the rotor in a measured interval of time, usually 40–70 seconds. The velocity is then obtained from the meter-rating table. (See fig. 11.) The time interval is measured to the nearest second with a stopwatch. (See fig. 53.)

The revolutions of the meter rotor during the observation of velocity are counted by an electric circuit that is closed each time the contact wire touches the single or penta eccentric of the current meter. A battery and headphone are

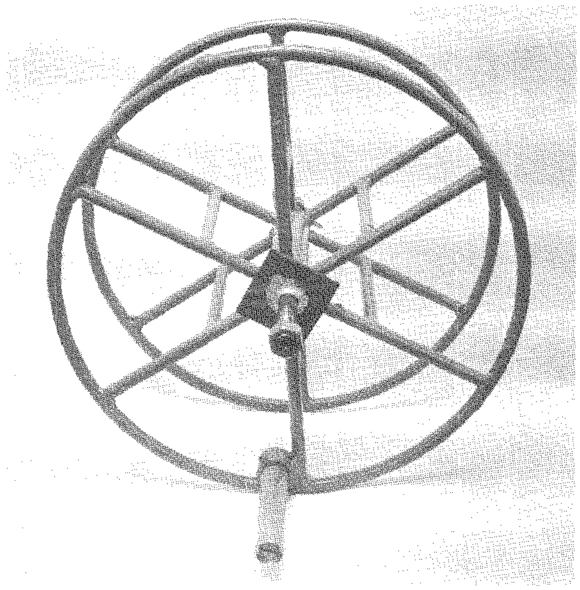

Figure 47.—Vertical-axis boat tag-line reel. When in use the axis of the reel is vertical.

parts of the electrical circuit, and a click is heard in the headphone each time the contact wire touches. (See fig. 54.) In many cases, compact, comfortable hearing-aid phones have been adapted to replace headphones.

A magnetic-switch contact chamber has been developed to replace the contact-wire chamber. (See p. 6.) An automatic electric counter has been developed for use with the magnetic contact chamber. (See fig. 54.) The counter can register up to 999 and has a reset button. A metal clip is attached to the counter so that it may be easily carried on the belt. The electric counter should not be used with the contact-wire chamber because at low velocities the contact wire wipes irregularly thereby sending several signals to the counter for each revolution.

Waders or boots are needed when wading measurements are made. Waders should be loose fitting even after allowance has been made for heavy winter clothing. Ice creepers strapped on the shoe of boots or waders should be used on steep or icy stream banks and on rocky or smooth and slippery streambeds. (See fig. 55.)

Measurement of velocity

The current meter measures velocity at a point. The method of making discharge measurements at a cross section requires determination of the mean velocity in each of the selected verticals. The mean velocity in a vertical is obtained from velocity observations at many points in that vertical. The mean can be approximated by making a few velocity observations and using a known relation between those velocities and the mean in the vertical. The various methods of measuring velocity are:

1. Vertical-velocity curve.
2. Two-point.
3. Six-tenths-depth.
4. Two-tenths-depth.
5. Three-point.
6. Subsurface.

Vertical-velocity curve method

In the vertical-velocity curve method a series of velocity observations at points well distributed between the water surface and the streambed are made at each of the verticals. If there is considerable curvature in the lower part of the vertical-velocity curve, it as advisable to space the observations more closely in that part of the depth. Normally, the observations are taken at 0.1-depth increments between 0.1 and 0.9 of the depth. Observations are always taken at 0.2, 0.6, and 0.8 of the depth so that the results obtained by the vertical-velocity curve method may be compared with the commonly used methods of velocity observation. Observations are made at least 0.5 foot from the water surface and from the streambed with the Price AA meter or the vane meter and are made at least 0.3 foot from these boundaries with the Price pygmy meter.

The vertical-velocity curve for each vertical is based on observed velocities plotted against depth. (See fig. 56.) In order that vertical-velocity curves at different verticals may be readily compared, it is customary to plot depths as proportional parts of the total depth. The mean velocity in the vertical is obtained by measuring the area between the curve and the ordinate axis with a planimeter, or by other means, and dividing the area by the length of the ordinate axis.

The vertical-velocity curve method is valuable in determining coefficients for application to the results obtained by other methods,

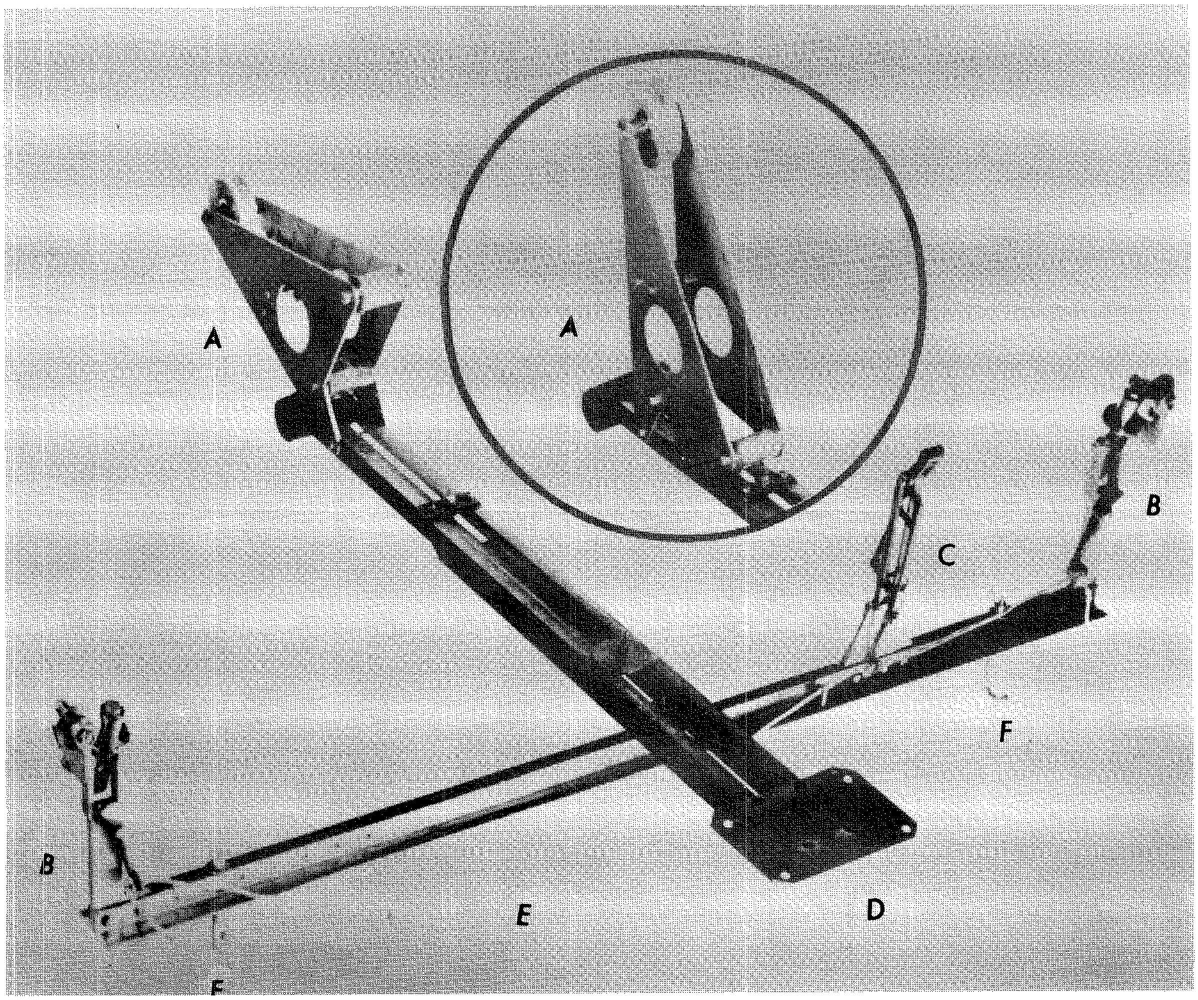

Figure 48.—Boom and crosspiece for use on boats. **A**, retractable end of boom; **B**, guide sheave and clamp for attaching to tag line; **C**, clamp to prevent movement of the boat along the tag line; **D**, plate to accommodate reel; **E**, rope to release clamps (**B**) to free boat from tag line; and **F**, clamps to attach crosspiece to boat.

but is not generally adapted to routine discharge measurements because of the extra time required to collect field data and to compute the mean velocity.

Two-point method

In the two-point method of measuring velocities, observations are made in each vertical at 0.2 and 0.8 of the depth below the surface. The average of these two observations is taken as the mean velocity in the vertical. This method is based on many studies of actual observation and on mathematical theory. Experience has shown that this method gives more consistent and accurate results than any of the other methods except the vertical-velocity curve method. (See p. 31.) The two-point method is the one generally used by the Geological Survey.

The two-point method is not used at depths less than 2.5 feet because the current meter would be too close to the water surface and to the streambed to give dependable results.

Six-tenths-depth method

In the 0.6-depth method, an observation of velocity made at 0.6 of the depth below the surface in the vertical is used as the mean velocity in the vertical. Actual observation and mathematical theory has shown that the 0.6-

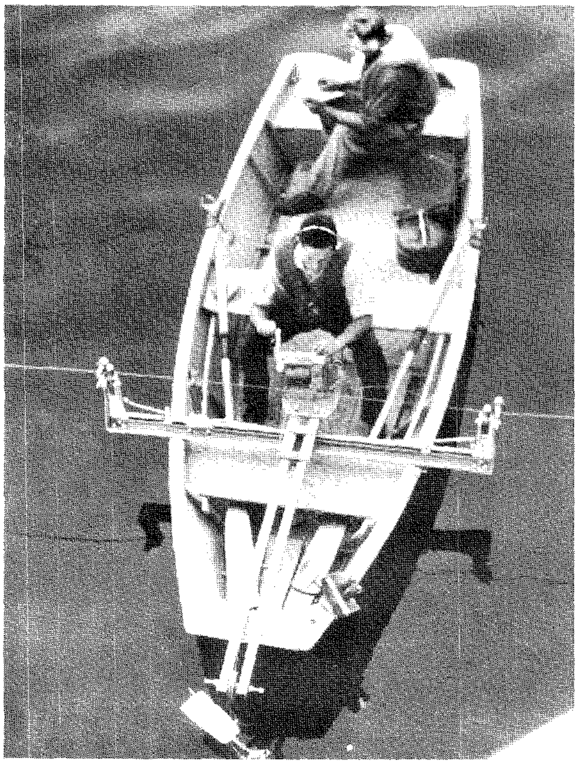

Figure 49.—Measuring equipment set up in a boat.

depth method gives reliable results and is used by the Geological Survey under the following conditions:

1. Whenever the depth is between 0.3 foot and and 2.5 feet.
2. When large amounts of slush ice or debris make it impossible to observe the velocity accurately at the 0.2 depth. This condition prevents the use of the two-point method.
3. When the meter is placed a distance above the sounding weight which makes it impossible to place the meter at the 0.8 depth. This circumstance prevents the use of the two-point method.
4. When the stage in a stream is changing rapidly and a measurement must be made quickly.

Two-tenths-depth method

The two-tenths-depth method consists of observing the velocity at 0.2 of the depth below the surface and applying a coefficient to this observed velocity to obtain the mean in the vertical. It is used mainly during times of high

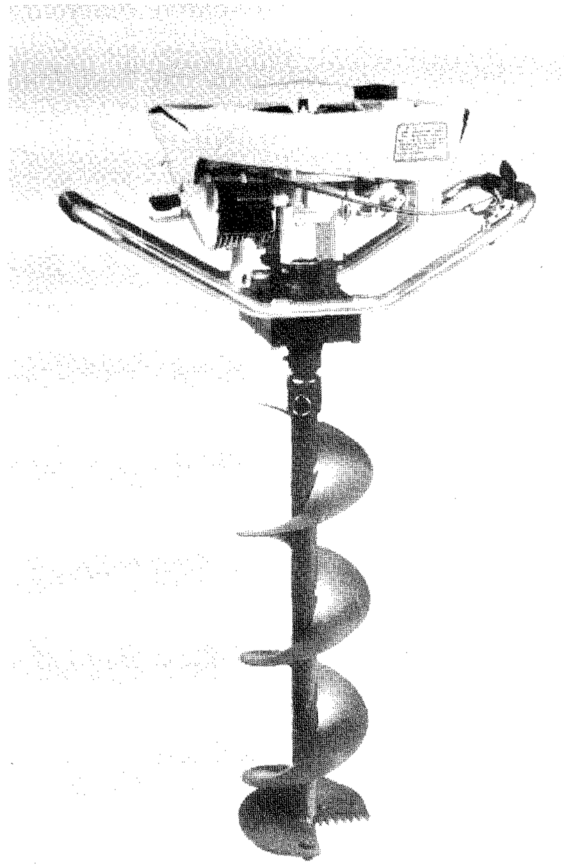

Figure 50.—Gasoline-powered ice drill. Photograph by permission of General Equipment Co.

water when the velocities are great, making it impossible to obtain soundings or to place the meter at the 0.8 or the 0.6 depth.

A standard cross section or a general knowledge of the cross section at a site is used to compute the 0.2 depth when it is impossible to obtain soundings. A sizeable error in an assumed 0.2 depth is not critical because the slope of the vertical-velocity curve at this point is usually nearly vertical. (See fig. 56.) The 0.2 depth is also used in conjunction with the sonic sounder for flood measurements. (See p. 16.) The two-point method and the 0.6-depth method are preferred over the 0.2-depth method because of their greater accuracy.

The measurement is normally computed by using the 0.2-depth velocity observations without coefficients as though each were a mean in

Figure 51.—Collapsible reel support and ice-weight assembly.

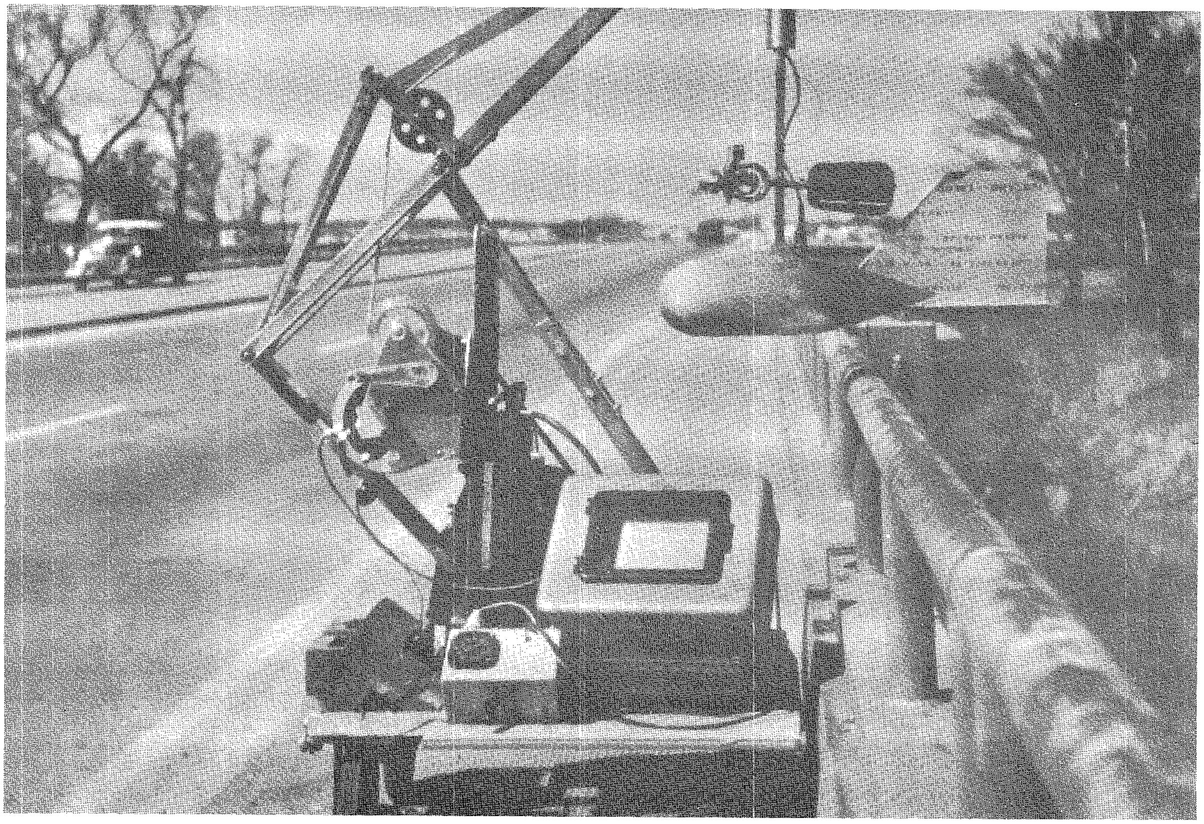

Figure 52.—Velocity-azimuth-depth assembly.

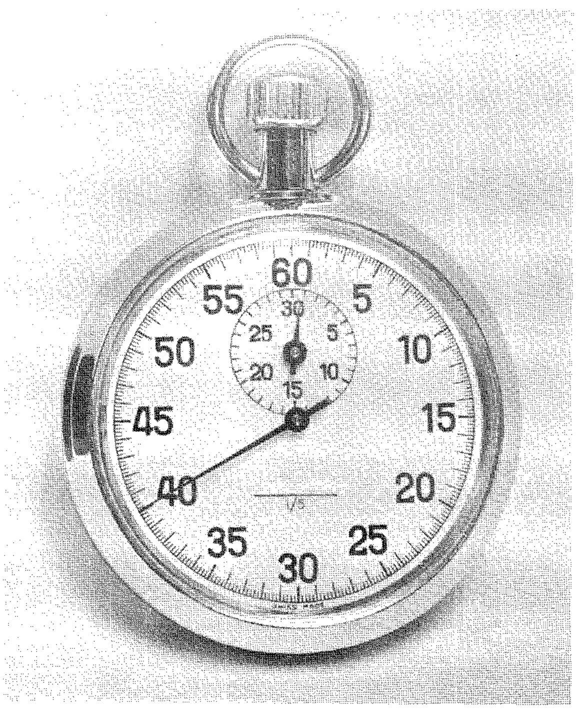

Figure 53.—Stopwatch.

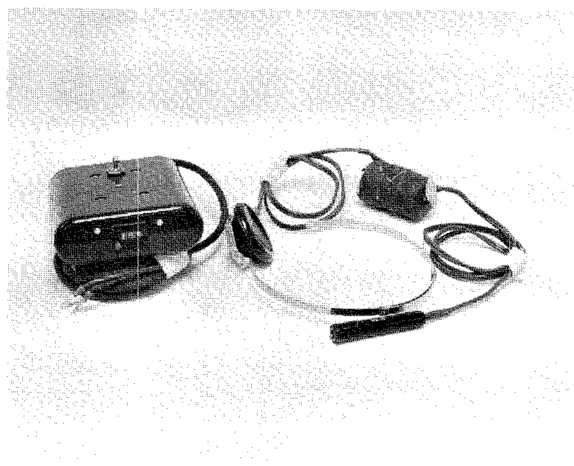

Figure 54.—Automatic counter (left) and headphone (right).

the vertical. The approximate discharge thus obtained divided by the area of the measuring section gives the weighted mean value of the 0.2-depth velocity. Studies of many measurements made by the two-point method show that for a given measuring section the relation

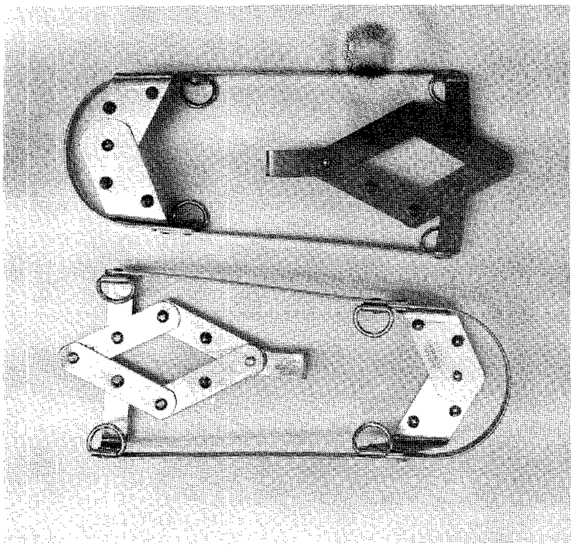

Figure 55.—Ice creepers for boots and waders.

between the mean 0.2-depth velocity and the true mean velocity either remains constant or varies uniformly with stage. In either circumstance, this relation may be determined for a particular 0.2-depth measurement by recomputing measurements made at the site by the two-point method using only the 0.2-depth velocity observation as the mean in the vertical. The plotting of the true mean velocity versus the mean 0.2-depth velocity for each measurement will give a velocity-relation curve for use in adjusting the mean velocity for measurements made by the 0.2-depth method.

If at a site enough measurements have not been made by the two-point method to establish a velocity-relation curve, vertical-velocity curves are needed to establish a relationship between the mean velocity and the 0.2-depth

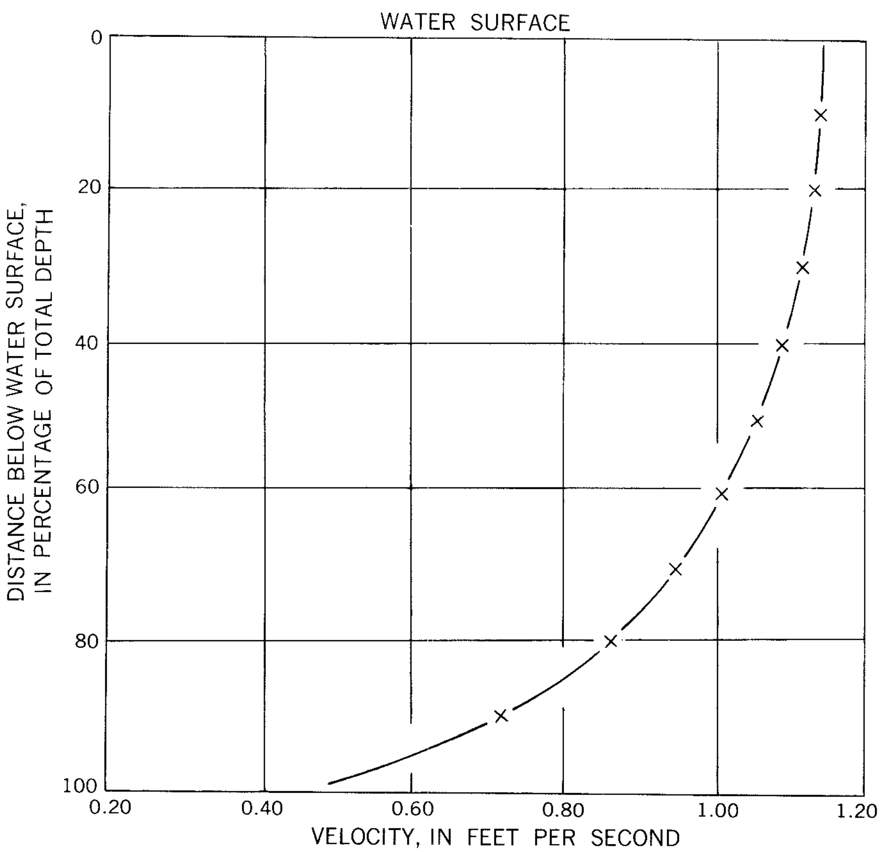

Figure 56.—Typical vertical-velocity curve.

velocity. The usual coefficient to adjust the 0.2-depth velocity to the mean velocity is about 0.88.

Three-point method

The three-point method consists of observing the velocity at 0.2, 0.6, and 0.8 of the depth, thereby combining the two-point and 0.6-depth methods. The mean velocity is computed by averaging the 0.2- and 0.8-depth observations and then averaging the result with the 0.6-depth observation. When more weight to the 0.2- and 0.8-depth observations is desired, the arithmetical mean of the three observations may be used. The first procedure is usually followed, however.

The three-point method is used when the velocities in the vertical are abnormally distributed. It is also used when the 0.8-depth observation is made where the velocity is seriously affected by friction or by turbulance produced by the streambed or an obstruction in the stream. The depths must be greater than 2.5 feet before this method can be used.

Subsurface method

The subsurface method consists of observing the velocity at some distance below the water surface. This distance should be at least 2 feet and preferably more for deep swift streams to avoid the effect of surface disturbances.

The subsurface method is used when it is impossible to obtain soundings and the depths cannot be estimated with enough reliability to even approximate a 0.2-depth setting. Coefficients are necessary to convert the velocities observed by the subsurface method to the mean velocity in the vertical. Vertical-velocity curves obtained at the particular site are used to compute these coefficients. The coefficients are generally difficult to determine reliably because they may vary with stage, depth, and position in the measuring cross section.

Current-meter measurement procedure

The first step in making a current-meter measurement is to select a reach of stream containing the following characteristics:

1. A straight reach with the threads of velocity parallel to each other.
2. Stable streambed free of large rocks, weeds, and protruding obstructions such as piers, which would create turbulence.
3. A flat streambed profile to eliminate vertical components of velocity.

It is usually not possible to satisfy all of these conditions. Select the best possible reach using these criteria and then select a cross section.

After the cross section has been selected, determine the width of the stream. String a tag line or measuring tape for measurements made by wading, from a boat, from ice cover, or from an unmarked bridge. String the line at right angles to the direction of flow to avoid horizontal angles in the cross section. For cableway or bridge measurements, use the graduations painted on the cable or bridge rail as described on page 17. Next determine the spacing of the verticals, generally using about 25 to 30 partial sections. With a smooth cross section and good velocity distribution, fewer sections may be used. Space the partial sections so that no partial section has more than 10 percent of the total discharge in it. The ideal measurement is one in which no partial section has more than 5 percent of the total discharge in it, but this is very seldom accomplished when 25 partial sections are used. The discharge measurement shown in figure 2 had 6.2 percent of the total discharge in the partial section with the greatest discharge. Equal widths of partial sections across the entire cross section are not recommended unless the discharge is well distributed. Make the width of the partial sections less as depths and velocities become greater. Usually an approximate discharge can be obtained from the stage-discharge curve. Space the verticals so the discharge in each vertical is about 5 percent of the discharge from the rating curve.

After the cross section has been selected and the stationing determined, assemble the appropriate equipment for the current-meter measurement and prepare the measurement note sheets to record the observations. (See fig. 2.) For each discharge measurement record the following information:

1. Name of stream and location to correctly identify the established gaging station; or name of stream and exact location of site for a miscellaneous measurement.

2. Date, party, type of meter suspension, and meter number.
3. Time measurement was started using military time.
4. Bank of stream that was the starting point.
5. Control conditions.
6. Gage heights and corresponding times.
7. Water temperature.
8. Other pertinent information regarding the accuracy of the discharge measurement and conditions which might affect the stage-discharge relation.

Identify the stream bank by either LEW or REW (left edge of water or right edge of water, respectively, when facing downstream). Record the time in the notes periodically, during the course of the measurement. This time usually should be synchronized with the time of punch on the digital recorder. (See fig. 2.) This is important because if there is any appreciable change in stage during the measurement, the time is needed to determine the mean gage height for the measurement. (See p. 53.) When the measurement is completed, record the time and the bank of the stream where the section ends.

After the equipment and the note sheet have been readied, begin the measurement. Indicate on the note sheet the distance from the initial point to the edge of the water. Measure and record the depth at the edge of water.

After the depth is known and recorded, determine the method of velocity measurement. Normally the two-point method or the 0.6-depth method is used. Compute the setting of the meter for the particular method to be used at that depth. Record the meter position (as 0.8, 0.6, 0.2, . . .). After the meter is placed at the proper depth, permit it to become adjusted to the current before starting the velocity observation. The time required for such adjustment is usually only a few seconds if the velocities are greater than 1 fps, but for lower velocities, particularly if the current meter is suspended by a cable, a long period of adjustment is needed. After the meter has become adjusted to the current, count the number of revolutions made by the rotor for a period of 40–70 seconds. Start the stopwatch simultaneously with the first signal or click, counting "zero," not "one." End the count on a convenient number given in the meter rating table column heading. Stop the stopwatch on that count and read the time to the nearest second, or to the nearest even second if the hand is on a half-second mark. Record the number of revolutions and the time interval.

If the velocity is to be observed at more than one point in the vertical, determine the meter setting for the additional observation, time the revolutions, and record the data. Move to each of the verticals and repeat this procedure; record the distance from initial point, depth, meter-position depth, revolutions, and time interval, until the entire cross section has been traversed. (See fig. 2.)

If the direction of flow is not at right angles to the cross section, find the velocity vector normal to the section. Measure the cosine of the horizontal angle (fig. 57) by holding the note sheet in a horizontal position with the point of origin (0) on the left edge of the note sheet (fig. 2) over the tag line, bridge rail, or any other feature parallel to the cross section. With the long side of the note sheet parallel to the direction of flow, the tag line or bridge rail will intersect the value of the cosine of the angle α on the top, bottom, or right edge of the note sheet. Multiply the measured velocity by the cosine of the angle to determine the velocity component normal to the measuring section.

Details peculiar to specific types of current-meter measurements are described in the following sections.

Current-meter measurements by wading

Current-meter measurements by wading are preferred, if conditions permit. (See fig. 58). Wading measurements offer the advantage over measurements from bridges and cableways in that it is usually possible to select the best of several available cross sections for the measurement.

Use the type AA or the pygmy meter for wading measurements. Table 2 lists the type of meter and velocity method to use for wading measurements for various depths.

If a type AA meter is being used in a cross section with an average depth greater than 1.5 feet, do not change to the pygmy meter for a few depths less than 1.5 feet or vice versa. Use

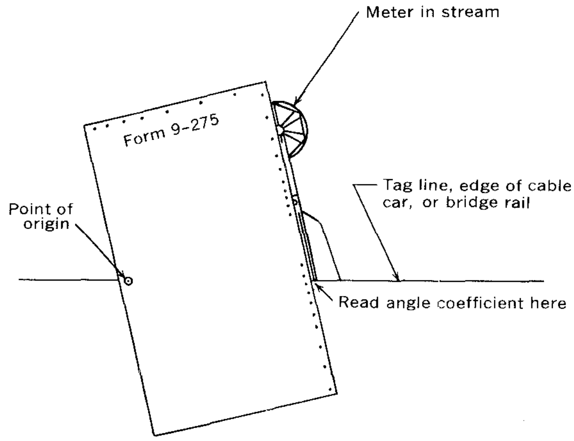

Figure 57.—Measurement of horizontal angles.

Table 2.—Current-meter and velocity-measurement method for various depths

Depth (feet)	*Meter*	*Velocity method*
2.5 and above	Type AA (or Type A).	0.2 and 0.8
1.5–2.5	do	.6
.3–1.5	Pygmy [1]	.6

[1] Used when velocities are less than 2.5 fps.

the type AA meter at depths as shallow as 0.5 foot. Its use is not recommended below depths of 1.0 foot because the registration of the meter is affected by its proximity to the water surface and to the streambed. Do not use the type AA meter or the pygmy meter in velocities less than 0.2 fps unless absolutely necessary.

Coefficients given by Pierce (1941) for the performance of current meters in water of shallow depth and low velocities are no longer recommended for use, at least until further investigation.

Figure 58.—Wading measurement using top-setting rod.

When natural conditions for measuring are in the range considered undependable, modify the measuring cross section, if practical, to provide acceptable conditions. Often it is possible to build dikes to cut off dead water and shallow flows in a cross section, or to improve the cross section by removing the rocks and debris within the section and from the reach of stream immediately upstream from it. After modifying a cross section, allow the flow to stabilize before starting the discharge measurement.

Stand in a position that least affects the velocity of the water passing the current meter. This position is usually obtained by facing the bank, with the water flowing against the side of the leg. Holding the wading rod at the tag line, stand from 1 to 3 inches downstream from the tag line and 18 inches or more from the wading rod. Avoid standing in the water if feet and legs would occupy a considerable percentage of the cross section of a narrow stream. In small streams where the width permits, stand on a plank or other support rather than in the water.

Keep the wading rod in a vertical position and the meter parallel to the direction of flow while observing the velocity. If the flow is not at right angles to the tag line, measure the angle coefficient carefully.

During measurements of streams with shifting beds, the scoured depressions left by the hydrographer's feet can affect soundings or velocities. Generally, place the meter ahead of and upstream from the feet. Record an accurate description of streambed and water-surface configuration each time a discharge measurement is made in a sand-channel stream.

For discharge measurements of flow too small to measure with a current meter use a volumetric method, Parshall flume, or weir plate.

Current-meter measurements from cableways

The equipment assemblies for use on cableways are described on page 18.

The size of the sounding weight used in current-meter measurements depends on the depth and velocity to be found in a cross section. A rule of thumb is that the size of the weight in pounds should be greater than the maximum product of velocity and depth in the cross section. If insufficient weight is used, the sounding line will be dragged at an angle downstream. If debris or ice is flowing or if the stream is shallow and swift, use a heavier weight than the rule designates. The rule is not rigid but does provide a starting point for deciding on the size weight necessary. Examine notes of previous measurements at a site to help determine the size weight needed at various stages.

The Price type–AA current meter is generally used when making discharge measurements from a cableway. The depth is measured by using a sounding reel and the velocity is measured by setting the meter at the proper position in the vertical. (See table 3.) Table 3 is designed so that no velocity observations will be made with the meter closer than 0.5 foot to the water surface. In the zone from the water surface to a depth of 0.5 foot, the current meter is known to give erratic results.

Table 3.—Velocity-measurement method for various suspensions and depths

Suspension	Minimum depth (feet) 0.6 method	0.2 and 0.8 method
15 C .5, 30 C .5	1. 2	2. 5
50 C .55	1. 4	2. 8
50 C .9	2. 2	4. 5
75 C 1.0, 100 C 1.0, 150 C 1.0	2. 5	5. 0
200 C 1.5, 300 C 1.5	[1] 3. 8	7. 5

[1] Use 0.2 method for depths 2.5–3.7 feet with appropriate coefficient (estimated 0.88).

Some sounding reels are equipped with a computing depth indicator. To use the computing spiral, set the indicator at zero when the center of the current-meter rotor is at the water surface. Lower the sounding weight and meter until the weight touches the streambed. If a 30 C .5 suspension is used and the indicator reads 18.5 feet when the sounding weight touches the bottom, the depth would be 19.0 feet. To move the meter to the 0.8-depth position, merely raise the weight and the meter until the hand on the indicator is over the 19-foot mark on the graduated spiral (fig. 25); the hand will then be pointing to 15.2 feet on the main dial. To set the meter at the 0.2-depth position, raise the weight and meter until the hand on the indicator is pointing to 3.8 feet on the main dial.

One problem found while observing velocities from a cableway is that the movement of the cable car from one station to the next makes the car oscillate for a short time after coming to a stop. Wait until this oscillation has dampened to a negligible amount before counting the revolutions.

Tags can be placed on the sounding line a known distance above the center of the meter cups as an aid in determining depth. (See fig. 36.) The tags, which are usually streamers of different colored binding tape, are fastened to the sounding line by solder beads or by small cable clips. Tags are used for determining depth in two ways:

Set the tag at the water surface and then set on the depth indicator the distance which that particular tag is above the center of the meter cups. Then continue as if the meter cups themselves had been set at the water surface. This is the preferred procedure. If debris or ice is flowing, this method prevents damage to the meter.

With the sounding weight on the streambed, determine the depth by raising the weight until the first tag below the water surface appears at the surface. The total depth is then the sum of (a) the distance the weight was raised to bring the tag to the water surface, (b) the distance the tag is above the center of the meter cups, and (c) the distance from the bottom of the weight to the center of the cups. This method is sometimes used with handlines.

By using tags, the meter can be kept under water at all times to prevent freezing the meter in cold air. Tags are also used in measurements of deep, swift streams. (See p. 47.)

If large amounts of debris are flowing in the stream, raise the meter up to the cable car several times during the measurement to be certain the pivot and rotor of the meter are free of debris. However, keep the meter in the water during the measurement if the air temperature is considerably below freezing. Carry a pair of lineman's side-cutter pliers when making measurements from a cableway. If the weight and meter become caught on a submerged object or on floating debris and it is impossible to release them, cut the sounding line to insure safety. Sometimes the cable car can be pulled to the edge of the water and the debris can be released.

When measurements are made from cableways where the stream is deep and swift, measure the angle that the meter suspension cable makes with the vertical due to the drag. The vertical angle, measured by protractor p. 47), is needed to correct the soundings to obtain the actual vertical depth. (See p. 49.)

Current-meter measurements from bridges

When a stream cannot be waded, bridges may be used to obtain current-meter measurements. Many measuring sections under bridges are satisfactory for current-meter measurements, but cableway sections are usually better.

No set rule can be given for choosing between the upstream or downstream side of the bridge when making a discharge measurement.

The advantages of using the upstream side of the bridge are:

1. Hydraulic characteristics at the upstream side of bridge openings usually are more favorable.
2. Approaching drift can be seen and be more easily avoided.
3. The streambed at the upstream side of the bridge is not likely to scour as badly as at the downstream side.

The advantages of using the downstream side of the bridge are:

1. Vertical angles are more easily measured because the sounding line will move away from the bridge.
2. The flow lines of the stream may be straightened out by passing through a bridge opening with piers.

Whether to use the upstream side or the downstream side of a bridge for a current-meter measurement should be decided individually for each bridge after considering the factors mentioned above and the physical conditions at the bridge, such as location of the walkway, traffic hazards, and accumulation of trash on piles and piers.

Use either a handline, or a sounding reel supported by a bridge board or a portable crane to suspend the current meter and sounding weight from bridges.

Measure the velocity by setting the meter at the position in the vertical as indicated in table 3. Keep equipment several feet from piers and abutments if velocities are high. Estimate the depth and velocity next to the pier or abutment on the basis of the observations at the vertical nearest the pier.

If there are piers in the cross section, it is usually necessary to use more than 25–30 partial sections to get results as reliable as those from a similar section without piers. Piers will often cause horizontal angles that must be carefully measured. Piers also cause rapid changes in the horizontal velocity distribution in the section.

Footbridges are sometimes used for measuring canals, tailraces, and small streams. Rod suspension can be used from many footbridges. The procedure for determining depth in low velocities is the same as for wading measurements. For higher velocities obtain the depth by the difference in readings at an index point on the bridge when the base plate of the rod is at the water surface and on the streambed. Measuring the depth in this manner will eliminate errors caused by the water piling up on the upstream face of the rod. Handlines, bridge cranes, and bridge boards are also used from footbridges.

When using a sounding reel measure the depth by methods described on page 40. To determine depth when using a handline, lower the sounding weight to the streambed, then raise the weight until one of the tags is at the water surface. Measure along the rubber-covered service cord with a steel or metallic tape or a graduated rod to determine the distance the weight is raised. The total depth of water is then the summation of (1) the distance the particular tag is above the meter cups, (2) the measured distance the meter and weight was raised, and (3) the distance from the bottom of the weight to the meter cups.

Another method of determining depths is to set the meter cups at the water surface and then lower the sounding weight to the streambed while measuring the amount of line that has been let out by one of the methods mentioned previously. This measured distance, plus the distance from the bottom of the sounding weight to the meter cups, is the depth of water. When using a handline, unwind enough cable from the handline reel to keep the reel out of water when the sounding weight is on the streambed at the deepest part of the cross section. If the bridge is high enough above the water surface, raise and lower the weight and meter by the rubber-covered cable rather than by the bare cable. When the meter is set for the velocity observation, stand on the rubber-covered cable or tie it to the handrail to hold the meter in place. This arrangement frees the hands to record the data.

The handline can be disconnected from the headphone wire and passed around a truss member with the sounding weight on the bottom. This eliminates the need for raising the weight and meter to the bridge each time a move is made from one vertical to another, and is the principal advantage of a handline.

Current-meter measurements from ice cover

Discharge measurements under ice cover are made under the most severe conditions (fig. 59) but are extremely important because a large part of the discharge record during a winter period may depend on one measurement.

Select the possible locations of the cross section to be used for a measurement from ice cover during the open-water season when channel conditions can be evaluated.

Figure 59.—Ice rod being used to support current meter for a discharge measurement, top; and ice drill being used to cut holes, bottom.

The equipment used for cutting or drilling the holes in the ice is described on page 27.

Never underestimate the danger of working on ice-covered streams. When crossing, test